Foreword

The Estuary Management Policy of the New South Wales Government has been developed in conjunction with other government policies that address resource planning and management on a catchment basis. The Estuary Management Policy focuses on tidal waterways and coastal lakes, waterbodies which are an essential component of coastal catchments and which are characterised by the interplay of saline coastal waters and freshwater runoff from the land (see Appendix A for a statement of the Estuary Management Policy).

The objectives of the Policy will be implemented by the government's Estuary Management Program, which aims at the production and implementation of Management Plans for all estuaries in New South Wales. The preparation of these plans will be supervised by Estuary Management Committees made up of representatives of the local council(s), relevant State Government authorities, Catchment Management Committees and interested community groups.

In the course of formulating an Estuary Management Plan, community groups with commercial, ecological or other public interests in the estuary, together with government authorities, will be able to present their preferences and requirements for the future nature conservation, rehabilitation, development and use of the waterbody. The Committee will then determine a list of management recommendations and objectives to be implemented by Local Government, State Government and community groups. After its public exhibition and consequent amendment, the Estuary Management Plan should be formally adopted by local council(s).

It is recognised that estuaries vary widely in their natural attributes, degree of development and, to a lesser extent, in the legal and administrative mechanisms whereby they are controlled. In this regard, the program provides appropriate flexibility in the formulation of Estuary Management Plans.

This Manual has been produced to assist the community to implement the government's Estuary Management Policy in accordance with existing legislation.

The Estuary Management Policy is a component policy of the State Rivers and Estuaries Policy of the New South Wales Government, which in turn comes under the umbrella of Total Catchment Management. The objectives of the Estuary Management Policy are entirely consistent with the Catchment Management Act, 1989, under which Catchment Management Trusts and Catchment Management Committees are formed.
Acknowledgements

This Manual has been prepared under the direction of a Steering Committee comprising the following people drawn from the indicated organisations.

Paul Adam
Coast and Wetland Society

Jennifer Burchmore
NSW Fisheries

Jane Chrystal
Environment Protection Authority

Colin Creighton
Department of Conservation and Land Management

John Downey
Association of Councils on Estuaries

Michael Geary
Public Works Department

Peter Hughes
Department of Planning

Duncan Leadbitter
Ocean Watch

Leighton Llewellyn
National Parks and Wildlife Service

John Patten
Department of Conservation and Land Management


to better manage our estuaries
### Contents

<table>
<thead>
<tr>
<th>Foreword</th>
<th>Acknowledgements</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th><strong>Introduction</strong></th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td>The Estuary Management Process</td>
<td>9</td>
</tr>
<tr>
<td>Study boundaries</td>
<td>9</td>
</tr>
<tr>
<td>step 1 form Estuary Management Committee</td>
<td>10</td>
</tr>
<tr>
<td>step 2 assemble existing data</td>
<td>10</td>
</tr>
<tr>
<td>step 3 carry out Estuary Processes Study</td>
<td>11</td>
</tr>
<tr>
<td>step 4 carry out Estuary Management Study</td>
<td>12</td>
</tr>
<tr>
<td>step 5 draft Estuary Management Plan</td>
<td>13</td>
</tr>
<tr>
<td>step 6 review Estuary Management Plan</td>
<td>13</td>
</tr>
<tr>
<td>step 7 adopt and implement Estuary Management Plan</td>
<td>14</td>
</tr>
<tr>
<td>step 8 monitor and review the management process</td>
<td>15</td>
</tr>
<tr>
<td>Technical and research assistance</td>
<td>16</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Administration</strong></th>
<th>17</th>
</tr>
</thead>
<tbody>
<tr>
<td>Local Councils</td>
<td>18</td>
</tr>
<tr>
<td>Public Works Department</td>
<td>19</td>
</tr>
<tr>
<td>Department of Conservation and Land Management</td>
<td>19</td>
</tr>
<tr>
<td>Department of Planning</td>
<td>20</td>
</tr>
<tr>
<td>Environment Protection Authority</td>
<td>20</td>
</tr>
<tr>
<td>NSW Fisheries</td>
<td>20</td>
</tr>
<tr>
<td>National Parks and Wildlife Service</td>
<td>21</td>
</tr>
<tr>
<td>Maritime Services Board</td>
<td>21</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Government financial assistance</strong></th>
<th>23</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grant conditions</td>
<td>23</td>
</tr>
<tr>
<td>Income from royalties</td>
<td>24</td>
</tr>
<tr>
<td>Income from Crown land</td>
<td>24</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Appendices</strong></th>
<th>25</th>
</tr>
</thead>
<tbody>
<tr>
<td>A New South Wales Estuary Management Policy</td>
<td>25</td>
</tr>
<tr>
<td>B Physical characteristics and behaviour of NSW estuaries</td>
<td>27</td>
</tr>
<tr>
<td>C Estuarine water quality</td>
<td>31</td>
</tr>
<tr>
<td>D Estuarine habitat</td>
<td>63</td>
</tr>
<tr>
<td>E Estuarine flora and fauna of special concern</td>
<td>75</td>
</tr>
<tr>
<td>F Human impacts</td>
<td>95</td>
</tr>
<tr>
<td>G Estuarine monitoring and process models</td>
<td>101</td>
</tr>
<tr>
<td>H Total Catchment Management</td>
<td>111</td>
</tr>
<tr>
<td>I Administration of Crown land</td>
<td>117</td>
</tr>
<tr>
<td>J Management of human activities</td>
<td>125</td>
</tr>
<tr>
<td>K Management of water quality</td>
<td>131</td>
</tr>
<tr>
<td>L Management of extractive industries</td>
<td>145</td>
</tr>
<tr>
<td>M Management of threatened fauna</td>
<td>151</td>
</tr>
<tr>
<td>N Estuary rehabilitation</td>
<td>159</td>
</tr>
</tbody>
</table>

| **Glossary of technical terms** | 183 |
| **Glossary of scientific names** | 195 |

DRAFT to better manage our estuaries
The challenge is to better manage our estuaries...

To better manage our estuaries there is a need to provide a coordinated planning approach...

To foster the better management of our estuaries, the Government has formulated an Estuary Management Policy...
Introduction

New South Wales has some 130 estuaries along its coastline. These estuaries form a rich and diverse tapestry of waterbodies that vary in nature and size, including:

- the long, mangrove-fringed river estuaries of the north coast, where tidal effects are felt over 100 km upriver (e.g. the Clarence River Estuary)
- the many lake estuaries distributed along the central and south coasts, that vary in waterway size from 150 km² (Lake Macquarie) to 2 km² (Narrabeen Lagoon) and smaller
- the massive, rock-flanked, drowned river valleys of the central coast, such as the Hawkesbury River, and
- the large marine embayments such as Port Stephens and Jervis Bay.
Collectively, the estuaries of New South Wales are of immense environmental, social and economic value.

Estuary waters, shores and fringing wetlands form the foundation of the coastal food chain and provide habitat for a diverse variety of aquatic and terrestrial animals.

Estuaries are of significant importance to nature conservation: a number of animal species dependent on New South Wales estuaries are endangered or threatened with extinction.

The catchment of an estuary is an attractive place in which to work, live and play, and it is not surprising that 75% of the State's population live in the immediate proximity of estuaries and that many major urban areas are sited adjacent to these waterbodies.

Estuaries are an important focus of tourism and recreational activities and are of significant economic importance to New South Wales:
- the commercial catch of estuarine-dependent fish, crustacea and molluscs is worth some $80 million per year
- recreational fishing, much of which is based on estuarine waters or estuarine-dependent fish, is worth over $500 million per year
- sand and gravel worth over $100 million per year is removed from the bed and banks of New South Wales estuaries.
Because of their attractiveness and value, estuaries are used for a wide variety of purposes by different groups of people. Often these uses are in conflict.

Sand and gravel extraction may degrade or eliminate seagrass beds that provide important nursery areas for young fish.

Nutrient inputs from urban areas, rural areas or from sewage treatment plants can reduce water quality.

Poorly planned shoreside developments can destroy animal habitat, be an eyesore, reduce public access to estuarine shores and cause pollution.

Estuaries are the endpoints of many detrimental activities of many upstream catchment activities. Over the past 200 years, the inappropriate use, conflicting use and over-use of estuaries and catchments in New South Wales have left them in a degraded state.

Today, many estuaries are characterised by:
- murky, silt-laden waters that also contain high levels of nutrients and other deleterious substances
- silted and poorly flushed waterways
- the loss of wildlife habitat through shoreside developments and the infilling of wetlands
- restricted public access
- reduced populations of aquatic and terrestrial fauna, some of which are at risk of extinction.

Estuaries and their immediate catchments are now subject to ever-increasing pressures for additional development and the expansion of existing uses.

There is also great concern for nature conservation and environmental protection of estuarine habitats.

The estuaries of New South Wales are a valuable State asset. Ecologically, ethically and economically, the people of New South Wales can ill-afford their estuaries to suffer further degradation.

Many of the existing problems have arisen from unwise developments in the past, when the complexity and inter-relationships of the ecological, physical and chemical processes of an estuary and its catchment were poorly understood.

Today, such processes are better appreciated:
- surveys of tidal behaviour, sediment movement and water quality are undertaken on a more-or-less regular basis
- wildlife surveys of the aquatic and fringing terrestrial ecosystems are becoming more common.

While the interactions between many estuarine processes are better understood today, additional data and research are required.

The challenge is to better manage our estuaries, not only to halt on-going degradation, but also to rectify past damage, with the overall object of achieving an integrated, balanced, responsible and ecologically sustainable use of these resources into the future.
To better manage our estuaries there is a need to provide a coordinated planning approach...

The current management process is necessarily lengthy due to:
- the complexity and interactions of the underlying estuarine processes, and
- the multiplicity of authorities involved in estuarine management.

An estuary and its immediate catchment form a complex system of ecological, physical, chemical and social processes which interact in a highly involved, and at times unexpected, fashion.

The diverse nature of estuarine lands, waters and processes results in the division of estuary management between a number of government authorities.

For example, the ownership and control of estuarine waterfront and submerged lands is spread across a spectrum of private landholders, local councils, trustees, Crown land and other New South Wales Government authorities (e.g. Maritime Services Board, Public Works Department and National Parks and Wildlife Service).

For estuary users and development proposers, this complex estuary management structure may require dealing with a number of government authorities and complying with several different Acts of Parliament.

To better manage our estuaries, there is a singular need to provide a coordinated planning approach that allows proposals for development, nature conservation and remedial works to be assessed on an integrated and objective basis.

Such a planning framework needs to incorporate the inter-relationships between the estuary processes themselves and to consider all catchment activities that affect the estuary.
An Estuary Management Plan will provide the necessary coordinated planning base provided it:

- reflects the considered and objective views of all major parties using, interested in or affected by estuarine activities
- is formally adopted as planning policy by local council(s)
- is implemented by council(s), government authorities, interest groups and the community in general.

An Estuary Management Plan will also be of value:

- for preparing specific proposals, by providing the requirements and attitudes of regulatory authorities
- for directing future developments to the more suitable areas of the estuary
- for assessing proposals on an integrated basis (potentially adverse effects may become beneficial when viewed within a broad integrated plan, e.g. the design of dredging programs to increase tidal flushing and so improve water quality).

A vital part of the Estuary Management Process is community involvement and action.

In many cases, much of the gradual on-going degradation of our estuaries has arisen from the individually small, but collectively significant actions of a multitude of small landholders (e.g. urban runoff and agricultural runoff).

Solving these problems will require widespread community awareness, cooperation and action, both within the upper and immediate catchment areas of an estuary.

Each of the authorities currently involved in estuary management has provision for community consultation. It is not proposed that any of the existing checks and balances in current procedures be removed. Rather, the intention is to facilitate and coordinate the decision-making process through the development and application of Estuary Management Plans at the local level. This approach is entirely consistent with the tenets of Total Catchment Management and Ecologically Sustainable Development.
To foster the better management of our estuaries, the Government has formulated an Estuary Management Policy...

The primary goal of the Estuary Management Policy is to encourage the integrated, balanced, responsible and ecologically sustainable use of the State's estuaries.

The government's Estuary Management Policy can be realised through existing legislation - no new legislation is proposed. However, as the estuary management planning process proceeds, any areas of overlapping legislation, duplication, etc between government authorities may be rationalised.

The essence of the Policy is promotion of cooperation between the State Government, Local Government, Catchment Management Committees, landholders and estuary users in the development and implementation of Estuary Management Plans for each estuary.

Estuary Management Plans should reflect the agreed position of all regulatory authorities and interested parties in relation to the future nature conservation, rehabilitation and development of the estuary.

Estuary Management Plans will be prepared under the guidance of Estuary Management Committees. Each Committee will consist of representatives of local council(s), State government departments and authorities (as necessary), local community groups and representatives of Catchment Management Committees and trusts.

Estuary Management Policy

- to promote cooperation and coordination of concerned authorities and interested parties in the development of Estuary Management Plans

Estuary Management Process

- a coordinated planning approach involving concerned authorities and interested parties

Estuary Management Plan

- the agreed position of concerned authorities and interested parties in relation to future development, nature conservation and remedial works

6 to better manage our estuaries
Two major benefits are expected from this approach.

First, it will allow Estuary Management Plans to be formulated quickly because the proposed management process draws together in one forum all relevant groups and agencies.

Second, it will assist preparation and assessment of proposals for development and/or nature conservation because planning and other recommendations of an Estuary Management Plan will be available to guide the proponent in selecting suitable sites and activities.

While an Estuary Management Plan should indicate the requirements and attitudes of the various approval authorities, the existence of such a plan does not imply automatic approval of any conforming proposal. All existing approval procedures will still have to be followed.

The recommendations of an Estuary Management Plan should be formally adopted by all relevant local and state government authorities.

Once adopted, the recommendations become policy statements that should be implemented through the full range of plans, strategies and management practices available to authorities.

In the case of local councils, this would include zoning and development standards in Local Environmental Plans, Development Control Plans, as well as building and engineering policies used in the assessment of development and building applications and the construction of public works.

Studies, investigations and works undertaken by local councils in developing and implementing Estuary Management Plans are eligible for a 50% subsidy under the Estuary Management Program administered by the Public Works Department.

The Estuary Management Manual has been produced to help develop and implement soundly based Estuary Management Plans.


Readers should note that the Manual does not provide 'solutions'. Rather, it presents a framework for making decisions that will result in better and sustainable estuary use.

The appendices in the Manual provide information on the underlying physical, chemical and ecological processes to assist those proposing development, nature conservation or remedial works, and to assist those assessing the appropriateness of such proposals.
The Estuary Management Process

**Study boundaries**

An estuary can be defined as any semi-enclosed body of water which has an open or intermittently open connection with the ocean, and in which water levels vary in a predictable, periodic way in response to the ocean tide at the entrance (see Appendix B).

While simple, this definition is not particularly useful for management purposes.

Estuarine processes - be they physical, chemical or biological - together with estuarine amenity and uses, can be influenced by factors external to traditional estuarine boundaries, e.g. surface runoff from upstream catchment areas.

For the purposes of estuary management and the preparation of Estuary Management Plans, the “study boundaries” of an estuary need to extend as far inland, out to sea and along the coast as necessary to encompass all the processes of significance to estuarine quality and amenity.

Thus, within the context of Total Catchment Management and any Catchment Management Plan that may apply to the terrestrial components of an estuary, Estuary Management Plans may include controls and recommendations for areas that are outside traditional estuarine boundaries or are subject to other policies of the New South Wales Government, such as the Coastline Hazard Policy or the State Environmental Planning Policy on Coastal Wetlands (SEPP 14).

In these circumstances, consultation with the appropriate Catchment Management committees and inclusion of members of these committees on the Estuary Management Committee is both appropriate and recommended.
The Estuary Management Process

**step 1**

form Estuary Management Committee

In all cases where the bed of an estuary is Crown land, the New South Wales Government will encourage local council(s) to form an Estuary Management Committee to be chaired by a local council. The composition of the committee will depend upon the specific issues and problems in the subject estuary. In order to be effective, the committee should include representatives of relevant authorities, local community groups and users of the estuary.

As a matter of course, each committee will usually include representatives of the Department of Conservation and Land Management, the Department of Public Works, and the Catchment Management Committee for the catchment area draining to the estuary.

Community representatives should include local ratepayers and members of any relevant local action or environmental groups concerned with management of the estuary, together with any specific 'user groups' of the estuary (e.g. fishermen, recreational users).

If appropriate, representatives should also be included from NSW Fisheries, the National Parks and Wildlife Service, the Department of Planning and any other relevant government authorities.

The Estuary Management Policy is a component policy of the NSW Rivers and Estuaries Policy, which in turn comes under the umbrella of Total Catchment Management.

The objectives of the Estuary Management Policy are entirely consistent with the Catchment Act, 1989, under which Catchment Trusts and Catchment Management Committees are formed.

If a catchment has both a Catchment Management Committee and an Estuary Management Committee, the two committees should consult each other, preferably through joint membership.

In these circumstances, the two committees should jointly define their respective roles and terms of reference to ensure a coordinated approach to land and estuary management.

**step 2**

assemble existing data

Often, there is a considerable body of data relevant to estuarine processes and management, generally in the form of maps and reports, scattered between various government departments and agencies.

One of the first tasks of the Estuary Management Committee should be to arrange for the discovery and assembly of these data. This will provide a basis for assessing the type and scope of any additional data which may need to be collected in future studies and programs.

The Committee may also commission any necessary studies to review these data and determine the need for additional investigations. Possible sources of data include:

- community input
- local environmental groups
- personal historical data (floods, surges, shoaling behaviour, loss of habitat, etc.)
- local government
- planning studies
- environmental impact statements
- environmental studies for local environmental plans
- development applications
- drainage plans

Public Works Department
- tidal hydraulics
- sediment movement
- tidal prism
- estuary flushing
- flooding

National Parks & Wildlife Service
- species and distribution of aquatic flora and fauna
- endangered species inventory
- habitat including wetlands
- reserves
- Aboriginal sites

10 to better manage our estuaries
NSW Fisheries
- species inventories of fish and aquatic invertebrates
- details of commercial fish catches
- oyster leases
- habitat e.g. mangroves, seagrasses and wetlands
- aquatic reserves

Department of Conservation and Land Management
- topographic and cadastral maps
- aerial photographs and other remotely sensed images
- details of Crown land and public reserves
- land resources
- sand and gravel operations
- stormwater erosion controls
- waterfront and waterway occupancies

Environment Protection Authority
- State of The Environment reports (biennial), which include water quality data
- inventory of current discharge licences (including licence conditions)

Department of Planning
- SEPP 14, Wetlands Policy
- regional environmental studies

Academic Institutions
- specialist advice concerning many of the ecological, physical and chemical processes of relevance to estuaries.

Fees may be charged for the preparation and assembly of these data. These costs are eligible for the 50% State subsidy under the Estuaries Management Program.

Before management options for an estuary can be meaningfully considered, it is generally necessary to define the 'baseline' conditions of the various estuarine processes and the interactions between them, by carrying out an Estuary Processes Study.

One of the first tasks of the Estuary Management Committee will be to oversee the Study.

An Estuary Processes Study needs to measure and document the following:
- the various physical processes of importance to the estuary, e.g. tidal behaviour, freshwater behaviour, salinity, flushing and mixing behaviour, sediment transport, etc.
- the various water quality parameters of importance to the estuary, e.g. salinity, turbidity, nutrients, toxic materials, suspended solids, etc.
- the various ecological and biological parameters of importance to the estuary, e.g. species types, the nature, areas and health of different estuarine habitats, endangered species, etc.

It is expected that the Estuary Management Committee will normally engage consultants or government departments to undertake the highly specialised investigations required in an Estuary Processes Study. Funding will be available for these tasks.

Some of the information required for a Processes Study - perhaps a considerable amount - may already be available from a variety of sources.

Estuarine processes are ever-changing: from the daily fluctuation of tides, to the seasonal variation of breeding cycles, to the rare occurrences of major droughts and floods and their impact on freshwater inflows. An Estuary Processes Study needs to address, and if possible measure and document, these variations in baseline conditions, including any significant historical changes, e.g. in the area of seagrass beds.

An important aspect of an Estuary Processes Study is the extent to which human activities have modified or disrupted the estuarine processes, e.g. the area and significance of loss of habitat, the source and delivery processes of deleterious water quality substances.

Equally important is the definition of interactions between the different processes, e.g. whether poor breeding success in one species is caused by loss of habitat, reduced feeding opportunities, poor water quality, or the impact of urbanisation (noise, dogs, cats), etc.

Not all the information from an Estuary Processes Study will be available when the Estuary Management Plan is formulated (it would be impractical to wait for the completion of long-term investigations). Because of this, the plan will require a certain degree of flexibility and may require amendment from time to time. Nevertheless, work can proceed under experienced technical direction as research continues.
The Estuary Management Process

step 4

carry out

Estuary Management Study

An Estuary Processes Study provides essential background information on estuarine processes and their interactions. An Estuary Management Study uses this information, together with additional studies, to define management objectives, options and impacts.

An Estuary Management Study will seek to:
- identify the significance of the estuary in terms of broader coastal planning issues
- identify ‘essential features’ of the estuary, be they physical, chemical, biological, aesthetic, social or economic
- document ‘current uses’ and conflicts of use in the estuary
- identify possible future land-uses and assess their impact on the ‘essential features’
- assess the need for nature conservation and remedial measures
- identify and assess management objectives, and
- assess planning controls, works and other strategies to achieve these objectives.

identify the significance of the estuary in terms of broader coastal planning issues

Many broader coastal planning issues relate to the future conservation and development of estuarine resources.

Any one estuary may have a significance extending beyond the local planning boundaries, e.g. as a port for fishing and trade, as a tourist destination, or as a conservation area of regional, national or international significance.

identify ‘essential features’ of the estuary, be they physical, chemical, biological, aesthetic, social or economic

The identification of the essential features of an estuary is fundamental to the definition of management objectives.

The ‘essential features’ of an estuary are those features which make the estuary important in a local, regional or national sense. Such features could be aesthetic (visual, archeological), ecological (significant habitats, important breeding areas), social (recreation), economic (commercial fishing, sand and gravel extraction) or of some other type.

Typically, the essential features of an estuary will be multi-faceted - an estuary will often be of importance for a variety of reasons.

document ‘current uses’ and conflicts of use in the estuary

The documentation of the current uses of an estuary provides a framework for assessing the physical, legal and social basis of possible management options.

‘Current uses’ refers to all activities associated with the use of waterfront lands, submerged lands and the water body itself.

Documentation of current uses includes details of the various land-use activities, land occupation, land tenure and control, legal entitlements and obligations, conflicts of use and the impact of existing uses on the natural environment.

identify possible future land-uses and assess their impact on the ‘essential features’

In defining management objectives, it is also necessary to consider likely future land-uses and their impact on the natural environment.

assess the need for nature conservation and remedial measures

Consideration of the need for nature conservation or remedial measures will also determine management objectives.
identify and assess management objectives

All of the above factors need to be weighed up in defining management objectives. This will not be an easy task; it will involve compromise and trade-offs. Notwithstanding these difficulties, the identification of management objectives is essential to the preparation of a sound Estuary Management Plan.

assess planning controls, works and other strategies to achieve these objectives.

Finally, an assessment needs to be made of the possible strategies that could be used to achieve management objectives, and the impact of these strategies on estuarine ecosystems and users.

At this stage, it may become apparent that some management objectives cannot be fully realised because of excessive cost, a lack of effective control, etc.

It may be necessary to re-define management objectives in terms of 'manageability' and the likelihood of attainment. Again, this phase of an Estuary Management Study may be characterised by compromise and trade-offs.

Public education and awareness programs may also play an important role in achieving the objectives of the plan.

---

step 5
draft Estuary Management Plan

An Estuary Management Plan consists of a scheduled sequence of recommended activities that need to be undertaken to achieve the estuary management objectives.

Completion of the Estuary Processes and Management studies will provide a sound basis for the formulation of a Management Plan, which takes into account the considered views of all parties on the Estuary Management Committee. The Plan may require trade-offs and compensatory balances if differing viewpoints are to be accommodated.

Activities incorporated in a Management Plan may relate to nature conservation, rehabilitation, development, education and other matters.

Some management measures are 'one-off' in nature, e.g. remedial works and the adoption of a Local Environmental Plan.

Other measures are on-going, such as improvement in land management practices, community education programs, and monitoring surveys.

Yet other measures will need to be phased in over time, e.g. changes in land-use that can only be realised on lease expiry or sale of land.

---

step 6
review Estuary Management Plan

Estuary Management Plans will be subject to public display and review.

This will provide all interested or affected parties with the opportunity
- to assess what is proposed for the estuary, the means and implications of proposed controls, etc.
- to register any objections or suggestions.

The Estuary Management Committee will take these comments into account when finalising the Estuary Management Plan.

The display and review process for Estuary Management Plans should be organised and undertaken by local council, the same procedure as for other local planning instruments.

It is recommended that the local council chairing the Estuary Management Committee undertake the organisation of this task and that the plan be displayed at the offices of all local councils affected by its recommendations.

After public display and any necessary amendments, an Estuary Management Plan should be formally adopted by local council(s).
The Estuary Management Process

step 7
adopt and implement Estuary Management Plan

The following methods can be used, either separately or collectively, to implement the recommendations of an Estuary Management Plan:

- local environmental plans and development control plans introduced by local government
- plans of management for Crown land
- environmental planning policies introduced by state government, e.g. SEPP 14, Wetlands Policy
- designation of aquatic reserves and protected land
- construction of physical works by local government, state government, the private sector or community groups, either individually or collectively
- controls in the form of regulations imposed by State Government authorities
- other measures, such as community education programs.

local environmental plans and development control plans introduced by local government

Zoning of various areas of the estuary - including the water body and bed - in accordance with the provisions of the Environmental Planning and Assessment Act, 1979, may be an appropriate management measure which should be considered by Estuary Management Committees.

For example, Sutherland Shire Council has introduced a '7(a) Environmental Protection (Waterways)' zoning in their draft Local Environmental Plan. This zoning covers all waterways and land below high water mark in the Shire. A wide range of water-based recreational and commercial activities are permissible within this zone only with council's consent.

Management objectives for such zones might include control of recreation activities on the surface and control of activities on the bed that affect fish habitat.

In a similar way, zoning could incorporate seasonal factors, e.g. in order to minimise disturbance during the breeding season of the Little Tern (an endangered species), land use controls could prohibit the dredging of prime habitat areas at this time.

Planning and development controls can be imposed by local government via either local environmental plans and development control plans.

Note that the Environmental Planning and Assessment Act provides for a local environmental plan to be formulated and implemented jointly by two or more councils (for those cases where an estuary is controlled by several councils).

The Department of Planning has prepared a set of provisional zoning guidelines which may be useful to the Estuary Management Committee. Committees should also consult the Department of Planning Publication 'Rural Land Evaluation Manual' (1988).

plans of management for Crown land

environmental planning policies introduced by state government, e.g. SEPP 14, Wetlands Policy

State government policy may be implemented through State Environmental Planning Policies (e.g. SEPP 14) and regional environmental plans, together with leases or licenses required for the use of Crown land, the issue of permits for various activities, and regulations by the Maritime Services Board and NSW Fisheries.

designation of aquatic reserves and protected land

Specific estuarine areas can be designated as an aquatic reserve under the Fisheries and Oyster Farms Act, 1935, or as protected land under the Soil Conservation Act, 1938.
construction of physical works by local government, state government, the private sector or community groups, either individually or collectively

Physical works for remedial purposes can be constructed by relevant authorities and the community.

Depending upon the nature and extent of the physical works, formal approval via the Environmental Planning and Assessment Act may be required.

At the simplest level, where formal approval is not required, the proposed works might be constructed by community groups and council acting together, with council providing the funds.

For physical works requiring formal approval, it is necessary that a proponent be nominated. This might be the local council or a government department or authority. The major function of the proponent is to steer the proposal through the approval process and then administer construction.

Irrespective of size and whether or not formal approval is required, all works and activities recommended in an Estuary Management Plan will be eligible to receive the 50% funding subsidy from the State Government under the Estuary Management Program.

controls in the form of regulations imposed by state government authorities

Estuary Management Plans will be largely implemented by local government through available planning instruments, such as those under the Environmental Planning and Assessment Act.

Sections of Estuary Management Plans may also be appropriate for implementation under other legislation. For example, management recommendations for national parks and nature reserves may be appropriate for inclusion within plans of management prepared by the National Parks and Wildlife Service. Similarly, management details and recommendations for Crown land foreshores and the bed of the estuary could be implemented as a plan of management for Crown lands under the Crown Lands Act, 1989.

This integrated approach to estuary management, together with the coordination of activities arising from the estuary management planning process, will lead to a greater efficiency in land administration, improved waterway and foreshore management, and increased community input and involvement in the management of public lands within estuaries.

Having adopted a Management Plan and commenced its implementation, it will be necessary to undertake monitoring studies to ensure that management activities and controls are having the desired effects on estuarine habitat, quality and amenity.

Monitoring programs will generally be of two types:

- on-going 'baseline monitoring' to measure the general 'health' of the estuary
- 'event monitoring' to record the impact of some specified change.

In addition to collecting monitoring data, it is also necessary to review these data to assess the success or otherwise of implementation activities.

In the light of these findings, it may be necessary to amend the Estuary Management Plan, even to the extent of changing its objectives.

An Estuary Management Plan is not a static instrument. It needs to be reviewed on a regular basis and updated where necessary to cater for the changing needs and desires of society.

Continuing monitoring and review are essential elements of the Estuary Management Process.
The Estuary Management Process

Technical and research assistance

Technical assistance for the undertaking of Estuary Process Studies and for the formulation and implementation of Estuary Management Plans is available from the State Government through various government authorities whose activities are directly applicable to estuary management.

Examples of the types of services provided by government authorities are:

- The National Parks and Wildlife Service which undertakes wildlife and Aboriginal culture research activities
- NSW Fisheries, which undertakes fish and fish habitat research activities
- The Department of Planning, which is responsible for environmental and land-use planning
- The Department of Conservation and Land Management, which undertakes land resource surveys, soil conservation programs, catchment management programs, activities to manage reserves, and Crown land assessment
- The Environment Protection Authority, which develops strategies for environment protection, including the production of guidelines (e.g. Urban Stormwater Manual)
- The Public Works Department, which supervises tidal, hydraulic and sedimentary process studies
- The Forestry Commission, which undertakes vegetation mapping and revegetation studies; and
- The Department of Health, which can identify insects.

Other institutions can also provide a number of services of relevance to estuary management.

The more prominent institutions and the services they can provide include:

Australian Museum
- identification of aquatic fauna
- identification of insects

National Herbarium
- identification of estuarine flora
- vegetation mapping

Universities
- a wide variety of specialist advice and assistance on estuarine matters.

Fees charged for services from these authorities or institutions are eligible for the 50% subsidy under the Government’s Estuary Management Program.
Administration

Local councils have a key role to play in the better management of estuaries.

In general, local councils are responsible for land-use allocation and development in the immediate area surrounding an estuary.

Moreover, local councils have significant planning and development powers as consent authorities under the Environmental Planning and Assessment Act, 1979.

Finally, local councils, working with Catchment Management Committees, also act as an interface between the community and state authorities.

Thus, local councils can strongly direct and influence land-use allocation and development in the environs of an estuary. Their central role on the Estuary Management Committee reflects this responsibility.

In addition, a number of State government authorities have statutory responsibilities for different aspects of estuary management.

Other organisations can also provide valuable information and assistance.
Local Councils

Within the requirements laid down from time to time by the State Government, a council is responsible for the planning and management of land within its own area, including estuaries and their catchments.

Estuary Management Committee
As part of its normal planning responsibilities, council should form and chair an Estuary Management Committee to oversee the estuary management process and produce an Estuary Management Plan.

Where more than one council has jurisdiction over lands either adjacent to an estuary or affecting estuarine ecosystems and amenity, the affected councils should determine which council will chair the committee.

Estuary Management Plan
Once an Estuary Management Plan has been formally adopted by council(s), elements of the plan should be implemented, where appropriate, by:

- incorporation into environmental planning instruments, plans of management, etc.
- application of development conditions
- construction of remedial or other works
- promotion of public awareness and cooperation.

The State Government will provide financial assistance by way of:

- a 50% subsidy for the preparation of Estuary Management Plans, including the various studies and investigations undertaken as part of this process, and
- a 50% subsidy for the construction of remedial works, on-going monitoring programs, community awareness activities, etc. (see Section 6).

Environmental Planning and Assessment Act
The Environmental Planning and Assessment Act, 1979, provides the statutory framework for environmental planning in New South Wales. It has the object of encouraging:

- the proper management, development and conservation of natural and man-made resources (including agricultural land, natural areas, forests, minerals, water, cities, towns and villages) for the purpose of promoting the social and economic welfare of the community and a better environment
- the promotion and coordination of orderly economic use and development of land
- the protection, provision and coordination of communication and utility services
- the provision of land for public purposes
- the provision and coordination of community services and facilities
- the protection of the environment.

environmental impact assessment
Councils are encouraged to ensure that the objectives and recommendations of Estuary Management Plans are reflected in assessing development proposals.

Public works proposed in an Estuary Management Plan (those works funded partially or completely from the public purse) are subject to the provisions of the Environmental Planning and Assessment Act, 1979.

If a specific development proposal requires consent and is a 'designated development' (such as sand and gravel extraction), Council must consider the findings of an Environmental Impact Statement in assessing the proposal.

planning instruments
Estuary Management Plans should be implemented by councils through local environmental plans, development control plans, building policies and public works.

development applications
When considering development applications for estuarine lands, councils must have regard to matters set out in Section 90 of the Environmental Planning and Assessment Act.

These include the provisions of any environmental planning instrument or draft instrument, including a draft state environmental policy or regional environmental plan.
<table>
<thead>
<tr>
<th>Public Works Department</th>
<th>Department of Conservation and Land Management</th>
</tr>
</thead>
<tbody>
<tr>
<td>The Public Works Department is the State's authority on a number of aspects of estuary management. Specifically the Department:</td>
<td>The New South Wales Department of Conservation and Land Management is the State's authority on land resource management. Because it administers Crown lands, which include the beds of most estuaries and much of their public foreshores and wetlands, the Department has an important role in estuary management. Important aspects of the Department in relation to estuary management include:</td>
</tr>
<tr>
<td>- administers the Rivers and Foreshores Improvement Act, under which a permit is required for any activity that could detrimentally affect water flows, and for any excavation from the bed or banks of a tidal waterway or from land within 40 metres from the top of the bank of a tidal waterway</td>
<td>- ownership of the bed of most tidal waterways to the mean high water mark (Crown land), except for those areas noted in Section 4 of Appendix A</td>
</tr>
<tr>
<td>- employs specialist hydraulic engineers with considerable experience in hydraulic and sedimentary estuary processes</td>
<td>- ownership of many estuary foreshore reserves and wetlands (Crown land)</td>
</tr>
<tr>
<td>- collects data necessary for estuary process studies, including tidal information, hydraulic processes, sediment movement, etc.</td>
<td>- land assessment, under the Crown Lands Act, 1989, of all Crown land that is subject to sale, lease, reservation or dedication, with the object of achieving a rational allocation of the use of Crown land</td>
</tr>
<tr>
<td>- directs the work of private consultants in the estuary processes field</td>
<td>- management of Crown reserves through local councils and/or trusts</td>
</tr>
<tr>
<td>- assists councils with the preparation of Estuary Management Plans</td>
<td>- the issuing of leases and licenses for activities involving Crown land</td>
</tr>
<tr>
<td>- advises and assists councils with the evaluation of significant development proposals for estuaries</td>
<td>- leadership of the Total Catchment Management process</td>
</tr>
<tr>
<td>- administers and manages the State Government's Estuary Management Program, which provides financial assistance in the form of a 50% subsidy for activities associated with the Estuary Management Process, as defined in this Manual, and any estuary restoration works agreed to in the Estuary Management Plan as an outcome of the Estuary Management Process.</td>
<td>- statutory powers to manage the felling of trees (a permit is generally required to remove any tree from a slope greater than 18 degrees, from within 20 metres of the bed or bank of a watercourse or from within a declared environmentally sensitive area)</td>
</tr>
<tr>
<td>- provision of consulting services and advice concerning land degradation (which affect the estuarine environment)</td>
<td>- expertise in natural resources assessment, including soil and vegetation mapping</td>
</tr>
<tr>
<td>- expertise in land management and the development and implementation of management plans, such as catchment management plans.</td>
<td>- leadership of the Total Catchment Management process</td>
</tr>
</tbody>
</table>

DRAFT

Administration

to better manage our estuaries
The Department of Planning is the State’s authority on planning and environmental assessment matters and is responsible for administering the Environmental Planning and Assessment Act and the Heritage Act.

Specifically, the Department:
- employs planners and specialists with particular expertise in coastal environment planning and natural resource management
- develops environmental planning policy and prepares guidelines and advice to councils and the community
- prepares State Environmental Planning Policies, regional environmental plans and circulars to councils on planning issues, as well as preparing S117 Directions for issue by the Minister for Planning
- performs a decision-making role and applies planning controls on certain coastal developments, including coastal wetlands and littoral rainforest
- carries out environmental protection and oversees the environmental assessment process
- administers the Heritage Act as it relates to protection of coastal heritage items
- conducts studies of the coast relating to environmental and development issues
- provides services to the New South Wales Coastal Committee
- assists councils with the preparation of local environmental plans.

On 1 March 1992, the Environment Protection Authority (EPA) was formed under the Protection of the Environment Administration Act, 1991. The State Pollution Control Commission was absorbed into the Authority.

Following the introduction of the Clean Waters Act in 1970, the State Pollution Control Commission, with the support of industry and the public, concentrated on controlling the many and varied point sources of pollution discharging into New South Wales waterways. The Environment Protection Authority is now focussing on what may be called 'second generation' water pollution control problems, i.e. diffuse or non-point sources of pollution.

The role of the EPA is:
- to protect, restore and enhance the quality of the environment in New South Wales having regard for the need to maintain ecologically sustainable development
- to reduce risks to human health and prevent degradation of the environment by the means listed in the Act.

Specific activities of the EPA in relation to estuary management include:
- environmental monitoring
- licensing of point-source pollution discharges (both water and air)
- establishment of a set of goals and objectives for waterways;
- participation in beach protection programs.

NSW Fisheries is responsible for the protection and regulation of all aquatic animal and plant life in New South Wales, excluding marine mammals. This responsibility includes all species of fish, shellfish (marine, estuarine and freshwater) and aquatic plants, and extends to the protection of fish habitats.

Specific permission is required from Fisheries for dredging or reclamation works and for cutting mangroves below mean high water mark.

Under the Fisheries and Oyster Farms Act, 1935, there are provisions to control the placement of structures on recognised fishing grounds, to protect waters from substances injurious to fish, and to regulate the use of explosives. To protect fish species and fish habitats, aquatic reserves (marine and estuarine protected areas) can be proclaimed in any waters (including estuaries).

Fisheries controls the activities of recreational fishermen, the licensing of commercial fishermen and fishing boats, the licensing of all aquaculture ventures and the leasing of areas for oyster cultivation.

In relation to estuary management, Fisheries has a significant assessment role when development proposals or draft documents, such as planning instruments or land assessments, are referred for comment. Fisheries may recommend conditions on development applications in estuaries, which may become 'conditions of consent'.
National Parks and Wildlife Service

The Service has three areas of statutory responsibility which are applicable to estuaries:

- management of national parks and other land areas under the National Parks and Wildlife Act, which include some estuary foreshores, and in a few cases, sub-tidal areas
- statewide conservation of native fauna (marine mammals, terrestrial mammals, birds, reptiles and amphibia) and native protected plants
- statewide conservation of Aboriginal and other cultural sites.

Within designated National Parks, the statutory responsibilities of the Service include the protection of both species and habitats.

Outside designated National Parks, the Service has statutory power under new legislation - Endangered Fauna (Interim Protection) Act, 1991 - to protect species and habitats.

To promote appropriate nature conservation practices in non-National Park areas, the Service negotiates directly with landowners to encourage essential habitat conservation.

About one third of Australia's bird species rely on wetlands to some extent. In dry times these birds depend principally on estuarine wetlands. Australia is a signatory to a number of international conventions relating to the protection of migratory birds, many of which depend on estuarine habitats.

Fauna protected under the National Parks and Wildlife Act, include these birds and species which are primary inhabitants of estuaries, such as waterbirds, waders and seabirds. The Service has the power to increase the legal protection of individual species by designating them as 'endangered' and including them in Schedule 12 of the National Parks and Wildlife Act.

The National Parks and Wildlife Service is also the owner of land under estuarine waters of National Parks, e.g. in the Myall Lakes National Park and the headwaters of Cowan Creek. However, management of such areas is covered by the provisions of the National Parks and Wildlife Act and is not addressed in this Manual.

The Species Management Plan Program of the National Parks and Wildlife Service has developed management plans for selected species and groups of species, e.g. the Little Tern.

Maritime Services Board

The Maritime Services Board controls all matters of navigation within estuaries.

In terms of estuary management, any proposal for an activity or development which could have an effect on navigation must have the concurrence of the Board. Common examples include piled moorings, jetties and breakwaters. The requirement applies to all structures which project below mean high water level, irrespective of the ownership of the land under them.

In the ports of Sydney, Botany Bay, Newcastle and Port Kembla, the Board is the owner of submerged land and also exerts significant controls over foreshore land. However, management of these areas is outside the scope of this Manual.

DRAFT
to better manage our estuaries
Government financial assistance

The New South Wales Government will assist the formulation and implementation of Estuary Management Plans by providing technical and financial assistance.

For investigations and activities associated with the development and implementation of Estuary Management Plans, a 50% subsidy is available under the government’s Estuary Management Program, which is administered by the Public Works Department. In determining funding priorities within the Estuary Management Program, the Public Works Department will seek advice from other government agencies as necessary.

Activities eligible for subsidy include data collection and review, surveys, the undertaking of Estuary Processes and Estuary Management Studies, the preparation, display and review of Estuary Management Plans, and the undertaking of management activities recommended in the plan, including works, public awareness programs, continuing monitoring activities, etc.

Apart from direct financial subsidy to Council and other comparable organisations, technical assistance is also available for both formulation and implementation of Estuary Management Plans through various New South Wales government authorities.

Grant conditions

Application for subsidy can only be made by a legally constituted public body which can effectively control and be accountable for funds.

The applicant could be a single council, a number of councils acting jointly (through a committee, for example, under Section 521 of the Local Government Act), a Trust or other responsible authority.

The applicant must be the proponent of the proposed activity for which subsidy is sought. In the case of a subsidy for the undertaking of an Estuary Processes Study and an Estuary Management Study, the applicant would be the council’s Estuary Management Committee.

In the case of applications for remedial or other recommended works and activities, subsidies will only be granted when the Estuary Management Plan has been finalised and adopted by council(s), and its planning provisions incorporated in appropriate statutory plans.
**Income from royalties**

The Department of Conservation and Land Management collects royalties on dredged material, as it does for all non-mineral extractive resources taken from Crown land. For commercial operations, whether by government agencies or the private sector, the royalty rate is negotiated as part of the lease or license tenure agreement.

Royalties are normally paid into the State’s Consolidated Revenue, but Treasury may approve other arrangements in particular cases. Where the dredging is undertaken as part of an Estuary Management Plan, the royalties may be deposited in a special fund to be applied to rehabilitation works within the estuary. The dredging of Avoca Lake and its subsequent inclusion in a Management Plan is an example of such a scheme.

In some cases where dredging is a marginal economic proposition because of insufficient local demand or other factors, Government policy allows for royalties to be waived where it is necessary to encourage private operators to undertake works which have public benefit.

**Income from Crown land**

With Crown lands comprising the beds of most estuaries and much of the foreshore lands, income generated from activities on these lands may be available to assist in the Estuary Management Process, and in the undertaking of works and activities.

Much of the Crown foreshores are reserved with care, control and management vested in trusts such as local government. Under the Crown Lands Act, revenue from developments on these lands, such as from caravan parks, and marinas, must be reallocated to the care, control and management of Crown lands.

Land assessment activities undertaken by the Department of Conservation and Land Management as part of the estuary management planning process may also identify other areas of Crown lands that are most appropriately reserved and managed under the care and control of Council. These lands may have the potential to be developed or in some instances, currently generate revenue.

Examples could include various types of uses, waterfront and foreshore occupations that require increased levels of management in accordance with the strategies detailed within the Estuary Management Plan.

Financial planning is an essential facet of the estuary management planning process. The consideration of revenue from Crown lands and its expenditure to improve Crown land management is an important component of this financial planning.

---

24 to better manage our estuaries

DRAFT
Introduction to appendices

The appendices deal with a number of wide ranging estuary management issues.

In many cases, the following appendices describe estuarine processes and issues in isolation from each other. This has been done for reasons of simplicity and convenience. However, it must be recognised that estuarine processes and issues are individually complex, and often interact in an involved way with other processes and issues.

The Appendices fall into four major categories.

Appendix A is a statement of the New South Wales Government's Estuary Management Policy.

Appendices B to F present essential background information regarding the characteristics of New South Wales estuaries and the impact of human activities thereupon.

Appendices G to H describe two important tools of estuary management: Estuary Process Models and the procedure of Total Catchment Management respectively.

Various types of estuary process models, including hydraulic models, water quality models, sediment transport models and biological models, are used to assess the effects of proposed land-use changes on the estuarine environment. These models are often computer based.

Total Catchment Management has been progressively implemented in New South Wales over the last several years. Total Catchment Management provides a decision-making framework that takes into account all processes that affect a catchment. As such, it is eminently suitable for estuarine management because of the inter-related nature of estuarine processes.

Appendices I to N present various details and guidelines concerning estuary management.

Appendices

<table>
<thead>
<tr>
<th>Appendix</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>New South Wales Estuary Management Policy</td>
<td>27</td>
</tr>
<tr>
<td>B</td>
<td>Physical characteristics and behaviour of NSW estuaries</td>
<td>31</td>
</tr>
<tr>
<td>C</td>
<td>Estuarine water quality</td>
<td>63</td>
</tr>
<tr>
<td>D</td>
<td>Estuarine habitat</td>
<td>75</td>
</tr>
<tr>
<td>E</td>
<td>Estuarine flora and fauna of special concern</td>
<td>95</td>
</tr>
<tr>
<td>F</td>
<td>Human impacts</td>
<td>101</td>
</tr>
<tr>
<td>G</td>
<td>Estuarine monitoring and process models</td>
<td>111</td>
</tr>
<tr>
<td>H</td>
<td>Total Catchment Management</td>
<td>117</td>
</tr>
<tr>
<td>I</td>
<td>Administration of Crown land</td>
<td>125</td>
</tr>
<tr>
<td>J</td>
<td>Management of human activities</td>
<td>131</td>
</tr>
<tr>
<td>K</td>
<td>Management of water quality</td>
<td>145</td>
</tr>
<tr>
<td>L</td>
<td>Management of extractive industries</td>
<td>151</td>
</tr>
<tr>
<td>M</td>
<td>Management of threatened fauna</td>
<td>159</td>
</tr>
<tr>
<td>N</td>
<td>Estuary rehabilitation</td>
<td>165</td>
</tr>
</tbody>
</table>

To better manage our estuaries
**APPENDIX A  NEW SOUTH WALES ESTUARY MANAGEMENT POLICY**

1 Preamble
2 Policy Statement
3 Policy Implementation
4 Assistance

1 PREAMBLE

New South Wales estuaries and their immediate catchments serve many purposes. The climate is moderate; visual and recreational amenity are high; they are highly desirable places in which to live and work. About 75% of the State's population live in towns and cities located adjacent to estuaries. Population densities along the coastline can be as high as 6,000 people per km².

Estuaries are popular places for a wide variety of active and passive recreational pursuits. They are the basis of many of the State's valuable commercial activities. Most tourists from within New South Wales and elsewhere are attracted to estuarine locations and activities. The majority of the fish, shellfish and crustaceans harvested in New South Wales are either caught or spend part of their life cycle in estuaries. Most of our sand and gravel is won from the floodplains or beds and banks of estuaries.

Estuaries and their associated wetlands are of immense environmental value, providing a variety of habitats for many aquatic and terrestrial organisms.

Many of the above uses are in direct conflict with one another. In recent times, these conflicts have been compounded by recognition of the limited number and nature of our estuaries on the one hand, and through increasing pressures to further develop estuaries on the other. Quite apart from conflicts between human use and estuarine ecology, many human activities are also in conflict with each other. For example, urban waterside developments can restrict public access to the foreshore; oyster farming can reduce recreational use; etc.

Over the period of European settlement, this increasingly intensive use of estuaries and their catchments for a variety of activities has led to a general degradation of the estuarine environment. Water quality has deteriorated; beds of estuaries have become silted; mangrove, seagrass and other important habitat areas have been reduced and degraded; fish stocks are declining; certain species of fauna are becoming endangered and threatened and are finding it increasingly difficult to survive.

Increasing public recognition of these issues has highlighted the need to significantly improve the management of the State's estuaries.

2 POLICY STATEMENT

The New South Wales Government recognises the ecological, social and economic importance of the State's estuaries and is concerned about the long-term consequences of their accelerating degradation. In response to this concern, an Estuary Management Policy has been developed. This policy, which forms part of a suite of catchment management policies, provides for the assessment of all estuarine uses, the resolution of conflicts, and the production of a unified and sustainable management plan for each estuary, including remedial works and the redirection of activities, where appropriate.

The general goal of the Government's Estuary Management Policy is to achieve an integrated, balanced, responsible and ecologically sustainable use of the State's estuaries, which form a key component of coastal catchments. Specific objectives of the policy are:

- protection of estuarine habitats and ecosystems in the long-term, including maintenance in each estuary of the necessary hydraulic regime.

- preparation and implementation of a balanced long-term management plan for the sustainable use of each estuary and its catchment, in which all values and uses are
considered, and which defines management strategies for:

- conservation of aquatic and other wildlife habitats;
- conservation of the aesthetic values of estuaries and wetlands;
- prevention of further estuary degradation;
- repair of damage to the estuarine environment; and
- sustainable use of estuarine resources, including commercial uses and recreational uses as appropriate.

To achieve these objectives, the Policy incorporates the following:

- preparation of Estuary Management Plans which take account of ecological, economic and social issues pertaining to each estuary and its catchment, as well as its hydraulic behaviour;
- availability, under the New South Wales Government's Estuary Management Program, of financial and technical assistance to Local Government on the basis of 1:1 subsidy (1 State Government: 1 Local Government) for the development and implementation of Estuary Management Plans, including remedial works and other key implementation activities;
- production of an Estuary Management Manual to facilitate policy implementation;
- statutory protection, under existing legislation, of the necessary and effective hydraulic behaviour and nature conservation values of river estuaries, coastal lakes and associated tidal wetlands; and
- stewardship of estuary assets by all responsible authorities consistent with the above objectives.

3 POLICY IMPLEMENTATION

The policy itself will be implemented through the preparation and implementation of Estuary Management Plans, as developed through the process depicted in Figure A1.

This involves the formation of an Estuary Management Committee, chaired by Local Council, to supervise subsequent investigations and the ultimate formulation of an Estuary Management Plan. Important steps in this process are the undertaking of Estuary Process and Estuary Management Studies. An Estuary Process Study defines baseline conditions for the various physical, chemical and biological estuarine processes and interactions between them and between other land and water uses. An Estuary Management Study defines management objectives, options and impacts on the estuary. This leads to the formulation of an Estuary Management Plan, which consists of management policies and a scheduled sequence of activities that need to be undertaken to achieve the estuary management objectives. The Estuary Management Process involves public participation at all stages.

4 POLICY APPLICATION

The Estuary Management Policy and this Manual apply to all tidal waterways, intermittently tidal coastal lakes and non-tidal coastal lakes in New South Wales, where all or most of the bed of the waterway is Crown land, and as such, is administered by the Department of Conservation and Land Management. The following tidal areas are exceptions, with the authority responsible for care, control and maintenance of the bed of the waterway shown in brackets:

- the ports of Sydney, Newcastle, Port Kembla and Botany Bay (Maritime Services Board);
- national park areas, such as the tidal waterway within Myall Lakes National Park and part of Cowan Creek (National Parks and Wildlife Service);
- part of Georges River at Chipping Norton (Chipping Norton Lake Authority, as advised by the Department of Public Works); and
- Lake Illawarra (Lake Illawarra Authority, as advised by the Department of Public Works).

For these areas, the relevant agencies will be encouraged to put similar management plans in place and to suitably involve the community in the decision-making process.
Fig. A.1   Elements of the Estuary Management Process
5 ASSISTANCE

Assistance from the New South Wales Government is available in the form of:

- technical advice;
- data collection, studies and investigations; and
- 50 percent subsidy of the cost of investigations (including Process and Management Studies) and any subsequent remedial works and measures associated with the development and implementation of estuary management plans.

Applications for financial assistance can be made by a single council, a number of councils acting jointly (through a committee, for example, under Section 521 of the Local Government Act), a Trust, or other responsible authority. The applicant must be a legally constituted public body which can effectively control and be accountable for funds. The formal adoption of an Estuary Management Plan is a necessary requirement before State funds will be made available for any works and measures.
APPENDIX B

PHYSICAL CHARACTERISTICS AND BEHAVIOUR OF NEW SOUTH WALES ESTUARIES

1 Introduction
2 The Estuarine Domain
3 Estuarine Limits
4 Formation of Estuaries in New South Wales
5 Tidal Behaviour
6 Tidal Behaviour of New South Wales Estuaries
7 Water Movement
8 Salinity Behaviour
9 Sediment Movement
10 Mixing Processes
11 The Movement of Surface Pollutants
12 Microlayers
13 References

1 INTRODUCTION

An estuary is a meeting place. It is the name given to the lower reaches of a creek, river or lake where freshwater meets saltwater, where the randomly varying discharges from upstream catchment areas meet the cyclic ebb and flood of tidal discharges, and where the aquatic flora and fauna of freshwater regimes meet their marine counterparts.

This Appendix describes representative estuary types along the New South Wales coastline and the way in which they were formed. Three physical processes of importance to estuary behaviour and management are also described - the movement of water, salinity and sediment along estuaries. A brief description is also given of mixing processes in estuaries and the movement of surface pollutants, aspects important to estuarine water quality. Although these various physical processes are described independently, it is important to realise that they interact in a complex way. Further, even more complex interactions occur between these physical processes and estuarine habitats and ecosystems.

It is essential that all these inter-actions are identified and taken into account in planning and management programs for estuaries.

2 THE ESTUARINE DOMAIN

The word 'estuary' is derived from the Latin 'aestus', meaning tide. Traditionally, an estuary is defined in terms of the limit of penetration of oceanic salt, which moves upstream under the influence of the ocean tide. In this sense, a commonly used definition is that of Pritchard (1952), who defined an estuary as 'a semi-enclosed coastal body of water which has a free connection with the open sea and within which sea water is measurably diluted with fresh water derived from land drainage'. However, this definition does not include the many lakes and lagoons on the New South Wales coast which are only intermittently open to the ocean.

A broader definition of an estuary would take into account the diversity and spatial variability of estuarine fauna and flora. Hutchings and Collett (1977) define estuaries as the tidal portions of river mouths, bays and coastal lagoons, irrespective of whether they are dominated by hypersaline, marine or fresh water conditions. Included in this definition are inter-tidal wetlands, where water levels can vary in response to the tidal levels of the adjacent waterway, together with perched freshwater swamps, as well as coastal lagoons which are intermittently connected to the ocean.

It is simplest, therefore, to define an estuary as any semi-enclosed body of water having an open or intermittently open connection with the ocean, in which water levels vary in a predictable, periodic way in response to the ocean tide at the entrance.
3 ESTUARINE LIMITS

The Upstream Boundary

In hydraulic terms, the upstream boundary of an estuary is simply the location of the tidally influenced area. In many estuaries, the tidal limit is a considerable distance upstream from the salinity limit. For example, the tidal limit of the Hawkesbury River occurs at Yarramundi, which is some 140 km upstream from the river mouth, whereas the salinity limit occurs around lower Portland, which is only 80 km upstream from the river mouth.

In estuaries such as the Georges River and Port Hacking, where tidal behaviour is curtailed by man-made weirs and other structures, tidal and salinity limits coincide.

The actual limit of tidal influence varies with time, depending upon freshwater flows and the natural variability of tides. It can be difficult to determine the 'tidal limit' by mere observation. Towards the limit of tidal influence, flood flows may persist for as little as 1 hour, and may be so modest as to go unnoticed by casual observers. Figure B1 shows a gravel bar in the Hawkesbury River which is approximately 1 km downstream of the tidal limit. Although the flood tide at this locality is reduced to a rise of only 0.2 m, it is sufficient to drown the freshwater rapids over the bar. Given that the gravel bar is exposed for 90% of the time, a casual observer would not credit that it was subject to regular and predictable tidal influence.

The limit of tidal influence in an estuary is rarely constant. Apart from short-term cyclical changes in response to the ever-changing ocean tides, the upstream boundary of an estuary can vary over long time spans according to both natural processes and artificial disturbance. For example, sand extraction in the vicinity of the limit of tidal influence in the Hawkesbury River has caused the tidal limit to move a further 10 km upstream over the last 100 years.

The Downstream Boundary

In hydraulic terms, the downstream boundary of an estuary can be considered as the location where any change in bottom topography has no substantial effect upon tidal behaviour within the estuary.

The downstream boundary is not always obvious, but it corresponds to the seaward limit of the entrance bar in most situations in New South Wales (the Ebb Terminal Lobe of Figure B2).

Drowned estuary mouths, which do not generally have an entrance bar, present a problem for any definition of the downstream boundary of an estuary. There is usually no distinct change in bed topography in the vicinity of the mouth, only a gradual transition in the movement of bed sediments from tide dominated to wave dominated processes. In these circumstances, a convenient geographical location is usually selected as the downstream limit of the estuary (e.g. Sydney Heads).

Lateral Boundaries

Whereas the upstream and downstream boundaries of an estuary have been defined on the basis of hydraulic behaviour, the lateral boundaries of an estuary are best defined in ecological terms.

The shallow and inter-tidal margins of an estuary are crucial to the diversity and productivity of marine life. These areas contain seagrass meadows, mangrove forests and saltmarshes, all of which generate large amounts of organic detritus, which forms the foundation of the estuarine food chain.

The lateral boundaries of an estuary should embrace all wetlands - salt, brackish and fresh - which interact with tidal and flood flows. The lateral boundaries should also include those marshes which are inundated only during extreme tides or flood events.

Upstream Catchment Areas

Whilst the above boundaries define the limits of an estuary, they isolate the estuary from its tributary catchment areas.

In essence, an estuary acts as a funnel to convey freshwater runoff from the land into coastal waters. A number of catchment activities affect the volume and quality of this runoff. Floodwaters and stormwater runoff...
Figure B1  Effect of Tides on Water Flow Near the Tidal Limit of the Hawkesbury River
EBB TIDE DOMINATED SEDIMENTARY PROCESSES
FLOOD TIDE DOMINATED SEDIMENTARY PROCESSES
WAVE DOMINATED SEDIMENTARY PROCESSES

ESTUARY

Figure B2 Entrance Bar at an Estuary Mouth

Figure B3 Salt Marsh Wetland

often contain significant quantities of suspended solids, natural and artificial nutrients, pesticides, etc., some of which are detrimental to estuarine ecosystems.

Upstream catchment activities are the single most important factor in determining the present-day nutrient balance and water quality of estuaries. The impact of ‘external’ activities, which occur beyond the strictly defined estuarine limits, points to the need for a ‘total catchment management’ approach in managing estuaries.

4 FORMATION OF ESTUARIES IN NEW SOUTH WALES

Roy & Thom (1981) and Roy (1984) have developed a comprehensive geological model of the evolution of the coastal plain, coastline and estuaries of New South Wales. The model has been based on the results of many stratigraphic, geomorphological and coastal process studies. The following discussion is necessarily brief. The reader is referred to Chapman et al (1982) for further details.

Evolution of the New South Wales Coastline

The bedrock valleys in which estuaries lie have been gradually infilled with terrestrial sediment over tens of thousands of years. Over this time, they have also undergone multiple cycles of erosion and infilling with marine sediments in response to varying sea levels (see Figure B4).

During periods of lower sea levels (up to 140 m below present), estuaries extended further seaward, eroding new and lower bed levels. During periods of sea level rise, vast quantities of marine sand were reworked (i.e. transported) landwards across the inner continental shelf as landward moving (transgressing) sand sheets. In many locations along the New South Wales coast, separate barriers can be recognised, corresponding to cycles of sea level variation.

Figure B4 Sea Level Variations
Throughout the central and north coast of New South Wales, two distinct barriers are apparent: the ‘Outer’ and ‘Inner’ Barriers (see Figure B5). The ‘Outer Barrier’ consists of a belt of beach, dune, estuarine and lagoonal sediments from the Holocene age (i.e. sediments deposited within the last 10,000 years). The eastern edge of the Outer Barrier forms the present day coastline of New South Wales.

Landward of the Outer Barrier, and often separated from it by an inter-barrier depression, is a second belt of marine sediments, referred to as the ‘Inner Barrier’. Carbon Dating of humus, charcoal, shell and basal corals has consistently indicated that Inner Barrier sands are Pleistocene in age, and originate in the period 140,000 years to 30,000 years before present.

The separation of the Inner and Outer Barriers can lead to the formation of extensive estuarine channels between both barriers. Newcastle Bight is such an example, where Tilligerry Creek extends south-west from Port Stephens, and Fullerton Cove forms a basin behind the same barrier, but is connected to the Hunter River (see Figure B6).

The Outer (Holocene) Barrier is present, to varying degrees, along the whole coast of New South Wales, but is well developed in the north. The Inner (Pleistocene) Barrier is generally not found south of Newcastle. Roy and Thom (1981) advance reasons for this.

There are significant differences in the minerals of the Inner and Outer Barrier sediments. The most striking difference is the tendency for Inner Barrier sands to exhibit induration, or the weak cementing together of the sediments, and strong discolouration. Colours of the inner barrier sediments vary from grey to brown in colour, and this, coupled with the rock-like nature of the indurated sediments, leads to the common name ‘coffee rock’. At sites along the north coast, long term erosion of the Outer Barrier has left indurated Inner Barrier sands outcropping at the present day beach face (see Figure B7).

Evolution and Classification of New South Wales Estuaries

The evolution of estuaries in New South Wales has been determined by the degree of barrier formation. This in turn has been largely influenced by the inherited coastal topography of the estuaries, as described below.

![Figure B5  Inner and Outer Barriers off Newcastle Bight (Source: Chapman et al, 1982)](image-url)
As sea level approached present day mean sea level, extensive outer barriers were formed across the mouths of broad, shallow embayments. Landward of these barriers, estuaries were created in the form of broad tidal lakes connected to the ocean by narrow tidal inlets through the barrier. In small embayments, tidal flows into the small lakes were insufficient to maintain permanent entrances.

Deep narrow-mouthed embayments, such as Port Jackson and the Hawkesbury-Broken Bay System, led to different form of estuary evolution. The transgressing sand sheets were unable to completely fill the mouths of deep embayments before sea level stabilised. The incipient barriers remained submerged and the estuaries developed as drowned river valleys with wide mouths which extended across the width of the embayment.

The estuaries of New South Wales can be classified into three generic groups and four different stages of maturity (Roy, 1984). The generic types are:

- Drowned river valley estuaries
- Barrier estuaries
- Saline coastal lakes
The different stages of maturity within each estuary type reflects the gradual infilling that occurred over geological timescales. Infilling has occurred from the seaward side, (marine sand) from the landward side (fluvial sediments), and by the accumulation of calcareous and carbonaceous sediment produced by biological processes within the estuary itself (e.g. plankton and molluscs). Figures B8, B9 and B10 show stages of infilling (i.e. maturation) of each estuary type.

Infilling rates are variable between estuaries because of differences in the size, lithology, topography, coastal setting and the geographical location of upstream catchments. Individual estuaries, therefore, can differ markedly in the extent to which they have progressed towards maturity. Hence, despite the common age of the New South Wales estuaries, a diversity of stages of maturity and associated estuarine conditions exists today.

Examples of Estuary Types

(a) Drowned River Valley Estuaries

Drowned River Valley Estuaries are easily recognisable because of their wide bedrock-flanked mouths, the presence of a submerged tidal delta and the absence of a sub-aerial sand barrier at their entrances. Upper catchment sediments have reclaimed the upstream reaches of drowned river valleys, which today consist of extensive floodplains with tidal river channels, e.g. Georges River upstream from Picnic Point and the Hawkesbury River upstream from Wisemans Ferry. Downstream of these areas, the basic form of the original drowned river valley remains as a steep sided and deep muddy basin, which deepens and widens in the seawards direction.

The size and depth of the relict drowned valley is dependent upon the dimensions of the parent valley and the relative sediment supply from the upper catchment. For instance, in Port Hacking, which has only a small upper catchment and therefore a relatively low sediment yield, there is a difference of 30 m in depth between the upper fluvial delta (formed from terrestrial sediments) and the shoals of the submerged tidal delta at the entrance (formed from marine sediments).

(b) Barrier Estuaries

Young barrier estuaries exist as tidal lakes. They are characterised by relatively small upper catchments. Consequently, the sedimentation that has occurred since sea levels stabilised has not been sufficient to infill the initial back-barrier lake (see Figure B11).

The shape, depth and size of the tidal lakes are variable depending upon the size of the parent embayment and the rates of sediment supply from the catchment. They vary from very small systems like Narrabeen Lagoon (area 2.1 sq. km; average depth 1-2 m) to Lake Macquarie, the largest tidal lake in Australia (area approximately 150 sq. km; average depth approximately 6 m).

Mature Barrier Estuaries have been created by extensive river systems with relatively high sediment loads. The high sediment loads have infilled the initial back-barrier lake with alluvium, causing the development of sinuous river channels discharging directly into the ocean ("Tidal Rivers"). Contiguous floodplains with backwater swamps and cut-off bays are vague reminders of the former back-barrier lakes.

Mature barrier estuaries range in size from large systems like the Clarence, Richmond and Hunter Rivers to small systems like Coffs, Bonville and Currumbene Creeks (see Figure B12).

(c) Saline Coastal Lakes

Saline lakes are small systems which have intermittent entrances that are closed to the ocean for most of the time. Under natural conditions, the ocean entrance opens only when a large build-up of catchment runoff breaches the beach berm. Saline coastal lakes comprise mostly small systems such as Dee Why and Manly Lagoons, but they can include larger systems such as Wollumboola Lake (see Figure B13).

5 TIDAL BEHAVIOUR

The movement of water in and out of an estuary is predominantly influenced by the tides. Freshwater effects are generally small (but often of significance with respect to water quality), except during times of flood.
Evolution of a Drowned River Valley Estuary Showing Stages of Infilling (after Roy 1982)
Figure B9  Evolution of a Barrier Estuary Showing Stages of Infilling (after Roy 1982)

Dimensions approximate. Tidal range in the estuaries shown in relation to that in the open ocean.
Figure B10  Evolution of a Coastal Lake Showing Stages of Infilling (after Roy 1982)
Ocean Tides

Coastal water levels fluctuate in a regular and predictable fashion in response to the gravitational effects of the moon, sun and planets on the oceans of the earth. The tidal range varies from tide cycle to tide cycle in response to the ever-changing relative positions of these bodies. However, the tidal range undergoes a regular monthly cycle, increasing to a maximum over a fortnight (Spring Tides) and then decreasing to a minimum over the next fortnight (Neap Tides), because of the monthly orbit of the moon around the earth. Solstice tides, or 'King Tides' occur in June and December of each year, when the sun is directly over the Tropics of Cancer and Capricorn respectively.

Tides along the New South Wales coastline are semi-diurnal in nature, i.e. high water and low water occur about twice daily (the actual period of a tidal cycle is about 12.5 hours). They are sinusoidal in shape and have a pronounced diurnal inequality (successive high tides differ markedly). This is illustrated in Figure B14. The ocean tidal range varies only slightly along the New South Wales coast, from a mean spring range of 1.1 m at Eden in the far south, to 1.3 m at Sydney. Between Sydney and Tweed Heads, the ocean mean spring range is approximately constant at 1.3 m.

The variation of ocean tide levels is conveniently expressed as a series of 'tidal planes', or heights of standard tides above a datum, usually Indian Spring Low Water. Tidal planes are determined by a mathematical analysis of tidal records. Indian Spring Low Water is a convenient measure of low water below which the tide seldom falls, and thus is a useful datum for navigation purposes. Table B1 shows the commonly adopted tidal planes and their values in Sydney Harbour at Fort Denison.
The confined and often shallow nature of estuaries has a number of effects on the tidal movement of water into, along and out of an estuary. The more important of these effects are now briefly described.

**Tidal Propagation**

The tidal rise and fall of ocean water levels propagates along an estuary as a wave of long wave length. The speed of travel or celerity of this wave, e.g. the speed at which 'high water' and 'low water' travel upstream from the estuary entrance, varies with water depth, the deeper the water, the faster the wave celerity.

**Tidal Lag**

Tides require time to propagate along an estuary. The delay between a standard state of the tide at the estuary mouth, such as high tide, and the occurrence of the same state of tide inside the estuary is referred to as 'tidal lag' (see Figure B15).

**Tidal Distortion**

If the tidal range is appreciable compared to the mean depth of the estuary, the speed of propagation of the tide at high water will be significantly faster than at low water. This causes the shape of the tidal wave to become progressively more distorted as it moves landward. This 'tidal distortion' results in a 'saw-tooth' tide curve, in which the rise of the tide is noticeably faster than its fall (see Figure B15). As a consequence, peak flood tide velocities are greater than peak ebb tide velocities. This is of considerable significance with respect to sediment transport (see Section 9).

**Elevated Half Tide Levels**

The higher celerity of the flood tide compared to the ebb tide results in a tendency for greater upstream movement of water on the flood tide compared to downstream movement on the

![Figure B14 Typical Ocean Tides in New South Wales](image)

![Figure B15 Tidal Characteristics at the Entrance and Head of a Tidal River](image)
ebb tide. This leads to a dynamic 'trapping' of water in the upper reaches of the estuary, as reflected in a super-elevation of half tide level (see Figure B15). Elevated half-tide levels act to increase the seaward flow of water and so provide an overall flow balance. This effect is sometimes referred to as 'tidal pumping', i.e. 'tidal distortion' results in the tide 'pumping' water upstream.

Fortnightly Tides

The 'trapping' of water in the upstream reaches of an estuary, as described above, is a dynamic phenomenon that varies with the strength of the tides. Variation in the volume of trapped water during a monthly Spring-Neap tide cycle can produce a significant fortnightly variation in half tide level (the 'Fortnightly Tide'). This internally generated tide shows up on tidal records as a slow day-to-day variation in the mean water level from a maximum to a minimum and then back to a maximum again over a period of about 14 days (see Figure B16). 'Fortnightly tides' are strongest in long shallow estuaries with a large ratio of tidal range to depth, and are an important secondary mechanism of mass movement of water along the estuary (see Section 7). They can be mistaken for the effect of increased freshwater flows or tidal surge caused by meteorological effects.

Amplification of Tidal Range

In certain estuaries, the ocean tidal range is amplified, or increased, in upstream reaches of the estuary because of resonance effects. This occurs because the frequency of the ocean tide is close to the frequency of free oscillation of the main estuary channel (which is dictated by its length and depth). Amplification of tidal range is common in mature barrier estuaries and in drowned river valley estuaries along the New South Wales coastline. A narrowing of the waterway cross-section in an upstream direction also encourages tidal amplification.

Impact of Estuary Works

The propagation of the tide along an estuary is affected by the geometry of its bed, especially water depths. In particular, tidal propagation in tidal rivers is very sensitive to water depths over the first several kilometres upstream from the estuary mouth. Many developments take place in the entrance reaches of estuaries (e.g. harbours, training walls, navigation channels, reclamation and dredging) By virtue of their ability to significantly alter depths in the most tidally sensitive reach of the estuary, such developments can affect tidal behaviour along the entire estuary. For example, extraction of 760,000 m$^3$ of sand from the first 2 km of the Tweed Estuary affected tidal water levels by up to 0.3 m and tidal flows throughout the entire estuary (PWD, 1979).

6 TIDAL BEHAVIOUR OF NEW SOUTH WALES ESTUARIES

The length, width and depth of an estuary affects the propagation of tides along the waterbody. It is convenient to discuss the tidal behaviour of New South Wales estuaries from the point of view of estuary shapes rather than...
estuary types. With regards to tidal behaviour, a mature barrier estuary, such as the Hunter River, is identical to a mature drowned river valley estuary, such as the Karuah River. The three estuary shapes influencing tidal behaviour are as follows:

- Tidal Rivers;
- Drowned River Valley Estuaries; and
- Tidal Lakes.

**Tidal Rivers**

Tidal rivers are characterised by narrow, shallow channels of relatively constant width and constant depth, consisting predominantly of sandy bed sediments, and include the mature stages of barrier estuaries and drowned river valley estuaries.

The shallow nature of the channels promotes tidal resonance which is counter-balanced by energy losses across entrance shoals and frictional dissipation at the sandy bed. Consequently, the tidal range along the estuary nearly always displays initial attenuation, followed by mild amplification before complete damping at fluvial gravel and sand bars around the head of the estuary.

This behaviour is illustrated by the Manning River (see Figure B17). At Manning Point, which is only three kilometres upstream from the estuary mouth, the tidal range is only 50% of the ocean value (because of the dissipative effects of the entrance bar). At Wingham Brush, near the upstream tidal limit of the estuary and some 45 km upstream from the mouth, the tidal range has been amplified to about 70% of the ocean value.

![Figure B17 Tidal Characteristics of a Tidal River (Manning River)](image-url)
Initial attenuation of tidal range does not occur in estuaries such as the Hunter River, which have artificially deepened entrances associated with active port facilities.

**Drowned River Valley Estuaries**

The younger stages of drowned river valley estuaries are characterised by channels which generally deepen and widen in the seawards direction. The landward narrowing of the channel promotes tidal amplification through the concentration of flows. As the channel shallows, tidal resonance also helps to maintain a high tidal range. River valley estuaries display no initial attenuation but often exhibit amplification of the ocean tidal range.

In such estuaries, the tidal range is only attenuated in the upstream reaches where the cumulative dissipative effects of bed friction dampen tidal flows. For example, amplification occurs over most of the length of the Hawkesbury River, which is in New South Wales. The tidal range at Wisemans Ferry, which is approximately midway along the estuary, is 16% greater than the ocean range. The tidal range at Windsor, which is 123 km upstream from the estuary mouth, is slightly less than ocean range. Upstream of Windsor, the presence of coarse shallow sand shoals abruptly reduces tidal range to 26% of the ocean value (see Figure B18).

![Figure B18 Tidal Characteristics of a Drowned River Valley Estuary (Hawkesbury River)](image-url)
Tidal Lakes

Tidal lakes include young barrier estuaries and saline coastal lakes (when open to the sea). They are characterised by a broad expanse of tidal water, connected to the ocean by a relatively small tidal channel, referred to as a tidal inlet. The depth of water in the lake is always greater than that of the inlet.

Tidal lakes always display severe attenuation with tidal range diminishing from full ocean range at the mouth to often as little as a few centimetres over distances of only 1-5 km (see Figure B19).

7 WATER MOVEMENT

Water moves along an estuary under the influence of two primary ‘forcing’ mechanisms - freshwater inflows attempting to drain to sea and the regular tidal movement of seawater into and out of the estuary. In addition, tidal and salinity behaviour within the estuary generate a number of ‘secondary currents’, which while of low velocity, are of considerable significance with respect to mixing and sediment transport.

Freshwater Inflows

Freshwater inflows fluctuate in a more-or-less random fashion in response to surface runoff from tributary catchments. The construction of major dams in upstream catchment areas reduces both the volumes of ‘freshwater’ runoff and the ‘freshwater flushing’ of estuaries. In times of drought, ‘freshwater’ inflows may be absent, or may consist principally of the constant discharge of sewage effluent and other wastewaters.

Figure B19  Tidal Characteristics of a Tidal Lake (Lake Macquarie)
Freshwater inflows impart a net seaward excursion to water particles over each tidal cycle, and thus promote estuary flushing (see Section 10).

Tidal Flows

(a) Ebb and Flood Tides

The vertical rise and fall of the tide produces horizontal flows in the form of tidal currents. Depending on the tidal range, entrance characteristics and the depth of the estuary, tidal currents can have quite fast velocities (up to 1.0 m/s).

The incoming or rising tide is traditionally referred to as the ‘flood tide’ because it ‘floods’ the channel. The outgoing tide is referred to as the ‘ebb tide’. The strength of the ebb and flood tide velocities varies diurnally and over Spring-Neap cycles in exactly the same way as tidal water levels vary (Spring Tides produce the fastest tidal currents).

Tidal distortion in shallow estuaries leads to the flood tide having a shorter duration than the ebb. As a consequence, the peak flood tide velocities tend to be greater than the peak ebb tide velocities (see Section 5 and Figure B15). This is of considerable importance to sediment transport (see Section 9).

(b) Slack Water

The period of quiet water when the tide reverses from flood to ebb or vice versa is referred to as slack water. ‘High water slack’ is the name given to the tide change from flood to ebb; ‘low water slack’ refers to the tide change from ebb to flood. The duration of slack water is quite variable from one estuary to another and can last from 20 minutes to almost one hour.

(c) Phase Lag

Depending upon the type of estuary, the peak tidal discharge often occurs at different times to local high and low waters at the same location. This difference is referred to as ‘phase lag’.

At the entrance to tidal rivers, there is a phase advance of the order of 1-1.5 hours, i.e. peak tidal discharge occurs 1-1.5 hours earlier than the top and bottom of the tide. Slack water at the entrance of the tidal river usually occurs 1.5-2 hours after the top or bottom of the tide (e.g. Tweed River).

At the entrance to tidal lakes, discharge and water level variations tend to be in phase and peak ebb and flood tidal discharges coincide with the bottom and top of the tide respectively. Slack water occurs 3-4 hours after the top or bottom of the tide (e.g. Tuggerah Lake).

(d) Tidal Excursion

The total distance travelled by a water particle from low water slack to high water slack and vice versa is referred to as the tidal excursion. Typical tidal excursions in the tidal rivers of New South Wales are of the order of 5 km and vary from tide to tide. This represents the maximum distance travelled by a water particle during the rising or falling limb of the tide.

Tidal excursion is not to be confused with the distance travelled by the tide wave itself (e.g. high water), which propagates from the ocean to the end of the estuary each tide cycle, a distance of up to 143 kms in the case of the Hawkesbury River.

Freshwater inflows impose a net seaward movement on water particles over a tide cycle. In these circumstances, the ebb tide excursion is greater than the flood tide excursion. This is illustrated in Figure B20, which also shows the net effect of oscillatory tidal flows and seaward draining freshwater flows in flushing a ‘parcel’ of water out to sea.

(f) Tidal Prism

The total volume of water moving past a fixed cross-section of the estuary during each flood tide or ebb tide (i.e. slack water to slack water) is referred to as the tidal prism. The larger the tidal range within the estuary and the greater the dimensions of the estuary, the larger the tidal prism. On average, the ebb and flood tidal prisms are equal.
Whilst the tidal prism of many estuaries is large, it does not mean that these estuaries are well flushed. The movement of water contained in the tidal prism is largely oscillatory, as depicted in Figure B20. The net seaward flushing action over a tidal cycle results from two processes: freshwater advection and longitudinal dispersion. Freshwater advection refers to the net seaward displacement caused by freshwater inflows (see Figure B20). ‘Longitudinal dispersion’ is described in Section 10. The greater the freshwater inflow and the greater the tidal velocities, the better flushed the estuary.

Secondary Flows

(a) Gravitational Circulation

Saline coastal waters are carried into an estuary by the tides; freshwater inflows tend to wash the saltwater back out to sea.

The presence of salt in an estuary produces a longitudinal density gradient, with water densities around the mouth of the estuary being greater (because of higher salt concentrations) than densities around the head of the estuary. This results in the enhancement of flood tide velocities near the bed and ebb tide velocities near the surface. When averaged over a tidal cycle, this behaviour leads to residual currents, in which saline water flows upstream along the bottom of the estuary and less salty, even fresh water, flows seawards near the surface (see Figure B21). This pattern of residual flows is referred to as ‘gravitational circulation’ (it is driven by the gravitational forces resulting from density differences). Gravitation circulation can give rise to discharges which are 10 or 20 times greater than freshwater inflows. Gravitational circulation is an important mechanism of upstream sediment transport (see Section 9) and the longitudinal dispersion of salt in an estuary (see Section 10).

The presence of a longitudinal density gradient within an estuary also contributes to ‘elevated half-tide’ levels around the head of the estuary (see Section 5). The rise in half-tide levels represents a dynamic response in which the higher mean level of the freshwater in upstream reaches helps to counterbalance the greater density of seawater at the mouth of the estuary.

Whilst both tidal distortion and gravitational circulation contribute to elevated half-tide levels, the two processes have quite different effects on water movement. Tidal distortion results in greater peak velocities on the flood tide than on the ebb tide. Moreover, velocities tend to be greater over the entire water depth and the net residual current over a tidal cycle is effectively zero. In contrast, Gravitational Circulation produces a depth dependent pattern of currents and a net residual current over a tidal cycle.

Figure B20 Movement of ‘Parcel’ of Water Down an Estuary
(b) Wind Driven Currents

Wind shear at the water surface produces surface currents, counter-balancing currents at the bottom of the water column and large scale lateral circulations. Light winds having speeds up to about 6 to 7 m/sec are the most effective in moving surface waters. Wind driven surface currents have speeds of about 2% of the wind speed. Wind driven currents are a major mechanism in the transport and distribution of floating pollutants such as oil (see Section 11).

In sluggish tidal systems or bays, where surface tidal flows are weak, wind driven currents can be one of the main agents leading to effective water movement and mixing within the main waterbody. When a constant wind blows over a basin of variable depth, a laterally varying surface current is induced, flowing with the wind in shallow areas and as a return flow against the wind in deeper areas.

(c) Tidal Pumping

In shallow estuaries, tidal pumping results in a 'fortnightly tide' (see Section 5). This tide gives rise to a net circulation over a fortnight, leading to net upstream advection over the neap-spring half-cycle and net downstream advection over the spring-neap half-cycle. These residual flows can have a major effect on the distribution of dissolved pollutants along an estuary (see Section 10).

(d) Residual Flows

If tidal currents are averaged spatially over a cross-section of the estuary and temporally over a 14 day Spring-Neap tidal cycle, the net effect of secondary flows due to gravitational circulation, tidal pumping and freshwater flows is to produce a residual current (in contrast to the oscillatory tidal currents).

Residual flows affect the intrusion of salt and the dispersion of pollutants along an estuary. Broadly speaking, salt will not penetrate far along channels with a net seaward residual velocity in excess of 0.1 m/sec.

8 SALINITY BEHAVIOUR

Composition of Seawater

Seawater consists of a dilute solution of a mixture of salts (see Section 6 of Appendix C for details). The term 'salinity' refers to the total concentration of salts, and has a worldwide average of about 35 kg/m³, or 35 parts per thousand (ppt).

Mixing of Salt and Fresh Waters

The density of seawater is greater than that of freshwater and varies with both salinity and temperature. At a temperature of 20°C, seawater has a density of about 1025 kg/m³, whereas freshwater has a density of 1000 kg/m³. Although the difference in density is

![Figure B21 Gravitational Circulation in a Partially Mixed Estuary](image-url)
slight, it significantly affects estuarine circulation (see gravitational circulation of Section 7).

Because of its lesser density, freshwater tends to 'float' on top of the seawater (stratification). Turbulence generated by the movement of the water over the bed of an estuary causes vertical mixing, which tends to break down any saline-freshwater stratification. The faster the water movement, the stronger the turbulence and the greater the resultant mixing.

The ocean tide is the principal mechanism of water movement in an estuary. High tidal velocities produce strong vertical mixing resulting in little variation in salinity from the top to the bottom of the water column. Low tidal velocities are insufficient to cause complete vertical mixing and stratified conditions can develop (i.e. bottom salinities are greater than surface salinities).

Strong vertical mixing is a characteristic feature of the shallow estuaries in New South Wales.

Figure B22 Salinity Regimes in New South Wales Tidal Rivers
Salinity Regimes

(a) Well-Mixed Conditions

In well-mixed estuaries, the salinity distribution is almost uniform with depth (see Figure B22).

(b) Partially-Mixed Conditions

In partially-mixed estuaries, the salinity varies continuously through the depth of the water column with no evidence of a marked interface between the upper and lower layers. The salinity can vary over the depth by as little as 1 ppt and as much as 10 ppt (see Figure B22).

(c) Stratified Conditions

Stratified conditions are characterised by an abrupt increase in salinity over the water depth. In the absence of significant tidal velocities, vertical mixing in an estuary is weak. This allows the saltwater to move into the estuary as an ‘arrested salt wedge’, which can penetrate a long distance into a deep estuary. The freshwater overlying the wedge tends to entrain salt water as it moves seaward, thereby becoming more brackish as it approaches the estuary mouth (see Figure B22).

(d) Variations due to Freshwater Flow

Because of the great variation in freshwater inflows over time, the estuaries of New South Wales display all of the foregoing salinity regimes at different times, as shown in Figure B22. During periods of extended dry weather, when freshwater flows are extremely small, estuaries are well mixed, even deeper drowned river valley estuaries such as the Hawkesbury. During periods of wet weather, partially mixed conditions prevail. Under full flood flows, stratified conditions occur in entrance reaches and most of the salt may be washed out to sea.

Salinity Limit

In essence, the limit of salinity intrusion along an estuary is determined by the balance between the landward transport of salt by tidal processes and its seaward return by freshwater discharges. Salt and other dissolved substances are transported along an estuary by large-scale water movements and secondary currents, and by the longitudinal dispersion associated with velocity shear (see Section 10).

The major factor that affects the limit of saline intrusion along an estuary is freshwater inflow. Figure B23 shows the effect of freshwater discharge on the upstream location of the 1 ppt, 5 ppt and 10 ppt isohalines in the Hawkesbury River during 1977. Between days 150 and 290, the freshwater discharge decreased gradually from about 10 m$^3$/s to about 4 m$^3$/s. This allowed the 1 ppt isohaline to migrate upstream a distance of some 25 km. Figure B23 also illustrates the rapid downstream flushing that accompanies large runoff events. For example, between days 20 and 30, discharge increased from about 3 m$^3$/s to about 2000 m$^3$/s. This flushed the 1 ppt isohaline limit downstream some 40 km.

Tidal flows are very effective in moving salinity upstream. This is seen in the relatively quick migration of salinity back up an estuary after a major flood has washed it downstream. The post-flood recovery of salt in the Hawkesbury River - which involves an upstream salinity excursion of 40 km or more - takes place in 7-9 weeks (days 36 to 95, Figure B23).

9 SEDIMENT MOVEMENT

Sources of Sediment

Different types of sediment are supplied to an estuary by a variety of agents, as illustrated in Figure B24. River bank erosion and general catchment runoff produce large quantities of sand, silt and clay. Catchment runoff also delivers organic matter to the river/estuary. Littoral processes (i.e. processes in coastal waters) can supply large quantities of sand to an estuary. Wind action on dunes and inter-tidal sand banks carries fine sand into an estuary.

The main sources of sediment are shown in Figure B24 and comprise:

- erosion of upper catchment and transport by rivers and streams ($S_{r}$);
- littoral drift and/or bank erosion ($S_{l}$);
- disposal of domestic and industrial effluents and solid wastes ($S_{d}$);
Figure B23  Salinity and Freshwater Behaviour, Hawkesbury River, 1977 (after Druery & Dyson, 1985)

Figure B24  Sources of Sediment to an Estuary (McDowell & O'Connor, 1977)
- wind erosion of coastal dunes and drying inter-tidal shoals ($S_w$);
- entrance marine shoals and tidal delta sands ($S_d$);
- return of dredged spoil ($S_D$);
- decomposition and excretions of marine and river plants and animals ($S_a$).

**Biological Effects**

Filter feeders such as oysters remove clay particles and other suspended material from the water and eject them as larger agglomerates, which can settle from suspension under quiescent conditions. Diatoms and benthic algae growing on settled sediment under quiescent conditions can impart a slimy, weakly bonded texture to the sediment which inhibits erosion.

Seagrasses reduce tidal velocities near the bed and wave action on top of marine sediments, thereby encouraging the sedimentation of fine material.

**Modes of Sediment Movement**

Sediment particles being moved by water can undergo three distinct modes of motion:

- a rolling and/or sliding motion;
- a saltating or hopping motion; and
- suspended particle motion.

Flowing water exerts a 'shear stress' on the bed of an estuary, i.e. it imposes a force on the bed material in the direction of flow. The faster the water velocity, the greater the shear stress. When the shear stress at the bed just exceeds the critical value required for initiation of motion, sediment particles will begin rolling and/or sliding whilst remaining in continuous contact with the bed. As water velocity and shear stress increase, the particles then move along the bed in a series of more or less regular jumps, called saltations. At even higher levels of bed shear stress, upward turbulent forces can lift sediment particles from the bed and carry them into the water column. If these forces are greater than the submerged weight of particles, the particles will remain in suspension.

**Bed Load and Suspended Load Transport**

The transport of particles by rolling, sliding and saltating is called 'bed load transport', while the transport of suspended particles is called 'suspended load transport'. In addition to material from the bed of the estuary, suspended load may also include fine silt and clay particles from upstream catchment areas ('wash load').

Bed load and suspended load transport often occur simultaneously. The transition between both modes of transport is not well-defined.

Bed load transport is highly dependent upon water velocity, the rate of transport varying with about the cube of water velocity. Thus, slight changes in velocity can have a major effect on the rate of bedload transport. This is of considerable significance with respect to residual sediment fluxes (see below).

**Types of Sediment**

There are essentially two distinct types of sediments: 'sands' and 'muds'. The sediments of an estuary are often a mix of these two basic types, in any proportion.

(a) Sands

The behaviour of sand particles in water depends upon their 'settling velocity', or the rate at which they fall through quiescent water. This depends principally upon their size and shape, larger particles falling faster. Smaller sized sand particles can be more easily brought into suspension and maintained there by turbulent fluctuations.

(b) Muds

'Muds', which can be formed from a variety of different minerals, are characterised by very small particle sizes and 'cohesive' behaviour, i.e. mud particles tend to stick together. Whereas sand particles are inert chemically - their behaviour in water is governed by physical factors - mud particles are electrically charged. Consequently, the behaviour of muds is governed by physical, mineralogical and chemical considerations. For this reason,
behaviour of muds can vary from mud to mud and from estuary to estuary. Each mud needs to be investigated in its own right.

Factors Affecting Sediment Movement

(a) General Principles

General principles governing sediment movement are as follows:

- sediment transported in the water will settle at times or places of low wave or tidal activity. The rate of settling depends upon the grain size of sands and upon the mineralogy and chemistry of muds;

- sediment on the bed will be eroded and transported when the shear stress exerted on the bed by wave, tidal and freshwater action, acting either alone or together, exceeds a critical minimum value. The critical shear stress also varies according to sediment size, mineralogy and chemistry;

- if sediment is deposited in locations where the critical shear stress is not exceeded, or is exceeded only infrequently, then the sediment will slowly consolidate, increasing in both density and strength. As bed density increases, so the stress threshold for erosion increases, and the sediment deposit becomes more stable and less likely to be eroded by natural forces.

(b) Freshwater and Tidal Currents

The main mechanism causing sediment transport in estuaries are the currents caused by freshwater inflows and tidal behaviour. The faster these currents, the greater the shear stress and turbulence generated at the bed, and the greater the movement of sediment by bedload and suspended load transport.

(c) Residual Sediment Fluxes

The difference between peak flood flow and peak ebb flow velocities (tidal distortion, see Section 5) results in a net upstream movement of bed load, or a residual bedload flux.

Both tidal distortion and gravitational circulation facilitate a net upstream movement of suspended solids, i.e. a residual suspended load flux. Because of tidal distortion, the duration of high water slack is different from low water slack, thereby generating differences in the slack water settling opportunity for suspended particles. This, coupled with differences in current behaviour around the two slacks, can impart a net displacement to suspended sediment each tide cycle.

Movement of Sands

Bed load transport is the principal means by which sand is moved along the estuaries of New South Wales. Suspended load transport of sands occurs only in the immediate vicinity of estuary entrances, where high velocities (greater than 1 m/s) and wave action promote the suspension of sand grains. Many New South Wales estuaries have sandy beds, and sand transported as bedload leads to the formation of extensive underwater sand dunes (see Figure B25).

Figure B25  A Typical Sand Dune on the Bed of an Estuary

(a) Tidal Transport

Bedload transport is quite sensitive to small changes in velocity, such as those brought about by tidal distortion and gravitational circulation (see Sections 5 and 7 respectively). These two mechanisms generate residual bedload flux in the upstream direction. Together, these two processes result in a strong net upstream transport of marine sand that forms shoals and deltas in lower estuarine reaches.
(b) Freshwater Transport

Freshwater flows during large floods are much greater than peak tidal flows. Thus, floods can transport sand downstream at very high rates, as evidenced by the substantial scouring of shallow sand shoals that tends to occur during floods. The sand transported downstream by freshwater flows is deposited on the seaward face of the entrance bar (the ebb terminal lobe of Figure B2). After the flood dissipates, this sand is reworked by the action of waves and nearshore currents and is returned to the shoreline over a period of many months.

(c) Wind Transport

The action of wind on exposed sand dunes can transport considerable quantities of sand into an estuary. In fact, transport of sand by wind is one of the dominant factors in the sediment budget of exposed entrances such as Shoalhaven Heads, and may be the principal reason for the tendency of such entrances to close.

Some transport of sand grains from inter-tidal sand shoals exposed by the ebb tide also occurs through wind action.

(d) Wind Waves

Wind generated waves can have a significant effect on sediment production and movement along estuarine foreshores.

Within the narrow confines of river estuaries, wind generated waves are small and of short wave length (typically, the significant wave height is 0.3 m or less). Nevertheless, these waves can cause extensive riverbank erosion when the dominant wind direction coincides with a long, straight and wide stretch of the estuary.

Wind waves are often the dominant transport mechanism along the foreshores of tidal lakes (tidal and freshwater velocities in the body of the lake are generally low). Inter-tidal sand and mudflats around the peripheries of tidal lakes are formed as a result of wind waves and wind induced currents.

(e) Ocean Waves and Entrance Effects

The movement of sand into and out of the entrance of an estuary is a complex phenomenon because of the interaction of tidal, wave and freshwater transport processes. Figure B26 depicts the principal sediment pathways around an estuary entrance.

Waves breaking on the entrance bar bring into suspension considerable volumes of sand that can be carried into the estuary on the flood tide. Much of this sand is flushed back out of the estuary on the ebb tide, but a small amount is deposited in the estuary where it is transported upstream by the net flood tide transport caused by the tidal distortion.

Most of the sand transported out of the entrance by floods is deposited on or near the entrance bar from where it is carried to the updrift coastline by a process known as 'littoral bypassing' (see Figure B26).

Quite apart from their action in stirring up sediments from the entrance bar and promoting suspended sediment transport, the significance of ocean waves to estuarine sediment transport depends upon the entrance conditions.

Where there is a well-developed off-shore bar, ocean waves will break on the bar and little wave energy will penetrate the lower reaches of the estuary. In these circumstances, ocean waves have little effect on sediment transport within an estuary. Their principal role is to promote the suspension of sand grains around the entrance and suspended load transport.

In contrast, ocean waves can readily penetrate the lower reaches of drowned river valley estuaries, where they combine with tidal flows to produce a relatively complex pattern of sediment movement (e.g. the downstream reaches of the Hawkesbury River and Broken Bay). In some tidal lakes and rivers with relatively wide mouths, tidal sediment transport is enhanced by the penetration of waves through the entrance (e.g. Swansea Channel - see Figure B27).
DOMINANT FLOOD TIDE CURRENTS ACROSS TOP OF INNER BAY SHOALS

BUILD-UP OF INNER BAY SHOALS (OR RIVER SAND BARS) DUE TO FLOOD TIDE TRANSPORT OVERALL SHOAL SIZES CONSTANT WHEN REGIME REACHED

EBB CURRENTS CONCENTRATE INTO LOW TIDE CHANNELS AROUND SHOALS

LOCALISED REVERSAL OF LITTORAL DRIFT DUE TO MARGINAL FLOOD TIDE CHANNEL AND WAVE SHADOW AREA

AVERAGE EBB AND FLOOD TIDE TRANSPORT EQUAL WHEN ESTUARY IS IN REGIME

ENHANCED LITTORAL TRANSPORT IN MARGINAL FLOOD TIDE CHANNEL

SOUTH TO NORTH LITTORAL DRIFT ON OPEN BEACH

LEGEND

- DOMINATED BY EBB TIDE CURRENTS
- DOMINATED BY FLOOD TIDE CURRENTS
- DOMINATED BY BREAKING WAVES

Figure B26  Sediment Pathways at a Heavily Shoaled Estuary Entrance (After Fitzgerald et al., 1976)
Movement of Muds

Mud particles and aggregations of mud particles (flocs) have small settling velocities. Turbulent mixing keeps mud particles in suspension throughout the tide, except at slack water when a concentrated layer of mud forms near the estuary bed. Tidal distortion and gravitational circulation result in a net upstream movement of mud particles which are deposited around the limit of the gravitational circulation current.

Muds are cohesive materials and hence the processes of settling, consolidation and resistance to erosion are dependent upon cohesive properties, such as inter-particle bonding, as well as the hydrodynamic environment.

(a) Deposition

Muds will remain suspended in a body of moving water whilst the vertical mixing due to turbulence is equal to or greater than the rate of settling of individual particles. As velocities slow down, the vertical mixing decreases and deposition will gradually begin to occur.

The settling velocity of muddy sediment is dependent upon its concentration. At high concentrations, more collisions occur between particles and the resulting flocs are larger and settle faster than the smaller, basic particles. At low concentrations there is little or no interaction between the particles and the settling velocity tends to be constant. At very high concentrations, the particles actively interfere with each other and hinder settling.

(b) Erosion

Muds begin to erode when the shear stress imposed by water movement is equal to the shear strength of the surface layer of mud.

The ability of new mud deposits to resist subsequent erosion increases with time in response to a number of factors. First, consolidation occurs over time, which tends to increase the cohesion between individual particles and flocs and their resistance to erosion. Second, water currents progressively ‘armour’ the surface layer by breaking weak inter-particle bonds and promoting stronger re-bonding arrangements (if the new bonds are weak they will be broken again). Armouring increases with time and renders the deposit more erosion resistant.

In some cases, the strength won through consolidation and armouring will be insufficient to resist the erosive forces of the next half-tide cycle. In these circumstances, all the material will be re-suspended. In other cases, some of the deposit will be eroded and the remainder will be largely undisturbed. The residual deposit may then remain largely undisturbed until the next Spring Tide cycle, when it may or may not have gained sufficient strength to resist the stronger tidal currents.

(c) Mud Deposition Patterns

The pattern of mud deposition within an estuary varies seasonally and spatially in response to the variable nature of the salinity limit. Mud particles brought into suspension are transported upstream by the gravitational circulation (see Section 7). This produces a turbidity maximum near the upstream limit of the circulation, leading to increased deposition of muds at slack water. In other words, the gravitational circulation leads to a trapping of muds in the estuary. The location of the zone of maximum deposition will vary with...
freshwater flow and the resulting pattern of salt intrusion.

(d) Mud Trapping Efficiency

The mud trapping efficiency of an estuary drops off quickly as freshwater flows increase. During major floods, the high turbulence and flushing of the flood flows is sufficient to keep the very high suspended load in suspension and flush it entirely out to sea. Tidal lakes, however, act as stilling basins, and mud accumulates on the lake bed after each flood.

Drowned river valley estuaries and the artificially deepened port areas in estuaries (e.g. Newcastle) trap most of the mud brought into the estuary by small floods. This is a major concern for the maintenance of shipping channels. However, during major floods most of the mud is discharged to the ocean. This is just as well otherwise port areas would be buried in mud by a single major flood event. For example, the Hunter River Port Authority removes about 250,000 m$^3$ of mud from its navigation channels annually as part of its regular channel maintenance program. This is minor compared to the total mud load of the Hunter River, which in a single flood can exceed 5 million m$^3$ (PBP, 1989).

10 MIXING PROCESSES

'Mixing' refers to the inter-mingling of 'parcels' of water as they are moved along the estuary under the influence of freshwater flows, tidal flows and secondary currents. Mixing not only involves an exchange of water mass, but also of any substance dissolved in it, such as salinity, dissolved pollutants, etc. Hence, mixing processes are of importance to the distribution of salinity and water quality levels throughout the estuarine water mass.

Adective and Dispersive Transport

Adective and dispersive transport are the major processes by which dissolved matter is transported along and distributed throughout an estuary.

As water flows along an estuary it transports any dissolved matter with it ('adveктив transport'). During this process, water mixes with neighbouring 'parcels' of water. This mixing leads to a net transport of dissolved materials from regions of high concentration to regions of lower concentration ('dispersive transport').

The mixing of 'parcels' of water is principally caused by lateral and vertical variations in velocity along an estuary ('velocity shear'). Velocity variations result in faster 'parcels' of water - together with their dissolved loads - moving ahead of their slower neighbours, as depicted in Figure B28. Turbulence and eddies generated by the 'velocity shear' between neighbouring parcels result in the interchange of water and dissolved matter between parcels (see Figure B28).

Vertical Mixing

The principal mechanism of vertical mixing is the velocity shear caused by the bed of the estuary (surface and mid-depth velocities are faster than bed velocities). This results in the
generation of turbulence, principally at the bed, which promotes the mixing of overlying waters. Vertical mixing is responsible for ‘well-mixed’ salinity regimes (see Section 8).

Lateral Mixing

The major mechanisms promoting the mixing of waters across an estuary (laterally) are the velocity shear associated with lateral velocity gradients, wind shear, lateral tidal flows, large-scale eddies generated by obstructions, and bends and meanders in the alignment of major channels.

Figure B28 shows the lateral exchange of ‘parcels’ of water associated with the lateral variation across the estuary of longitudinal velocities. This lateral exchange promotes mixing across the estuary. Lateral variations in velocity are caused by the presence of the banks of the estuary and changes in water depth (deeper waters flow faster).

Wind shear and lateral tidal flows (e.g. the filling of inter-tidal areas on the flood tide) both result in the advection of water across an estuary and associated mixing. The presence of bends and meanders also results in water flows tending from one side of a channel to the other and associated mixing across the channel.

Obstructions, such as rock bars and shoals, also promote the flow of water across an estuary, both by the advection associated with redirected flows, and by the dispersion associated with lateral shear.

Longitudinal Mixing

A number of processes facilitate longitudinal mixing along the estuary, the most important being longitudinal advection in response to tidal and freshwater discharges, and the velocity shear associated with the lateral variation of longitudinal velocities. The effect of lateral velocity shear in ‘stretching out’ a lateral line of dissolved tracer along the estuary is apparent in Figure B28.

With respect to secondary currents, the net upstream residual current at the estuary bed caused by gravitational circulation advects material upstream and is especially important in the upstream penetration of salinity (see Section 8). The fortnightly ‘tidal pumping’ associated with the Neap-Spring tide cycle also generates a slowly varying cyclical current along the estuary, which although small, can advect water particles over substantial distances (several kilometres) because of its long duration (a half-cycle of 14 days).

A number of other factors promote longitudinal mixing. These include ‘large-scale boundary effects’, ‘tidal trapping’, ‘tidal loops’ and inter-connections between tidal systems.

‘Large-scale boundary effects’ refer to the mixing caused by the presence of bays and channels along an estuary. Waters are temporarily stored in these areas on the rising tide and released on the falling tide. This separation of the trapped waters from other waters moving along the estuary facilitates mixing by velocity shear and advective transport.

The presence of shoals generates strong velocity shear between fast-moving main channel flows and the slow moving waters that move in and out of shoal areas on the rising and falling tide. This behaviour leads to ‘tidal trapping’, whereby a discrete body of water is separated and ‘trapped’ over shoal areas on the flood tide, to be released on the ebb. This behaviour facilitates mixing by velocity shear and advective transport, as for large-scale boundary effects.

Finally, the presence of tidal loops in a large delta or the inter-connection of two tidal systems can give rise to a complicated pattern of residual flows that further enhance advective and dispersive transport along the estuary.

To sum up, mixing will be greatest in those estuaries where lateral and vertical velocity gradients are greatest, i.e. in estuaries where deep channels thread their way through shallow flats, where there are extensive shoals and peripheral bays and channels, and where tidal flows are fast.
11 THE MOVEMENT OF SURFACE POLLUTANTS

Floating Pollutants

Previous discussion in this Appendix on advective and dispersive transport and flushing behaviour of estuaries is only of relevance to dissolved substances, such as salinity and dissolved pollutants. The behaviour of floating pollutants, such as oil, is quite different (Section 15 of Appendix C describes the detrimental impact of oil on the estuarine environment).

Oil has a very low surface tension (hence its usefulness as a lubricant). This, coupled with its hydrophobic nature (water repelling) means that it tends to spread over the water’s surface as an unbroken thin film. Oil, when floating on a water surface, undergoes three types of transport:

- spreading,
- surface current advection, and
- wind driven advection.

As the oil spreads out and is transported across the surface of an estuary, the more volatile fractions evaporate and the more water soluble fractions dissolve or emulsify with the water mass. (Emulsification is fostered by breaking waves).

In addition to spreading out over the water surface, the oil film is carried along (advelted) by surface water currents associated with freshwater and tidal discharges (see Section 10 of this Appendix). Variation in surface velocities will result in additional spreading of an oil slick by lateral and longitudinal dispersion, as described in Section 10.

Finally, wind effects are of major significance to the spreading and transport of floating oil (see ‘Wind Driven Currents’ of Section 7 of this Appendix). Table B2 shows the measured rate of spread of an oil slick generated by 0.5 tonnes of Ekofisk crude oil subject to a wind speed of 6-9 m/s (Cormack & Nichols, 1977). The amount of oil causing the slick is about 500 litres or some two-and-one-half ‘44 gallon drums’. The rapid spread of the oil under windy conditions is readily apparent: after 3 hours, the slick covered 35 ha, whereas under calm conditions, it was estimated that the slick would have covered only 2 ha.

<table>
<thead>
<tr>
<th>Time (hrs)</th>
<th>Extent of Slicka (ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2.5</td>
</tr>
<tr>
<td>3</td>
<td>35</td>
</tr>
<tr>
<td>5</td>
<td>78</td>
</tr>
<tr>
<td>10</td>
<td>265</td>
</tr>
</tbody>
</table>

* Wind speed of 6-9 m/s.

12 MICROLAYERS

The transport of some pollutants can occur in the uppermost surface layers of the water column (the top millimetre or so) or via surface slicks (compressed microlayers). Organochlorines and heavy metals have been recorded in microlayers at concentrations of up to 10,000 times greater than that which would normally occur in the water column (Szekielda et al, 1972, Hardy et al, 1989, 1990). Such concentrations may have adverse effects on planktonic organisms that gather at the sea surface. Assessing the extent, concentrations and possible impacts of microlayers is both difficult and expensive, but their role in estuarine pollution is receiving increasing attention.

13 REFERENCES


C ESTUARINE WATER QUALITY

1 Introduction
2 Composition of Estuarine Water
3 Suspended Solids
4 Turbidity
5 Disease Organisms
6 Salinity
7 pH
8 Oxygen
9 Nutrients
10 Ammonia
11 Heavy Metals
12 Organic Chemicals and Pesticides
13 Fluoride
14 Methylene Blue Active Substances
15 Oils
16 Water Temperature
17 References

1 INTRODUCTION

The 'water quality' of a body of water is a measure of its suitability for particular uses. This is determined by a combination of factors, such as appearance and smell, and by the concentration of a variety of particulate and dissolved substances contained in the water (SPCC, 1990).

This Appendix briefly describes the water quality parameters of most concern in New South Wales Estuaries, how they are measured, and their known effects on estuarine biota and human amenity.

2 COMPOSITION OF ESTUARINE WATERS

Within an estuary, the composition of water - or 'water quality' - is determined by the interaction of the following processes:

- imports and exports of materials (particulate, dissolved and gaseous) via freshwater flows, coastal flows and the atmosphere;
- physical transport and mixing (advective and dispersive transport);
- energy inputs in the form of light and heat;
- chemical transformations; and
- biological processes.

Although the basic physical and chemical processes are well understood, their interactions are very complex. Far less is known of the effects of biological processes on water quality. The effects of water quality on ecosystems, especially long-term impacts, are also poorly understood.

Major factors determining the composition of estuarine waters are land-based runoff, seawater and 'point' sources of pollution such as sewage and industrial effluent discharges. The composition of land-based runoff and point sources of pollution is quite variable, depending upon catchment and industrial activities. The composition of seawater is relatively stable.

Parameters contributing to estuarine water quality may be classified as follows:

- suspended solids (particulate and colloidal matter);
- dissolved solids (including salts and organic compounds);
- floating matter (including oil, scum and debris);
- dissolved gases; and
- temperature (hot and cold water inputs).
3 SUSPENDED SOLIDS

Particulate material (i.e. non-dissolved matter) in the water mass is present as particles of various sizes. Under quiescent conditions, e.g. in a laboratory test flask, the larger sized particles will settle out. This fraction is referred to as 'settleable solids'. However, small-sized particles, typically clays or particles of organic origin, will remain in suspension, even after extended times of settlement. This fraction is referred to as 'colloidal solids'.

In an estuary, settleable solids are kept in suspension by the water turbulence generated by tidal and freshwater flows. Some colloidal solids, such as clay particles, tend to settle out in estuarine waters because of the effects of salinity in promoting flocculation. This occurs within the salinity range 0 to 5 parts per thousand (Day et al, 1989).

Suspended solids in estuarine waters can originate from a variety of sources. Settleable solids can be present as sand and coarse silt particles; colloidal solids can be present in the form of phytoplankton (microscopic aquatic plants); as fine silts and clays transported into an estuary via urban and rural stormwater runoff or in discharges of washings from sandpits, quarries and mines; and as decaying organic matter that originates from leaf litter, untreated sewage discharges, eutrophic conditions in the estuary and from certain industrial discharges.

Suspended solids can have a number of detrimental effects in estuaries. High levels of suspended solids reduce light penetration into the waterbody and hence limit photosynthetic activity and areas colonised by aquatic plants. Suspended solids concentrations as low as 200 mg/L can kill susceptible fish species by abrasive action on their gill tissues; suspended solids that settle can smother plants and benthic organisms. Finally, suspended solids make water look 'cloudy', aesthetically unattractive, and dangerous for boating and swimming if submerged obstacles are present.

4 TURBIDITY

Turbidity refers to the ability of water to transmit light. As such, the measurement of turbidity is of direct relevance to potential photosynthetic activity of submerged aquatic plants. Suspended solids reduce the ability of water to transmit light, the degree of reduction depending upon the concentration of solids and their ability to absorb and scatter light. In the laboratory, turbidity is measured by the degree of scattering produced when light is shone through a water sample under standard test conditions. In the field, turbidity is determined by lowering a standard black and white disc (Secchi Disc) into the water and measuring the depth at which it can no longer be seen.

5 DISEASE ORGANISMS

Disease causing micro-organisms enter estuaries via sewage, animal faeces or in urban runoff. Levels of coliform bacteria (e.g. Escherichia coli) are monitored as an indicator of faecal contamination. This is an indirect measure of the possible presence of water-borne human pathogens, such as the Hepatitis A virus.

The presence of faecal material in estuarine waters tends to be higher during heavy rain, because of sewer overflows and urban runoff. Human pathogens can endanger people in direct contact with the water (e.g. swimmers), or those eating contaminated filter-feeders (e.g. oysters), which can concentrate bacteria and viruses. Introduced pathogens can affect flora and fauna.

6 SALINITY

An obvious characteristic of estuarine waters is their saline nature, formed by mixing of seawater and freshwater (see Section 8 of Appendix B). Seawater consists of a dilute solution of a mixture of salts. Table C1 shows the ionic composition of seawater, which is remarkably constant throughout the oceans and seas of the world. The term 'salinity' refers to the total concentration of salts, and has a worldwide average of about 35 kg/m³, or 35 parts per thousand (ppt). The two most common constituents are the chloride ion (55% of total ion mass) and the sodium ion (30% of total ion mass).

Salinity levels along an estuary vary in response to both the degree of dilution of seawater by freshwater and the concentration of salts in the freshwater. The loss of water by evaporation from poorly flushed saline marshes and tidal lakes can result in hypersaline conditions (salinities greater than seawater).
Table C1  Average Composition of Dissolved Constituents in Seawater

<table>
<thead>
<tr>
<th>Major Ions</th>
<th>Concentration (mg/l)</th>
<th>Trace Elements</th>
<th>Concentration (mg/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chloride (Cl⁻)</td>
<td>19,340</td>
<td>Boron (B)</td>
<td>4.5</td>
</tr>
<tr>
<td>Sodium (Na⁺)</td>
<td>10,770</td>
<td>Silicon (Si)</td>
<td>5.0</td>
</tr>
<tr>
<td>Sulphate (SO₄²⁻)</td>
<td>2,712</td>
<td>Fluorine (F)</td>
<td>1.4</td>
</tr>
<tr>
<td>Magnesium (Mg²⁺)</td>
<td>1,294</td>
<td>Nitrogen (N)</td>
<td>0.25</td>
</tr>
<tr>
<td>Calcium (Ca²⁺)</td>
<td>412</td>
<td>Phosphorus (P)</td>
<td>0.035</td>
</tr>
<tr>
<td>Potassium (K⁺)</td>
<td>399</td>
<td>Molybdenum (Mo)</td>
<td>0.011</td>
</tr>
<tr>
<td>Bicarbonate (HCO₃⁻)</td>
<td>140</td>
<td>Zinc (Zn)</td>
<td>0.005</td>
</tr>
<tr>
<td>Bromide (Br⁻)</td>
<td>65</td>
<td>Iron (Fe)</td>
<td>0.003</td>
</tr>
<tr>
<td>Strontium (Sr⁺)</td>
<td>9</td>
<td>Copper (Cu)</td>
<td>0.003</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Manganese (Mn)</td>
<td>0.002</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Nickel (Ni)</td>
<td>0.002</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Aluminium (Al)</td>
<td>0.001</td>
</tr>
<tr>
<td>TOTAL</td>
<td>35,141</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: Day et al, 1989

7 pH

The acidity or alkalinity of estuarine waters is measured in terms of pH on a scale of 0 to 14. Neutral waters, i.e. waters in which acidity and alkalinity are in balance, have a pH of 7. Acid waters have a pH of less than 7, the lower the pH the stronger the acidity. Alkaline waters have a pH of greater than 7, the higher the pH the stronger the alkalinity. The range of pH in natural waters varies from about 4.5 for acidic, peaty, upland freshwaters to around 10 for waters supporting intense photosynthetic activity. Most natural waters have a pH in the range 6.5 to 8.5, but a range of 6.5 to 8.5 is preferable.

The pH level also affects the concentration and activity of a variety of chemical substances detrimental to wildlife, e.g. cyanide, ammonia, heavy metals and chlorine. Cyanide toxicity to fish increases as pH falls (i.e. as the water becomes more acid), whereas ammonia becomes more toxic as pH increases.

Seawater contains a small but significant amount of dissolved bicarbonate ions and dissolved carbon dioxide (see Table C1). This material forms a ‘buffering’ system which tends to maintain the pH of seawater within the slightly alkaline range 7.8 to 8.3. The dilution of seawater in estuaries reduces its buffering capacity, but pH still generally remains in the range 7.5 to 8.8 (Day et al, 1989).

Abnormal pH in an estuary can have a number of detrimental effects on the estuarine ecosystems, both direct and indirect. As pH levels increasingly depart from ‘normal’ values, fish suffer a number of ill-effects, which eventually lead to death. A range of pH values of 5.0 to 9.0 is considered allowable for fish, but a range of 6.5 to 8.5 is preferable.

Acid sulphate soils are one source of the acid pollution of estuarine waters (SPCC, 1990).

Many of the soils of low-lying areas around estuaries, especially in the north of the State, were formed by deposition in shallow estuarine waters. The lower layers, which are normally below the water table, contain high levels of pyrite (iron sulphide) derived from sea water. As long as the soil remains saturated, high pyrite levels are of no consequence. However, any excavation or drainage works which expose the soil to the air allows the pyrite to react with oxygen, producing sulphuric acid. Very low pH results, which also mobilises aluminium from the soil. The steady leakage of acid and aluminium into an estuary has an adverse affect on the ecosystem, but the effects of sudden flushes caused by floods can be catastrophic. Massive fish kills in the Tweed River in 1987 have been attributed to the effects of acid and aluminium toxicity (Creagh, 1991).
Dissolved Oxygen

Dissolved oxygen (DO) enters the estuarine water mass in the following ways (sources):
- from the photosynthetic activity of aquatic plants, including phytoplankton, macroalgae and macrophytes;
- by direct diffusion from the atmosphere;
- by turbulent aeration of estuary waters (e.g. breaking waves on estuary shores); and
- as an import in tidal and freshwater inflows.

Dissolved oxygen is lost from the estuarine water mass in the following ways (sinks):
- through the respiration of aquatic plants, animals and aerobic bacteria;
- by diffusion back to the atmosphere;
- by chemical oxidation processes; and
- as an export in outgoing flows.

Aquatic plants are net producers of oxygen during daylight hours, but are net consumers during the night. Because of this, dissolved oxygen levels vary diurnally, with lowest concentrations occurring around sunrise.

Apart from the above factors, a number of other physical and chemical factors also affect dissolved oxygen levels, of which water temperature and salinity, turbidity levels (high turbidity suppresses photosynthesis) and pH are of importance. Table C2 shows the effects of temperature and salinity on the solubility of oxygen in water. Oxygen solubility falls as temperature and salinity increases.

Thus, the solubility of oxygen in estuarine waters varies in response to several effects: seasonally in response to freshwater inflows and temperature changes; possibly daily in response to daily temperature changes; and semi-diurnally in response to the changing salinity associated with tidal flows.

Because of the significant changes that can occur in the solubility or 'saturation level' of DO, measured values are often quoted in relative terms as a percentage of the saturated value (in a similar fashion to relative humidity).

Most aquatic life requires oxygen to survive. Depending on temperature and salinity conditions, the saturated level of DO in an estuary generally lies between 6.5 mg/L and 9.0 mg/L. As DO levels fall, the most sensitive species of fish are either killed or move to other areas. As DO levels are further reduced only the most hardy species survive (e.g. mullet and eels), until ultimately all fish species are killed or driven away. Intermediate levels of DO cause environmental stress to animals, which renders them susceptible to disease and predation and leaves them less able to forage for food.

**Oxygen Demand**

The 'oxygen demand' of a waterbody is a measure of the level of organic matter present in the waterbody (both particulate and dissolved). Under favourable conditions, water borne bacteria can readily multiply to metabolise (consume) non-living organic matter present in the waterbody. Aerobic bacteria use dissolved oxygen in this process.

Oxygen demand should not be confused with dissolved oxygen levels. Oxygen demand

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>Salinity (ppt)</th>
<th>DO Solubility (mg/L)</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>0</td>
<td>11.3</td>
<td>Freshwater at Sea Level</td>
</tr>
<tr>
<td>25</td>
<td>0</td>
<td>8.4</td>
<td>Freshwater at Sea Level</td>
</tr>
<tr>
<td>25</td>
<td>35</td>
<td>6.9</td>
<td>Sea Water at Sea Level</td>
</tr>
</tbody>
</table>

Table C2  Effects of Temperature and Salinity on Oxygen Solubility in Water
releases a demand placed on the waterbody, irrespective of the ability of the waterbody to satisfy that demand from dissolved oxygen.

Biochemical Oxygen Demand (BOD) is a measure of the actual amount of oxygen that will be consumed from the water mass within a given period of time (usually 5 days) when the existing bacterial populations break down what organic matter they can. BOD is determined by incubating a water sample for 5 days at 20°C and measuring the actual oxygen uptake (BOD₅ value).

Not all of the organic matter is immediately available for bacterial breakdown. Much of it may be within living organisms (e.g. phytoplankton and bacteria themselves) or it may be highly resistant to breakdown (such as particles of plant origin).

Chemical Oxygen Demand (COD) is a measure of the oxygen required for the breakdown of all organic matter present in the water. Although COD is a less realistic assessment of the likely oxygen depletion due to bacterial processes, it is much quicker to measure than BOD, and is often used for this reason.

If the receiving water contains adequate levels of DO, bacterial activity will be of the aerobic type (i.e. oxygen consuming). As the bacteria break down the organic matter into simple compounds, they consume oxygen from the water mass and DO levels fall. If the concentration of readily metabolisable organic matter is sufficiently high, the bacteria may completely deoxygenate the waterbody (sometimes leading to a 'fish kill').

When DO levels fall below about 5% of saturation (0.2 - 0.4 mg/l), anaerobic bacteria, which obtain metabolic energy by the reduction of nitrates ('denitrification') and sulphates, then take over the further breakdown of any residual organic matter. However, as part of this process, hydrogen sulphide and methane gases, which are malodorous and aesthetically offensive, are produced. If anaerobic conditions persist for an extended period, the waterway may become 'septic', i.e. black coloured, and foul smelling.

9 NUTRIENTS

There are basically three types of vegetation growing in water: free floating microscopic algae (phytoplankton and diatoms); attached large algae (macroalgae); and rooted plants (aquatic macrophytes). Free floating and attached algae obtain their nutrients directly from the water mass. Rooted plants obtain their nutrients from the root medium, as well as from the water mass through their leaves.

Plant growth requires many different types of nutrients. However, the nutrients nitrogen and phosphorous are generally the 'limiting' nutrients determining the rate and amount of growth of aquatic plants. (Silicon may also be a limiting nutrient for diatoms).

If nitrogen and phosphorous are present in estuarine waters in excessive levels ('eutrophic' conditions), they can promote the uncontrolled growth of phytoplankton (an 'algal bloom') and the excessive growth of attached macroalgae and aquatic macrophytes. It should be noted that 'algal blooms' appear to be natural events in many parts of the world.

Increased nutrient levels in estuarine waters originate from the discharge of raw and treated sewage effluent, from urban and rural runoff and from some industrial discharges. Urban stormwater contains animal faeces and garden fertilisers. The widespread and inefficient use of agricultural fertilisers can result in high nutrient levels in rural runoff. Excessive nutrient levels are mainly a problem in those estuaries that are poorly flushed by the tides or freshwater flows.

Excessive algal growth can have a number of adverse effects on estuarine ecosystems and aesthetic quality, which include:

- Increased diurnal fluctuations in dissolved oxygen concentration in the water mass. Algae, like all plants, are net producers of oxygen during daylight hours and net consumers during darkness. Excessive algal growth causes saturated or super-saturated levels of dissolved oxygen during the daytime, but minimal levels during the night, which can lead to physiological stress in fish and other organisms. If the algal biomass is sufficiently large, all the dissolved oxygen will be consumed during the night time, leading to the death of fish and other oxygen breathing organisms (a 'fish kill'). Dead fish and dead vegetation then tend to wash up on the shores, where they decompose and produce unpleasant odours.
- Changes to the species of aquatic flora and fauna and numbers of individuals inhabiting the affected waters. For example, the fish that do best under eutrophic conditions are not highly valued by anglers and commercial fisherman; other algal types, such as blue-green algae, are encouraged.

- Diminished aesthetic appeal of estuarine waters because of the discolouration and turbidity caused by the high levels of phytoplankton. (The excessive growth of certain species of diatoms can impart a 'muddy' colour to the waters). This in turn results in a diminished recreational amenity, because poor clarity renders the water less attractive and less safe for pursuits such as swimming and diving (AEC, 1987).

Quite apart from nitrogen and phosphorus levels, a number of other factors influence algal growth. Meteorological conditions are significant (bright sunlight and still conditions appear to promote rapid growth); certain 'micro-nutrients' or other substances may be necessary to trigger growth.

(a) Phosphorus:

Phosphorus exists in a range of chemical forms in the aquatic environment. The two most common measures are 'filterable reactive phosphorus' (FRP) and 'total phosphorus' (TP). FRP is a measure of the level of phosphorus that is readily recycled through the organic biomass; TP includes FRP together with phosphorus bound to particulate matter, etc. Total phosphorus is the most meaningful determination of the element in terms of nutrient levels.

Catchment runoff is the main source of phosphorus in estuaries. Phosphorus is exported from estuaries by being flushed into coastal waters or in the bodies of migratory animals. All phosphorus which remains in an estuary eventually becomes permanently trapped in undisturbed sediments in the form of insoluble calcium compounds (Emsley, 1980).

Figure C1 shows the main links in the phosphorus cycle within an estuarine system. Phosphorus is found in the water body as
inorganic phosphates (PO$_4^{3-}$, HPO$_4^{2-}$ and H$_2$PO$_4^-$) and as a variety of organic phosphates. Compared with a terrestrial system, the turnover of phosphorus in a water body is very rapid, especially through bacteria, phytoplankton and zooplankton (Emsley, 1980). There is usually very little soluble phosphorus in the water because of rapid uptake by organisms, adsorption onto colloidal particles and precipitation to the sediments as calcium, aluminium or iron compounds.

Estuarine consumers (deposit feeders, grazers and carnivores) obtain phosphorus from their food and release it as solid or soluble excreta, and from their decaying bodies. Most of the detrital phosphorus is rapidly recycled through the food web.

Low oxygen and low pH levels are required to release phosphate that is bound to sediments. These conditions are found beneath the sediment surface, but as soluble phosphate diffuses upwards into the oxygenated layer it tends to react and bind with metal ions. It may require deoxygenation of the bottom waters, often caused by salinity stratification, to allow sufficient phosphate to enter the water column to stimulate phytoplankton growth (Bulleid, 1983).

Macroalgae, although generally attached to the substrate, obtain nutrients such as phosphorus directly from the water. Macrophytes, such as seagrasses, can absorb phosphates through their leaves, but obtain most nutrients through their roots from the sediments, as do mangroves and other emergent plants. Some phosphates are available from decaying detritus. Phosphate is also mobilised from sediments by root respiration. This process lowers oxygen levels and increases the acidity of the surrounding sediment by releasing carbon dioxide.

Although soluble inorganic salts are the primary nutrient source for the growth of phytoplankton and other plants, the rapid turnover of nitrogen within the estuarine system makes it more practical to use total nitrogen as the criterion for water quality.

Nitrogen enters an estuary via catchment runoff, tidal transport and diffusion from the atmosphere. It is lost from the system mainly by tidal and freshwater flushing and diffusion of gases to the atmosphere. The nitrogen cycle within an estuary is complex, but the most common pathways are shown in Figure C2.

All of the different forms of nitrogen are present in land-based runoff and can also be carried into an estuary by tidal transport. Nitrogen fixation, i.e. the conversion of gaseous nitrogen into ammonium ions and thence to organic forms, is carried out by bacteria and some forms of blue-green algae.

A variety of bacteria use inorganic ammonium, nitrite and nitrate ions in a number of energy-producing pathways. The dominant pathways vary between different parts of the water column and sediments, depending on the concentration of oxygen and other substances. Some nitrate is converted into a gaseous form by denitrifying bacteria. This is the main way by which nitrogen is lost from the estuarine ecosystem.

Phytoplankton and other plants take up inorganic nitrogen and use it in the synthesis of larger organic molecules. Animals obtain nitrogen from their food and excrete it in the form of ammonium, urea and uric acid.

The decomposition of dead animals and plants releases nitrogen as both organic and inorganic molecules. Dissolved organic nitrogen is further broken down by bacteria to release ammonium ions.

10 AMMONIA

Ammonia is a highly soluble gas which is present in water as ammonium ions (NH$_4^+$) and as free ammonia (NH$_3$).

High concentrations of ammonia are acutely toxic to fishes, and may cause loss of equilibrium, hyperexcitability, increased rates of breathing, cardiac output and oxygen...
uptake, and in extreme cases, convulsions, coma and death. At lower concentrations, ammonia has many ill-effects on fishes, including a reduction in hatching success, reductions in growth rate and morphological development, and pathologic changes in gill, liver and kidney tissue.

Acute ammonia toxicity is modified by several factors which include DO concentration, temperature, pH, previous acclimation to ammonia, fluctuating or intermittent exposure, carbon dioxide concentration, salinity and the presence of other toxicants. The acute and chronic toxicity of ammonia has been shown to increase as pH increases. Data on temperature effects on acute ammonia toxicity are limited and somewhat variable, but indicate that ammonia toxicity to fish increases as temperatures fall.

11 HEAVY METALS

Heavy metals, such as copper, lead, zinc, calcium, tin and mercury, can be acutely toxic to aquatic organisms. Even when present in sub-lethal levels, heavy metals can have a number of debilitating effects that reduce the health and survival of aquatic organisms. The toxic and sub-lethal effects of heavy metals are affected by a number of factors that include pH, salinity, temperature, DO and carbon dioxide levels, water hardness, etc.

Heavy metals tend to accumulate in fish and shellfish (e.g. mercury in some fish, arsenic in some crustacea). If sufficiently high, accumulated heavy metals in fish and shellfish are of public health concern and may lead to the closure of fisheries.

Heavy metals find their way into estuaries in a number of ways. They are present in urban stormwater, originating from atmospheric fallout, vehicle emissions (lowered since the introduction of lead-free petrol) and from galvanised iron roofs. They may also be present in industrial discharges and sewage effluent (from industrial wastes discharged to sewer). Heavy metals also originate from processing operations associated with sand mining and metalliferous mining.

Tin is rarely found in natural waters and then only in trace concentrations. The most likely source of tin in surface waters is via industrial process effluents from alloy manufacture, tin
plating operations and from defouling and anti-fouling paints used to maintain boat's hulls. The purpose of the active ingredients of these paints (often tin salts) is to kill algae and other marine organisms that attach themselves to the hull. The effects of tin on molluscs is of concern. Restrictions on the use of tin in marine paints are currently being introduced.

Lead is a persistent chemical which is biologically accumulated in aquatic organisms (upon digestion, immobilisation of lead leads to its buildup in organic tissues). Lead is acutely toxic to most aquatic organisms, killing them by destruction of gill tissue. At sub-lethal concentrations, lead has a number of chronic ill-effects which include mucus buildup on gill tissue (leading to suffocation and death), general enfeeblement and reduction in disease resistance and growth rates. The ingestion by waterfowl of lead shot (from waterfowl hunting) can cause lead poisoning and death in severe cases.

Zinc is present in natural waters in only trace amounts (3-50 μg/L in uncontaminated estuarine waters). Whilst small amounts of zinc are essential for all forms of life, excessive levels can have toxic and sub-lethal effects on aquatic wildlife. Zinc - like lead - also destroys gill tissues and bioaccumulates in aquatic organisms. Sub-lethal effects of zinc include general enfeeblement, reduced growth rates and pathological changes to many organs. The early stages of many saltwater invertebrates are sensitive to zinc.

12 ORGANIC CHEMICALS AND PESTICIDES

Organic chemicals other than pesticides are often associated with industrial operations and find their way into estuaries via effluent discharge. Pesticides (including herbicides) can be carried into estuaries with rural stormwater runoff. To a lesser extent, urban runoff also contains pesticides.

Organic chemicals in general and pesticides in particular can present long and short-term hazards to people, animals and aquatic ecosystems. Chlorinated hydrocarbons are of great concern because of their persistent nature and their bioaccumulation in the food chain, often to toxic levels. The decline in Osprey populations in New South Wales estuaries, could be attributed in part to 'eggshell thinning' caused by the build-up of chlorinated hydrocarbons in these animals. In New South Wales, the use of most chlorinated hydrocarbons is now either banned or restricted to very limited purposes.

13 FLUORIDE

Fluoride is another potentially toxic substance, but its effects on wildlife are not well documented. Although a relatively common constituent of minerals in sedimentary and igneous rocks, high levels of fluoride in natural surface waters are uncommon. Fluorides are used as insecticides, as a flux in the manufacture of steel, as a preservative, and in water treatment. Of some concern is the level of fluorides released from Aluminium Smelters (e.g. at Tomago on the New South Wales central coast). Fluoride is known to bioaccumulate in the bones of mammals and in mangrove vegetation. The long-term effects of accumulation are not clear. However, fluoride bonds with calcium, and could thus affect the egg shell formation of birds. The impact of fluoride on sensitive bio-indicator species such as some members of the amphibia, needs to be investigated.

14 METHYLENE BLUE ACTIVE SUBSTANCES

Detergents such as washing powders and liquids contain surfactants whose purpose is to facilitate the 'wetting' of items being washed. This enables the detergent itself to work more effectively in cleaning the item. The level of surfactants (and hence detergents) in water can be determined by measuring the amount of methylene blue active substance (MBAS).

Detergents have a range of ill-effects on aquatic organisms. Detergents are organic compounds, and as such can cause significant oxygen demands within a waterbody, resulting in depressed DO levels and attendant detrimental effects. Early detergents contained high levels of phosphates, an aquatic nutrient (modern detergents contain much lower levels). The surfactant effect of detergents can destroy natural water-repellant oil layers on animals, thereby wetting surfaces which are normally dry. This can facilitate attack by parasites, and in the case of aquatic plants, loss of control over gas and water exchange through surface tissues and subsequent death. In fishes, detergents cause strong sliming of gills and disrupt their sense of balance. Fish are
often killed as a result of exposure to high concentrations of detergents.

15 OILS

Petroleum products can enter estuarine waters in urban runoff (from road surfaces), by wind and tidal action following a spill at sea or within an estuary, and as oil leaks occur from the motors of commercial and leisure boats. In addition, raw sewage discharge contains small, but significant levels of fats and oils (see Section 11 of Appendix B for factors affecting the movement of floating oil).

Oil spills in the estuarine environment are of concern because of the physical smothering of seagrass beds, mangroves, waterbirds and other animals, and because of the general detrimental impact of oil on estuarine use and amenity. In addition, about 1% of an oil mass consists of water-soluble fractions that are quite toxic. These fractions dissolve into the water mass as the slick spreads, but tend to be concentrated at the surface (Chapman, 1985). Finally, many of the dispersants used to 'break up' oil slicks can create significant environmental problems in their own right.

Oil contains a number of different compounds which vary in boiling point, molecular weight and toxicity. Generally, those compounds with low molecular weights and low boiling points are the most toxic. These evaporate first so the toxicity of the oil mass itself tends to decrease noticeably a day or so after the oil has entered the receiving waters. However, these low molecular weight fractions are also the most soluble in water and so may become dispersed in the water surrounding the point of discharge. Oils from different sources have quite distinctive properties. For instance, refined petroleum products contain a higher proportion of the more volatile substances. The different characteristics of the various oil fractions will result in some fractions remaining on the surface as a slick, some forming emulsions (water-in-oil or oil-in-water), and some dissolving in the water.

Oil slicks can interfere with the respiration of aquatic insects. Oil and grease may also interfere with the transfer of oxygen from the air to the water body. Oil coatings damage aquatic plants and reduce the amount of food available for aquatic fauna. Surface oil adversely affects water birds, either directly causing death through smothering or loss of flight, or indirectly by destroying feeding beds.

16 WATER TEMPERATURE

Any discharge of water or wastewater can affect the temperature of the receiving waters, e.g. the discharge of cold bottom waters from dams, but the greatest impact comes from the discharge of spent cooling water from thermal power stations (see also Power Generation, Section 2 of Appendix F). For instance, the waters of Lake Macquarie are raised by up to 10°C near the cooling water outlet from Eraring Power Station (Marshman and Hodgson, 1991).

Whilst the return flow of cooling water from thermal power stations can have a number of detrimental effects on the aquatic environment, these are not as extreme as might be thought. In general, the aquatic ecosystem is relatively resistant to thermal stress, as the following general findings indicate (FAO, 1984).

- bacteria and phytoplankton appear to be resistant to thermal stress, even at temperatures in excess of 30°C;

- macrophytes are more sensitive to thermal stress. Their threshold may be less than 25°C in temperate waters, as along the New South Wales coastline, and up to 34°C in tropical waters;

- zooplankton (microscopic aquatic animals) are apparently quite resistant to thermal stress;

- benthos in temperate and sub-tropical waters are also quite resistant to thermal stress, tolerating temperatures 10°C above ambient levels and up to a maximum temperature of 35°C. If sensitive species are lost during peak summer temperatures, recolonisation occurs from adjacent areas.

- inter-tidal communities of sandy and rocky shores are resistant to thermal stress;

- most fish in temperate waters can tolerate a quite wide temperature range, but few are resident in water with temperatures of over 30°C.

Despite the apparent robustness of aquatic ecosystems to the direct effects of thermal stress, higher temperatures modify the toxic
effects of a number of substances such as heavy metals, ammonia, etc. Whilst the toxic effects of ammonia are reduced as temperatures increase, the effects of a number of heavy metals are increased, thereby further adding to physiological stress.

Since the 1960’s, the Electricity Commission of New South Wales has undertaken monitoring programs and has sponsored estuarine research aimed at understanding the effects of cooling water abstraction and return on estuarine lake processes. The study has covered water quality, seagrasses, algae, plankton, benthos, fish and prawns. The information has been reviewed during preparation of the Lake Macquarie Audit (SPCC, 1983) and the Lake Illawarra Audit of 1986, as well as during other reviews.

The available data indicate that thermal discharges resulting from over a quarter of a century of power station operation at Lakes Illawarra and Macquarie have not affected overall estuarine processes, although some changes have been detected in the immediate cooling water discharge zones where the temperature increase is greatest.

17 REFERENCES


APPENDIX D  ESTUARINE HABITAT

1 Introduction
2 Estuarine Food Web and Productivity
3 Habitat Types and Dependence
4 Open Waters
5 Rocky Reefs and Rocky Shores
6 Unvegetated Bed Sediments
7 Seagrass Beds
8 Inter-Tidal Sand and Mudflats
9 Beaches, Dunes and Sand-Spits
10 Mangroves
11 Saltmarshes
12 Swamp Forests
13 Ephemeral Lakes and Dune Lake Systems
14 Freshwater Aquatic Vegetation
15 Interdependence of Estuarine and Other Ecosystems
16 References

1 INTRODUCTION

Estuaries and their associated wetlands provide a variety of habitats that support plants and animals in a rich, diverse and highly interrelated web of aquatic and terrestrial ecosystems.

Estuaries play a major role in protecting juvenile fish from predation. They are also sources of food for juvenile and adult fish and breeding areas for some species. With respect to estuarine vegetation, West et al. (1985) presented an inventory of mangrove, saltmarsh and seagrass areas in New South Wales estuaries and Robinson & Benson (1990) reviewed the plant associations of various estuarine habitats as well as their conservation requirements.

Estuaries are also important feeding, roosting, breeding and recuperation areas for birds and other animals. Many species of migratory waders spend their non-breeding period in Australia building up fat reserves before flying to the northern hemisphere to again breed.

In addition to their ecological significance, estuarine habitats are of considerable significance to commercial and recreational fisheries. Estuaries provide renewable resources in the form of fish, crustacea and molluscs. Table D1 shows the annual commercial seafood production in New South Wales for the year 1990. The wholesale value of the catch was some $120 million, of which about two-thirds was derived from species that are dependent during all or part of their life cycle on estuaries. This is in general agreement with Pollard (1976), who calculated the estuarine dependent portion of the New South Wales commercial fish catch over the 11 year period to 1972 to be 70% by value.

While the commercial worth of the estuarine catch can be calculated easily, the monetary worth of estuarine habitats to the recreational fishery is more difficult to estimate. Surveys by McNair Anderson & Associates (MAA, 1978) and Pepperell (1985) established that approximately 30% of New South Wales residents (or 1,750,000 people) 'go fishing' at least once a year. In this latter study, the annual expenditure in New South Wales on fishing in 1980 was calculated to be $280 million (equivalent to $590 million in 1991).

Sixteen surveys of estuarine recreational fisheries have been conducted in New South Wales either directly by or under the auspices

Acknowledgement: The material in this Appendix was largely prepared by Craig Copeland of New South Wales Fisheries.
Table D1 Commercial Fisheries Production, New South Wales

<table>
<thead>
<tr>
<th>Type</th>
<th>Weight* (tonnes)</th>
<th>Valueb ($M)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fish</td>
<td>20,782</td>
<td>48.4</td>
</tr>
<tr>
<td>Crustacea</td>
<td>3,499</td>
<td>30.1</td>
</tr>
<tr>
<td>Molluscs</td>
<td>7,192</td>
<td>43.1</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>31,473</strong></td>
<td><strong>121.6</strong></td>
</tr>
</tbody>
</table>

* Based on New South Wales fisherman’s catch returns.

b Based on average 1990 market price for 91 species (Fish Marketing Authority, Annual Report, 1990).

of the Fisheries Research Institute (Henry, 1990). These surveys reveal that the main target species of recreational fishermen are Yellowfin Bream, Blackfish, Sand Whiting, Dusky Flathead, Snapper, Tailor, and Tarwhine. All of these species are dependent on estuarine habitats at some stage of their life cycle (SPCC, 1981).

The above values of the commercial and recreational fisheries understate their true worth: they do not include the value of accommodation, meals and other tourist services associated with the recreational fishery; nor do they include the value of the support services for the commercial fleet (fuel, bait, processing, marketing, etc.). Further, the above values ignore the fact that well managed fisheries are a sustainable resource, as is the economy based thereupon.

Estuarine habitat is also of significance to duck populations. Estuaries provide refuge for waterfowl in times of drought, especially Chestnut Teal. In 1990, some 6000 duck hunting licences worth $180,000 were sold in New South Wales.

Estuaries are also desirable venues for passive recreational pursuits and for nature watching, which also boost the local economy.

Thus, the richness of estuarine ecosystems contributes to our way of life in a number of fundamental ways. To preserve these ecosystems and our sustainable use of them, we must first, recognise the complex interactions between estuarine biota and their habitats, and second, use this knowledge to plan and manage estuarine development in an ecologically sensitive fashion.

2 ESTUARINE FOOD WEB AND PRODUCTIVITY

Figure D1 depicts in generalised form the estuarine food web. The highly inter-related nature of the various estuarine organisms is readily apparent.

The basic foodstuff of the estuarine food web is detritus and phytoplankton biomass. The various pathways by which these materials are cycled through the food web are shown in Figure D1.

Detritus comprises all non-living organic matter, including waste products and the remains of dead organisms, together with the associated microbial community (Day et al, 1989). Detritus originates from aquatic plants, especially seagrasses and mangroves, in the form of leaf litter, and from microbial decomposers in the form of the products remaining after the bacterial decomposition of dead animals. Phytoplankton growth is a function of the availability of nutrients and other factors (see Section 9 of Appendix C). Note that as well as being produced within an estuary, both detritus and nutrients can also be imported via freshwater and tidal flows.

The primary consumers consist of the zooplankton and ‘filter feeders’ (e.g. mussels, oysters) that eat phytoplankton, ‘deposit feeders’ (e.g. worms) that eat detritus, and ‘plant grazers’ that eat macrophytes (insects, some birds and some fish).
Secondary consumers consist of invertebrate predators (e.g. crabs and prawns) birds and fish.

Finally, tertiary consumers include humans, who eat fish, birds (ducks), filter feeders (mussels and oysters) and invertebrate predators (prawns and crabs).

Estuarine ecosystems are generally highly productive, i.e. they generate a large amount of living plant and animal matter (biomass).

There are a number of reasons for this:

- Freshwater inflows commonly import significant volumes of nutrients and detritus into estuaries. On the New South Wales coast, Glaister (1978) and Ruello (1973) found that prawn production in the Clarence and Hunter Rivers increased with increasing freshwater discharges.

- Estuaries are efficient 'nutrient traps' which capture and convert a large proportion of the...
nutrients cycled through them into biomass. Trap efficiency is facilitated by:

(a) sediments containing a high percentage of clay, which adsorbs phosphorus.

(b) the filtration of nutrients and organic particles from the water column by animals and the deposition of these materials on the sediments ('bio-deposition').

(c) oscillatory tidal flows, which inhibit the rapid throughflow of freshwater discharges, thereby increasing nutrient residence time and likelihood of uptake.

(d) salinity changes, which tend to flocculate suspended solids and adsorbed nutrients, and deposit these materials on the sediments.

- tidal mixing, which encourages the distribution of nutrients and organic matter throughout the estuary, thereby increasing the likelihood of uptake.

- nutrient storage and release in fringing tidal marshes, whereby nutrients tend to be converted into organic matter in mangrove and salt marsh communities during part of the year and released to the estuary (principally as leaf litter) during other parts of the year; and

- the 'nutrient pump' effect of macrophytes, whereby aquatic plants abstract nutrients from the sediments via their root systems and release a proportion of them back to the water column.

The coastal waters of New South Wales are typically 'nutrient poor'. Estuaries are probably the major source of nutrients in the nearshore zone along the New South Wales coastline.

3 HABITAT TYPES AND DEPENDENCE

Estuaries provide a wide diversity of habitats for plants and animals. Eleven broad estuarine habitats can be identified, as shown on Figure D2:

- open waters
- rocky reefs and rocky shores
- unvegetated bed sediments
- seagrass beds
- inter-tidal sand and mudflats
- beaches, dunes and sand-spits
- mangroves
- saltmarshes
- swamp forests
- ephemeral floodplain wetlands and dune lakes
- freshwater aquatic vegetation

Whilst these habitats and their ecosystems are now described separately, it is important to realise first, that they form an inter-related web of life support systems that encompass both themselves and terrestrial habitats and ecosystems, and second, that many estuarine species use a number of different habitats at different stages of their life cycle.

In fact, many species are explicitly dependent on different habitats at different stages of their life cycle. Consider for example, the Blackfish or Luderick. Adult fish spawn in near shore waters. Their floating larvae are carried into estuaries under the influence of local currents. The larvae remain in the surface waters of the estuary until they develop sufficient mobility to migrate to the estuary floor, where they shelter and grow in seagrass beds. At this stage of their life cycle, most of the food of the juvenile fish consists of small crustaceans. As they mature, the young fish leave the seagrass beds at high tide to forage over nearby mangrove flats. After about six months, the fish permanently leave the seagrass beds and are commonly found near rocky reefs or in mangroves. Their food now consists exclusively of algae.

As a further example of the need for multiple habitats, Table D2 shows the use of different habitats in Botany Bay by a variety of fish species at different life history stages.

Because of use and dependence upon multiple habitats, biologists refer to fish and other wildlife as being 'estuarine dependent' rather than 'habitat dependent'. For fish, four categories of estuarine dependence have been recognised:

1. Species in which all life stages are undertaken within an estuary, e.g. Dusky Flathead, Trumpeter Whiting and River Garfish.

2. Species which only leave the estuary to spawn, e.g. Yellowfin Bream, Luderick and Sand Whiting.

3. Species which are only estuarine dependent as juveniles, e.g. Snapper and Tarwhine.
Figure D2  Estuarine Habitats
### Table D2  Age-specific Habitats of Important Commercial Fish Species in Botany Bay

<table>
<thead>
<tr>
<th>Species</th>
<th>Life Cycle Stage</th>
<th>Spawning Grounds</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Small Juveniles</td>
<td>Large Juveniles</td>
</tr>
<tr>
<td>Dusky Flathead</td>
<td>Seagrass beds</td>
<td>Deep Mud</td>
</tr>
<tr>
<td></td>
<td>Mangroves</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Shallow mud</td>
<td></td>
</tr>
<tr>
<td>Sand Whiting</td>
<td>Seagrass beds</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Shallow sand</td>
<td></td>
</tr>
<tr>
<td>Trumpeter Whiting</td>
<td>Seagrass beds</td>
<td>Deep sand (s)</td>
</tr>
<tr>
<td></td>
<td>Shallow sand</td>
<td>Deep mud (w)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tailor</td>
<td>Seagrass beds</td>
<td>Seagrass beds (s)</td>
</tr>
<tr>
<td></td>
<td>Shallow sand</td>
<td>Deep sand (s)</td>
</tr>
<tr>
<td>Yellowfin Bream</td>
<td>Mangroves</td>
<td>Shallow sand (s)</td>
</tr>
<tr>
<td></td>
<td>Seagrass beds</td>
<td>Deep sand (s)</td>
</tr>
<tr>
<td></td>
<td>Shallow mud</td>
<td>Deep mud (w)</td>
</tr>
<tr>
<td>Tarwhine</td>
<td>Seagrass beds</td>
<td>Deep sand (s)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Deep mud (w)</td>
</tr>
<tr>
<td>Luderick</td>
<td>Seagrass beds</td>
<td>Seagrass beds (s)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: SPCC (1981);
Notes: (s) summer feeding grounds; (w) winter feeding grounds.

4. Species that generally live elsewhere and only spawn in the estuary, e.g. Sea Garfish, anchovy and herring.

4 OPEN WATERS

The open waters of an estuary serve as feeding grounds for a variety of birds and other animals. These include pelagic fish, such as tailor; reptiles, such as turtles and sea-snakes; birds, such as cormorants, terns, gulls and penguins; and mammals, such as whales and dolphins. The Southern Right Whale is known to use estuaries as calving grounds. Other species, such as albatross, may seek refuge in estuaries during inclement weather.

5 ROCKY REEFs AND ROCKY SHOREs

Temperate rocky reef and rocky shore habitats support a diverse mix of flora and fauna. They are outstanding sites for recreational fishing and diving. A number of studies around the Sydney region have characterised the fish fauna of these habitats and some general conclusions may be made about their role within an estuary.

Lincoln, Smith and Hair (1990) reported that surveys made during 1988 of rocky reefs in Sydney, Jervis Bay and Batemans Bay revealed an abundant and diverse fish fauna. One-hundred and thirty-six species of fish were recorded on natural reefs in these areas with the most common families being wrasses and leatherjackets. Many species were also of tropical origin.

The authors also noted that approximately 30% of the species at all sites were of economic importance. In particular, these were the Leatherjackets, Blackfish and fish from the families Sparidae (Yellowfin Bream, Snapper and Tarwhine) and Carangidae (Silver Trevally, Yellowtail and Samson Fish).

Burchmore et al. (1985) have described the recruitment of juvenile fishes to rocky reefs.
These juveniles are generally of a larger size than juveniles found in seagrasses, indicating that some growth is probably required in a seagrass habitat or elsewhere before species migrate to rocky reefs.

The presence on and within rocky reef - rocky shore habitats of a diverse assemblage of epibenthic life forms provides both juvenile and adult fish with a wide range of food items. The physical diversity of rocky reefs is also thought to provide important habitat to the fishes of tropical origin which recruit there during summer (Lincoln-Smith & Hair, 1990).

Studies of artificial reef communities have indicated that they also support significant numbers of fish, including many species of economic value such as leatherjackets and luderick. However, Burchmore et al. (1985) noted that the fish communities of artificial reefs were composed of more temporary residents and less permanent residents than their natural reef counterparts. Importantly, it was noted that natural and artificial reefs supported different fish communities, indicating that proposals to replace natural reefs with artificial reefs should be treated with caution.

Rocky shores and rocky reefs exposed at low tide contain food such as crabs, limpets, etc. (epibenthic fauna) that supports a variety of wading birds, eg. Sooty Oystercatchers and Reef Herons. Additionally, exposed reefs are important roost areas for species such as the Curlew Sandpiper and the Sanderling.

6 UNVEGETATED BED SEDIMENTS

By far the greatest proportion of most estuaries are submerged areas which are unvegetated and often of minimal physical variation ('bare' sand or mud beds). However, there can be a number of differences between these areas, which include:

- type of sediment e.g. from marine sand to mud.
- salinity - which depends on distance from the estuary mouth.
- water depth.
- position - in relation to other habitat types or in relation to flow patterns, i.e. mid channel, embayment etc.

Habitat types such as seagrass, mangroves and saltmarsh are important areas for recruitment of juvenile fish, particularly as these areas provide protection from predation. However, juveniles also occur in the shallow and deep areas of unvegetated sediments (Blaber & Blaber, 1980; SPCC, 1981; Weng, 1990). It has been suggested that juveniles in these areas escape predation because of schooling behaviour and camouflage (Weng, 1986), or because of turbid conditions obscuring juveniles from predators (Blaber & Blaber, 1980).

In Botany Bay, juveniles of Trevally, Yellowtail, Trumpeter Whiting, Mulloway and Tailor were found in deep sand and mud areas, while juveniles of Sand Whiting, Sand Mullet and Tailor were found in shallow sand areas (SPCC, 1981). Larger juveniles of many species were found to be more prevalent over unvegetated sediments. Species include those listed above as well as Dusky Flathead, Large-Toothed Flounder, Yellowfin Bream and Tarwhine. The diet of these fish was composed of prawns, bivalve molluscs, polychaetes and amphipods, all of which were common within or on the unvegetated substrates (SPCC, 1981). It has been postulated that greater food availability accounts for concentration of these species in these areas (Quinn, 1980).

In Moreton Bay, Queensland, Weng (1990) found 21 common fish species in unvegetated areas between one and four metres deep. The most abundant of these were Silver Biddy, Trumpeter Whiting, Long-Tailed Catfish and Yellow Perchlet.

In recent research in the Clarence and Richmond rivers, West (in prep.) found that the most numerically dominant fish species in deeper unvegetated substrates in both rivers were species of no significant commercial or recreational value. Southern Herring was the most common; others included Silver Biddy, Glass Perchlet, Striped Catfish and Striped Sole.

The above studies and studies in many other areas in New South Wales have indicated that large juvenile and adult prawns are often the numerically dominant organisms in areas of unvegetated sediments.

In New South Wales the three main types of prawns are School Prawn, King Prawn and Greasyback Prawn. Prawns are opportunistic feeders which ingest bacteria, algae and
meiofauna species during their juvenile stage. As they mature, small molluscs, crustaceans and polychaete worms also form part of their diet. Prawns, whilst a significant commercial fishery in themselves, are also one of the dietary items of estuarine fish.

7 SEAGRASS BEDS

All seagrasses are marine angiosperms (flowering plants) which have completely adapted to life in a saline and dynamic environment. Adaptations include modifications to the root system (in the form of creeping rhizomes), to pollination and seed dispersal mechanisms, and to internal gas exchange, water-balance and photosynthetic behaviour.

Six species of seagrass are found on the New South Wales coastline (West, 1985). These are Posidonia australis (strapweed), Zostera capricorni, Zostera muelleri, Heterozostera tasmanica (all in the family Zosteraceae and commonly called eelgrass), Halophila ovalis and Halophila decipiens (both called paddleweed).

The definition of seagrasses excludes another similar group of plants, namely Ruppia. These do not necessarily live in marine waters and are often pollinated above the water surface. They are usually found in brackish (diluted) waters rather than in seawater. There are three Ruppia species in New South Wales: maritima, megacarpa and polycarpa.

Table D3 describes characteristics of the New South Wales seagrasses and may help identify them.

In New South Wales there were approximately 155 km$^2$ of seagrass beds in 1984 (West, et al, 1985). Generally, seagrass meadows occur in the intertidal and sub-tidal zones of relatively shallow, sheltered inshore areas, typically in bays, estuaries, saline lagoons and lakes. The sub-stratum in which seagrasses grow is typically soft sediments consisting of any combination of sand and mud. The distribution of seagrasses is influenced by light intensity, which is required for photosyntheses. Therefore, depth and turbidity play an important role in the local extent of seagrass meadows.

Seagrass beds serve a number of important and basic ecological roles (see Poiner & Roberts, 1986):
- they are a source of significant amounts of detrital material;
- they are an important mechanism for nutrient cycling;
- they facilitate substrate stabilisation;
- they provide a variety of animal habitats; and
- they provide substrate for epibiota (small plant and animals living on the stems and leaves of seagrass).

Seagrass beds produce large amounts of organic matter. Depending on species and location, 1 ha of seagrass meadow may produce 3-20 tonnes of dried leaf matter per year. Thus, seagrass meadows are a major source of detrital material.

Seagrass beds provide juvenile fish with shelter and protect them from predation (Bell & Pollard, 1989). Most of the estuarine fish species of commercial importance spawn offshore, with larval and juvenile stages spent in seagrass beds (see Section 2). Hence, the maintenance and well being of seagrass beds are of fundamental importance to the success of commercial fisheries in New South Wales.

Not all seagrass beds are equally important to all fish species. Studies in the Hawkesbury Estuary have shown that the larvae of different fish species settle to the bottom of the estuary at different distances from the river mouth (Bell et al, 1988). Thus, to preserve the biological diversity of fish species in these circumstances, it is necessary to protect seagrass beds along the length of the estuary.

The cycling of organic matter and nutrients by seagrasses, especially via the detrital food chain, is crucial to biological productivity and population numbers within estuaries. The decomposition of seagrass litter is undertaken by vast populations of bacteria and fungi, which in turn are eaten by the small organisms that form the base of the predatory food web (zooplankton, worms, etc.). Seagrasses transfer nutrients to estuarine waters by exudation from living seagrass and through decomposition of seagrass litter.

Despite its high productivity, seagrass forms a direct food source for only a limited number of estuarine species. The main grazers are sea­urchins, amphipods, snails, some fish species (e.g. Garfish, Luderick and Leatherjackets),
Table D3  Seagrass Species Found in New South Wales

<table>
<thead>
<tr>
<th>Scientific Name</th>
<th>Common Name</th>
<th>Distinguishing Features</th>
<th>Approximate NSW Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Posidonia australis</td>
<td>strapweed</td>
<td>Leaves 30-60 cm long and 6-14 mm wide, buoyant green fleshy fruit found on beaches late December, strong 2 cm creeping rhizome, not intertidal</td>
<td>Occurs in about 20 New South Wales estuaries south of Wallis Lake</td>
</tr>
<tr>
<td>Zostera capricorni</td>
<td>eelgrass or</td>
<td>Leaves 1-50 cm long and 1-5 mm wide, has upright reproductive stems, slender rhizome, found on tidal flats, in most rivers and lagoons</td>
<td>Entire coast</td>
</tr>
<tr>
<td></td>
<td>ribbonweed</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Zostera muelleri</td>
<td>eelgrass</td>
<td>Very similar to above, but generally smaller leaves with notched tips</td>
<td>In very few estuaries, south of Jervis Bay</td>
</tr>
<tr>
<td>Heterozostera tasmanica</td>
<td>eelgrass</td>
<td>Very similar to above, but with leaves arising from upright stems (can be confused with reproductive stems of Zostera spp.)</td>
<td>In very few estuaries, south of Port Stephens</td>
</tr>
<tr>
<td>Halophila ovalis</td>
<td>paddleweed</td>
<td>Paired oval leaves, 1-5 cm long and 5-20 mm wide, delicate creeping rhizome usually white and translucent</td>
<td>Entire coast</td>
</tr>
<tr>
<td>Halophila decipiens</td>
<td>paddleweed</td>
<td>Very similar to above, except fine hairs visible under microscope</td>
<td>Not known</td>
</tr>
<tr>
<td>Ruppia spp.</td>
<td>sea tassel</td>
<td>slender, upright, often tangled stems up to 2 m long, with numerous branches and linear leaves, leaves less than 20 mm wide, generally surface-pollinated on long spiral stigmas</td>
<td>Entire coast</td>
</tr>
</tbody>
</table>

Source: West (1985)

together with turtles, Black Swan, ducks, geese and Dugong.

A number of wading birds appear to prefer feeding within seagrass beds, e.g. the Grey-Tailed Tattler and the Eastern Curlew.

The presence of seagrass beds reduces current flows and water turbulence, thereby facilitating the deposition of suspended sediments and limiting erosion and sediment transport and providing a safe haven for fauna.

Seagrass beds are quite fragile and are susceptible to many of the modern pressures on estuaries. Point sources of pollution, such as effluent outfalls, may cause excessive algal growths that smother seagrass areas. Dredging, large scale removal of seagrass beds or their periodic harvesting to ‘clear the waterway’ can have drastic effects on their viability and biological productivity. Other factors likely to limit seagrass growth include turbidity, current speed, water turbulence, sediment instability and salinity variations (Wood, 1959, 1959a; Higginson 1965; Larkum 1976; Harris et al, 1983). Once seagrass beds are lost, they do not necessarily recolonise quickly. Zostera spp are
generally rapid recolonisers. Strapweed, a less common species, does not appear to recolonise well. Its reduced presence in New South Wales estuaries is cause for concern (Larkum and West, 1990). Despite its ability to recolonise, areas of Zostera spp have been significantly reduced in New South Wales over recent decades. Studies of the Clarence River Estuary have shown that the present beds of Zostera spp cover only 20% of the area covered in the 1940’s. This marked reduction is cause for concern and may indicate a long-term change in some basic environmental factor. The lost area of seagrass (3 km²) had the potential to support some 5-10 million juvenile bream.

Finally, overseas experience has shown that the loss of seagrass beds can have marked ecological and commercial consequences. Loss of Zostera beds in the North Atlantic in the 1930’s led to the collapse of a fishery and the death of vast numbers of Brent and Canadian geese (Dexter, 1950; Kikuchi, 1980). The dredging of Thalassia beds in the Gulf of Mexico resulted in the local disappearance of commercial shrimps; a decline in Zostera beds caused by industrial pollution led to reduced fish and oyster yields in Japan (den Hartog, 1980; Kikuchi, 1980). Closer to home, a 70% reduction of seagrass beds in Westernport Bay, Victoria, is thought to be associated with an 80% fall in the catch of King George Whiting from these areas.

Clearly, a variety of factors influence the number of waders to be found foraging on a particular sand or mudflat. Differences and preferences between individual flats and areas are likely to be subtle. However, factors such as the ratio of length of shoreline to surface area of the exposed flat, nutrient input and distance to the nearest high water roost all affect the desirability of a particular sand or mudflat. Factors such as these need to be taken into account when planning developments within estuaries or major restoration works.

9 BEACHES, DUNES AND SAND-SPITS

Above-tide areas of the beaches, dunes and sand-spits that flank an estuary are important roosting and nesting areas for waders and a number of other shorebirds. These areas provide high tide roosting habitat and nesting habitat for species such as Little Tern, Bush Stone-curlew and Hooded Plover.

The frequent disturbance of waders at their high tide roosts can lead to unnecessary flight and severely drain their energy reserves. This may be critical for the smaller species, which use energy at a higher rate and need to feed for longer periods during exposure of sand and mud flats.

Disturbances of all descriptions, from beach vehicles and dogs to major reclamation works, continue to threaten beach nesting birds. As a consequence, some of these species are becoming rare and endangered. Habitat management programmes are needed to ensure their survival as breeding species in New South Wales (see Section 13). The New South Wales National Parks and Wildlife Service is currently in the process of preparing management plans for such species (e.g. the Little Tern, Smith, 1990 and NPWS, 1990; Waders, Smith, 1991 and NPWS, 1991).

10 MANGROVES

The word ‘mangrove’ applies to at least 90 species of trees worldwide, few of which are related to each other. These trees vary in size and appearance but are alike in that they
occupy the fringe of intertidal shallows between the land and sea, and have the ability to withstand regular fresh water and salt water flooding.

Mangroves are generally restricted to sheltered shorelines, although they sometimes grow in open rocky areas.

The soil or 'sediment' of the mangrove environment may be sand, but is more often a rich mud, high in nutrients but essentially anaerobic (lacking oxygen). Although flooding rains can form ponds and rivulets of fresh water in the mangrove forest, the trees must also be able to withstand being submerged twice daily by tidal salt water. In dry areas or during drought, evaporation can cause the salinity of the soil to rise to many times that of seawater.

There are at least five mangrove species in New South Wales (see Table D4). Of these, Grey Mangrove (Avicennia marina) and River Mangrove (Aegiceras corniculatum) are the two most common mangrove species whereas Red Mangrove (Rhizophora stylosa), Large-leaved Mangrove (Bruguiera gymnorrhiza) and Milky or Blind-your-eye Mangrove (Excoecaria agallocha) are located only in the northern estuaries. The Tweed River is the only estuary in which specimens of all five species of mangroves have been collected. Unconfirmed reports suggest that the Yellow-leaved Mangrove (Ceriops tagal) may also occur or have occurred in New South Wales.

### Table D4 Mangrove Species in New South Wales

<table>
<thead>
<tr>
<th>Scientific Name</th>
<th>Common Name</th>
<th>Distinguishing Features</th>
<th>Approximate NSW Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Avicennia marina</td>
<td>Grey Mangrove</td>
<td>Large tree, peg roots, dull grey leaf undersurface</td>
<td>Entire coast</td>
</tr>
<tr>
<td>Aegiceras corniculatum</td>
<td>River Mangrove</td>
<td>Shrub, salt on leaves, hooked fruit, dense thickets</td>
<td>Tweed River to Merimbula River</td>
</tr>
<tr>
<td>Excoecaria agallocha</td>
<td>Milky or Blind-your-eye Mangrove</td>
<td>Milky white sap on breaking stem or leaves</td>
<td>Tweed River to Manning River</td>
</tr>
<tr>
<td>Rhizophora stylosa</td>
<td>Red or Stilted Mangrove</td>
<td>Stilt roots, long curved smooth fruit</td>
<td>Tweed River to Sandon River</td>
</tr>
<tr>
<td>Bruguiera gymnorrhiza</td>
<td>Large-leaved Mangrove</td>
<td>Knee roots, long, straight ridged fruit</td>
<td>Tweed River to Clarence River</td>
</tr>
</tbody>
</table>

In addition, to these true mangroves, a species of hibiscus and a species of mistletoe (Amyema sp.) also occur in northern New South Wales mangrove areas. Williams and Harding (1979) provide a detailed key to the various ‘true’ mangroves and hibiscus and mistletoe.

Mangroves grow along the shores of many New South Wales estuaries, and in some places form extensive forests. In the early 1980's, the extent of mangrove areas in New South Wales was estimated to be some 107 km² (West, 1985). Two estuarine systems, the Port Stephens and Hunter River systems, accounted for 40% of this total (see Table D5).

All mangroves are land-plants which have adapted to the harsh environment at the terrestrial-marine interface. In such circumstances, the species had to overcome an unstable and low oxygen environment, cope with potentially toxic levels of dissolved sodium (either by excluding its uptake or by developing mechanisms to secrete it efficiently). Specific seed dispersal mechanisms were developed to foster the colonisation of other estuaries. Fruits are frequently adapted for dispersal on the tide and are often retained on the tree until germination has occurred, so that establishment occurs efficiently when fruit are shed. An additional colonisation strategy involves producing long
Mangrove Areas. New South Wales Estuaries

<table>
<thead>
<tr>
<th>Estuary</th>
<th>Area of Mangroves (km²)</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Port Stephens System</td>
<td>28.1</td>
<td>26%</td>
</tr>
<tr>
<td>Hunter River</td>
<td>15.9</td>
<td>15%</td>
</tr>
<tr>
<td>Hawkesbury River System</td>
<td>11.6</td>
<td>11%</td>
</tr>
<tr>
<td>Botany Bay System</td>
<td>6.0</td>
<td>6%</td>
</tr>
<tr>
<td>Clarence River</td>
<td>5.2</td>
<td>5%</td>
</tr>
<tr>
<td>Macleay River</td>
<td>5.2</td>
<td>5%</td>
</tr>
<tr>
<td>Richmond River</td>
<td>4.9</td>
<td>5%</td>
</tr>
<tr>
<td>Other Estuaries</td>
<td>31.1</td>
<td>27%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>108.0</strong></td>
<td><strong>100%</strong></td>
</tr>
</tbody>
</table>


cylindrical fruits which, upon falling from the tree, are able to penetrate the substrate and remain anchored there. Flowers are pollinated by a variety of animals, but typically by moths.

Hutchings and Saenger (1987) identified seven environmental factors essential for the development of extensive mangrove ecosystems, two of which are substrate and salinity. Mangroves grow most extensively in depositional areas of mud and muddy soils, although in sheltered areas they may also grow on sand, peat and coral. Once developed, mangroves foster the accretion of mud. Although some mangroves do not require brackish or salt-water to survive, most grow best in areas where some salinity is present. Because other plant species are generally inhibited by such saline conditions, competition is eliminated, which enhances the survival of the relatively slow growing mangrove species.

Mangroves play an important role in estuarine ecology. They provide organic matter to estuaries through the decomposition of leaf litter (up to 6 tonnes/ha of leaf litter are produced annually - West, 1985). They provide habitat for fish, birds, molluscs, crustacea, butterflies and other insects, and worms. Grazing of mangroves by cattle sometimes occurs; mangroves provide a source of pollen for apiarist's bees. Mangroves protect and stabilise the shoreline; maintain water quality by filtering land-based runoff; and provide recreational and educational opportunities.

Mangrove habitats are important to both juvenile and adult fish. At low tides fish are confined to drainage channels, but move out into the mangrove forest on the high tide. Recent studies in the Clarence River Estuary found that Flat-Tail Mullet, Dusky Flathead, Silver Biddy, Yellowfin Bream, Tailor and Southern Herring were the dominant species of commercial importance found in mangrove habitats. Both adults and juveniles of these species were present.

Generally the fish communities of mangroves are dominated by several species which recruit to the mangroves for only limited periods throughout the year. In Botany Bay, Bell et al (1984) found that temporary residents dominated the mangrove community in terms of both individuals (77%) and biomass (99%). The dominant species were Yellowfin Bream, Silver Biddy, Luderick, Dusky Flathead and Whiting.

Morton (1990), working in Moreton Bay, estimated that 94% of the mangrove biomass was of direct importance to the regional fishery in southern Queensland. The dominant species sampled were adults and juveniles of Mullet, Yellowfin Bream, Golden-Lined Whiting and Luderick. An estimate of $8380/ha for the value of marketable fish was made, which did not include the numerous commercially important juveniles captured, the value of non-commercial fish to the food chain, or the sustainability of the fishery in that area.
Many species of waterbirds, such as herons, bitterns, ibis, spoonbills and cormorants, either roost, feed or nest in mangroves (Kingsford, 1991). Mangroves provide habitat for honeyeaters and warblers (e.g. the Brown Honeyeater and the Mangrove Warbler). Many wading bird species also prefer to feed in association with mangroves, e.g. Bush Stone Curlew, Whimbrel, Common Sandpiper, Greenshank and Bar-tailed Godwit, whilst a number roost in mangroves, e.g. Grey-tailed Tattler and Terek Sandpiper.

In addition, mammals such as Water Rats also frequent mangrove areas, as do insect eating bats.

Finally, there are a number of species of butterfly that depend on mangroves. Illidge’s Ant-blue Butterfly and its attendant ant species are specific to mangroves, while a number of other species, e.g. the Copper Jewel and the Glistening Blue are at least partially dependent. At least one rare butterfly, the Dull Jewel, is associated with the mangroves of northern New South Wales.

11 SALTMARSHES

Saltmarshes occur on the landward side of mangroves, where tidal inundation is regular but infrequent. West (1985) estimated that the total area of saltmarsh in New South Wales was 57 km².

In New South Wales, saltmarshes are characteristically dominated by only a few plant species, including Red Samphire and Salt Couch. The plant communities of saltmarshes often occur in distinctive zones, determined by a complex interplay of factors, which include tidal scour on seedlings in the lower limit of the saltmarsh, competition with mangroves for light, competition between species, soil type, salinity gradient and inputs of freshwater (Clarke and Hannon, 1967; 1969; 1970; 1971).

Only limited studies have been made of fish species present in saltmarshes. It appears that fish tend to congregate in the deeper tidal channels through the marsh, moving out into shallow areas around high tide (Morton et al, 1988).

A recent study found that 19 species of estuarine fish used the saltmarsh habitat, 11 of these being of commercial importance (Morton et al, 1987). The most common fish were Yellowfin Bream, Flat-Tail Mullet and Fantail Mullet. Although these fish are predominantly bottom feeders, food of terrestrial origin was eaten by the Yellowfin Bream (insects, lizards and spiders). In the upper saltmarsh, ponds of water left by the retreating tide are inhabited by Mosquito Fish, Pacific Blue Eye and various gobies (Morton et al, 1988).

Saltmarshes provide organic matter to estuarine food chains, but are not as productive as seagrass or mangrove areas. They also help maintain estuarine water quality by filtering sediment from land-based runoff.

Saltmarshes may harbour important insect communities. Some rare butterfly species depend on saltmarshes and associated vegetation for completion of certain life phases, e.g. the larvae of the Saltpan Blue and Painted Skipper butterflies.

The presence of insects and small vertebrates in saltmarshes attracts waterbirds, such as herons, bitterns and egrets, and waders to these areas, e.g. Bush Stone Curlew, Double-banded Plover, Greenshank, Bar-tailed Godwit and Sharp-tailed, Pectoral and Curlew Sandpipers (Kingsford, 1991). Some bush birds, such as the White-fronted Chat, also feed and nest within saltmarsh vegetation.

Perhaps the greatest threat to the saltmarsh areas is land reclamation. Saltmarshes are often naively viewed as unproductive, unsightly and untidy areas that can ‘be put to better use’. Many previous saltmarshes in New South Wales now lie buried beneath sports fields (Adam, 1984). At Brisbane Water on the New South Wales central coast, some 130 ha of saltmarsh, or over half the original area, was lost by infilling (DEP, 1983).

12 SWAMP FORESTS

Swamp forests, which are generally located adjacent to wetland areas, represent the most inland habitat directly connected to an estuary. Swamp forests provide organic matter to the estuary (as detritus) and contain many terrestrial species of wildlife, as well as aquatic organisms. They also form buffer strips between the hinterland and the water.
Swamp forest trees consist principally of paperbark and casuarina, e.g. Broad-leaf Paperbark and Swamp Oak. Eucalypts such as Swamp Mahogany are also common.

A number of mammal species inhabit swamp forests in Eastern Australia, including the Water Rat, the rare False Water Rat, the Southern Bush Rat and the Grassland Melomys, all of which feed in both the aquatic and terrestrial environments (Smith, 1981). A number of other ground-dwelling mammals, aerial feeders such as bats, and reptiles such as Red-bellied Black Snake, Carpet Python and Land Mullet also live in swamp forests.

A number of birds and bats winter in Swamp Forests. The Broad-leaf Paperbark provides a significant food source for these animals. It is likely that northern New South Wales stands of Paperbark are extremely important overwintering sites (Nix, 1976).

13 EPHEMERAL LAKES AND DUNE LAKE SYSTEMS

The Ephemeral lakes associated with estuaries are temporary water bodies created by overflow from the main drainage channels. Because they are only intermittently filled, the waters of these temporary reservoirs experience extreme physical and chemical variations. This does not necessarily mean that they are devoid of fauna. In studies of temporary streams within Australia, species richness amongst macro-invertebrates was found to be extremely high, often with considerable species overlap between permanent and temporary water bodies (Boulton and Suter 1986). Therefore ephemeral water bodies may be of considerable importance to vertebrates seeking food, and an integral part of the ecology of the floodplain as a whole.

The geomorphology of coastal dune wetlands is diverse: they can occur in deflation hollows in swales (mainly on the older inner barrier); and as lagoons infilled to varying degrees, between the inner and outer barriers or enclosed within bedrock spurs. Some of these dunal wetlands have extensive catchments on bedrock: some lagoons and swales are perched above the water table on accumulated humic material, and others intercept the water table. Dune lakes vary in terms of their connection with the sea. Heavy rains and flooding can lead to overflow from most lakes and semi-permanent connections with the sea. Salinity is usually low within these lakes and the water is typically acidic and humic. The biota are usually distinctive and differ somewhat from those of any nearby main drainage channels. The biological communities are usually simple. Energy pathways appear to rely on the input of organic matter and are therefore at risk of pollution (Timms 1986).

14 FRESHWATER AQUATIC VEGETATION

Although the majority of estuarine waterways are bordered by either mangrove or saltmarsh, the upper reaches of the estuary are often characterised by aquatic plants that are basically freshwater species with some salt tolerance.

Aquatic freshwater vegetation occurs in distinct zones: deeper water vegetation commonly consists of Ribbon Weed and Water Thyme; whilst in shallow waters, vegetation includes Common Reed and Cumbungi.

The limit of freshwater aquatic vegetation generally marks the brackish interchange between freshwater upstream reaches and saline downstream reaches. Many freshwater fish species migrate between the fresh and brackish water areas. The movement of juvenile fish in and out of brackish waters is aided by the presence of aquatic vegetation, such as Ribbon Weed and Common Reed. This is particularly true of the Australian Bass, which uses reed beds during its larval and juvenile life stages (Harris, 1980).

In areas of freshwater aquatic vegetation, terrestrial invertebrates make up a substantial portion of the diet of many fish, especially in summer (Harris, 1985). The significance of freshwater aquatic vegetation was confirmed by a recent study of the upper reaches of the Hawkesbury Estuary. Some 37 species of fish were recorded in Ribbon Weed and Water-Thyme habitats. The predominant species were a carp gudgeon, Flathead Gudgeon, Glass Perchlet and Bullrout. Adjacent unvegetated areas supported a less diverse and less abundant community of fish.

Upstream areas of freshwater vegetation provide a source of food for many waterbirds and waders, e.g. ducks, geese, Black Swan.
and Common Sandpipers. These birds feed upon both terrestrial invertebrates and submerged vegetation, crustacea and other small vertebrates, such as frogs and fish.

15 INTERDEPENDENCE OF ESTUARINE AND OTHER ECOSYSTEMS

Much of the discussion of this Appendix has consisted of a description of various estuarine habitats and their importance to the estuarine ecosystem as a whole. The inter-dependence of these habitats has been stressed, together with the use of multiple habitats within the estuary by various organisms during different stages of their life cycle.

But estuarine ecosystems in themselves are not independent and are not isolated from other ‘external’ ecosystems. Rather, estuaries form part of regional, national and global ecosystems through direct connection via water flows (transport of nutrients, detritus, larvae, plankton, etc.) or through indirect connection via the movement of certain fauna. The links between specific estuaries and other ecosystems may span hundreds of metres or thousands of kilometres. Hence, a disturbance to a specific estuarine ecosystem may be reflected in detrimental effects in ecosystems remote from the estuary.

With respect to fish movements, some freshwater species such as the Australian Bass migrate downstream to spawn in estuaries. Estuarine-dependent marine species such as Sea Mullet may utilise several estuaries during their northward spawning migrations, whereas other marine species such as Snapper move from estuary to offshore reef. Individual King Prawns and estuarine fishes have been recorded as migrating over hundreds of kilometres. There is no certainty that the larvae of a particular animal will enter the same estuary its parent once occupied.

With respect to bird movements, migration distances can be dramatic with some estuarine-based species migrating to the northern hemisphere on a seasonal basis. Other species, such as the Pelican, migrate between the coast and inland waterways on an opportunistic basis, whereas Black Swans move into estuaries during times of drought and loss of inland waterways.

A number of species of pelagic seabirds occasionally seek refuge in estuaries during periods of rough weather. Nineteen species that rarely enter estuaries (mainly albatrosses, petrels and shearwaters) have been sighted in Botany Bay from vantage points in Botany Bay National Park (Morris, 1989).

Other seabirds, such as the Little Penguin are more estuarine-dependent, although not wholly restricted to this environment. A colony of some 300 pairs has been recorded on Lion Island (8 ha) in the Hawkesbury Estuary (Lane, 1975) and a colony of 1500 pairs breeds on Bowen Island (50 ha) in Jervis Bay (Lintermans, 1989) where bait fish abound.

Waterbirds rely on freshwater to a large extent to complete their life cycle. They include Pelican, ibises, herons, bitterns, egrets, cormorants, Black Swan, geese (e.g. Magpie Goose), ducks (particularly Grey Teal, Chestnut Teal, Hardhead and Black Duck) and kingfishers.

All of these birds are recorded in estuaries at times, especially during droughts when inland waters dry up and contract. The shallow waters of estuaries provide excellent feeding habitat for many water birds. Ducks feed on submerged vegetation and invertebrates in the sediment; Herons stand motionlessly for long periods awaiting a passing fish.

The estuarine food sources of water birds can be reduced or destroyed by a number of activities: upstream dams reduce freshwater flows and fish populations; fish kills deplete the food supplies of fish-eating birds such as cormorants and herons; temperature and water quality changes affect benthic communities and hence the food available to ducks.

From the above discussion, it is clear that estuaries are highly productive ecosystems on which many surrounding and at times far reaching communities are dependent.

16 REFERENCES


APPENDIX E  ESTUARINE FAUNA AND FLORA OF SPECIAL CONCERN

1 Introduction
2 Legislation
3 Amphibians
4 Reptiles
5 Waders
6 Birds of Prey
7 Terns and Gulls
8 Other Seabirds
9 Mammals
10 Fish
11 Flora
12 References

1 INTRODUCTION

Many estuaries along the New South Wales coastline support a range of bird life and other species that are of special concern because they are threatened, endangered or rare. In many cases, the reduction in population numbers has come about through the detrimental effects of human activities.

This Appendix lists estuarine fauna and flora of special concern, but first international, national and state agreements and legislation aimed at protecting such species is described.

2 LEGISLATION

International Agreements

Australia is a signatory to a number of international agreements aimed at protecting wetlands and migratory birds and other animals. These agreements include the Ramsar Convention on the Protection of Significant Wetlands (1975), the Bonn Convention on the Conservation of Migratory Species of Wild Animals (1979), the Japan-Australia Migratory Bird Agreement of 1974 (JAMBA), and the China-Australia Migratory Birds Agreement of 1988 (CAMBA). Australia is currently negotiating to sign a similar migratory birds agreement with Russia, and other agreements are likely to follow.

National Agreements

The report entitled 'Endangered Vertebrates of Australia and its Island Territories' was adopted by the Council of Nature Conservation Ministers in 1984. This report lists a number of endangered birds and other animals dependent upon New South Wales estuarine habitats.

State Legislation

The Endangered Fauna (Interim Protection Act, 1991 made amendments to the National Parks and Wildlife Act, 1974 and the Environmental Planning and Assessment Act, 1979. Schedule 12 of the National Parks and Wildlife Act is currently being reviewed under the Endangered Fauna (Interim Protection) Act, 1991. Prior to this new Act, endangered fauna in New South Wales were listed under Schedule 12 of the NPW Act, which includes the following categories and criteria for the listing of such species:

Part 1  Fauna of Special Concern

(i) Species at risk or endangered in any part of Australia, except New South Wales, which have experienced long term population decline, or species included on endangered fauna lists of other Australian States and/or Territories; or

(ii) Australian or migratory species listed as rare, threatened, vulnerable or endangered in the I.U.C.N. Red Data Book (being the worldwide list of such fauna), or

(iii) Species the subject of a Federal Act or
International Agreement but not included in Parts 2, 3 or 4 of the NPW Act.

Part 2 Vulnerable and Rare Fauna

(i) Species especially vulnerable to exploitation in New South Wales or;

(ii) Species whose population is naturally small in New South Wales and while not immediately threatened, may rapidly become extinct should any adverse development occur.

Part 3 Threatened Fauna

Fauna occurring in New South Wales, but in restricted habitat, in numbers adequate for survival and possibly common over parts of its range, but which has declined in numbers, or habitat has declined, at a rate which gives cause for concern.

Part 4 Fauna in Imminent Danger of Extinction

Fauna occurring in New South Wales in such low numbers that it is in imminent danger of extinction and survival is dependent on special protective measures or no reliable record since 1949.

Part 5 Marine Mammals

Part 5 of Schedule 12 protects marine mammals (all marine mammals in New South Wales are protected), which include all cetaceans (whales and dolphins), pinnipeds (seals) and sirenids (dugong).

3 AMPHIBIANS

There are up to 26 species of frog that occur in and around estuaries in New South Wales, one of which (Litoria jervisiiensis) is protected (Part 4A, Schedule 12A, NPW Act). Under the new Endangered Fauna (Interim Protection) Act, 1991, all frogs in New South Wales are protected. Frogs are important food items for fish, birds and possibly mammals. They are also outstanding 'bio-indicators', since they appear to have little tolerance for highly acidic waters or pollution.

4 REPTILES

A number of species of lizard, (e.g. Eastern Water Dragon), snake (e.g. Yellow-bellied Sea-snake) and turtle (e.g. Leathery Turtle) have been recorded within New South Wales estuaries. The Leathery Turtle is of particular significance as it is listed as 'Fauna of Special Concern' under Schedule 12, Part 4, of the NPW Act, 1974, and is listed in Appendix 2 of the Bonn Convention. Most sightings of the Leathery Turtles have occurred along the eastern seaboard of Australia in more populated areas. Large adults are typically found year-round in larger bays, estuaries and rivers (Cogger, 1988).

5 WADERS

At least 50 of the 62 species of waders recorded in New South Wales occur regularly in estuaries (Kingsford, 1990). The majority of these are non-breeding summer migrants from the northern hemisphere, typically breeding within the Arctic circle.

Most estuarine waders are protected by the JAMBA and CAMBA Migratory Bird Agreements. They are also listed as 'endangered fauna' under Schedule 12 of the NPW Act.

Waders utilise a number of habitats, both within and outside estuaries, on a daily basis. After high tide, they fly from their roosts (typically mangroves or non-tidal beach areas) to forage on the receding tide. A number of different habitats are used for foraging: Beach Stone-Curlews prefer ocean beaches, inter-tidal mudflats and rocky shores amongst mangroves or saltmarshes; Bar-Tailed Godwits feed on sand and mudflats, often amongst seagrass, but also at times in saltmarshes, mangroves and on ocean beaches (Lane, 1987).

In some seasons, significant inland rains draw waders away from the coast. At times, inland wetlands contain more waders than estuaries.
At least 12 estuarine species of waders regularly occur inland and a further 16 species are occasionally recorded there (Kingsford, 1991).

Differences in the niche habitats of waders, as described above, emphasise the need for estuaries and their ecosystems to be managed on an integrated basis.

There are a number of concerns regarding the conservation of waders in New South Wales estuaries. These include the on-going intensive pressure for development of estuaries, disturbance of inter-tidal feeding and roosting sites, pollution by oil spills and toxic substances, and disturbance of nests of beach-nesting species.

6 BIRDS OF PREY

There are a number of fish-hunting birds of prey that forage, roost and nest within and in the general vicinity of estuaries. These include the White-bellied Sea-eagle, the Whistling Kite, Marsh Harrier and the Osprey. The White-bellied Sea-eagle is listed as 'fauna of special concern' in Schedule 12 of the NPW Act. It is also covered by the CAMBA Migratory Birds Agreement.

The Osprey is of particular concern. It is listed as 'vulnerable and rare fauna' on Schedule 12 of the NPW Act. It is also listed in Appendix 2 of the Bonn Convention 1979. Earlier this century, the Osprey population declined severely on a worldwide basis because of 'egg-shell thinning' caused by the bioaccumulation of DDT. Pesticides are likely to have had an effect in New South Wales, where Ospreys have been found to carry high levels of dieldrin.

The total breeding population of Ospreys in New South Wales is estimated to be only 45-50 pairs. Optimal feeding habitat is a shallow estuary, river or other water body with suitable nesting trees and feeding perches. Mullet species feature prominently in the diet of Ospreys.

Potential threats to the welfare of Ospreys include loss of traditional nest trees, disturbance of nest sites, reduction in the quality and quantity of food supply, degradation of estuarine systems, effects of pesticides (especially egg shell thinning), egg collecting, shooting and collision with powerlines (Clancy, 1991; Llewellyn, 1991).

7 TERNs AND GULLS

Terns and gulls are a significant component of the bird life within the estuaries of New South Wales. New South Wales species include the Silver Gull, Kelp Gull, White-winged Tern, Gull-billed Tern, Caspian Tern, Common Tern, White-fronted Tern, Little Tern and Crested Tern.

The Kelp Gull, White-winged Tern, Caspian Tern, Common Tern and Little Tern are specifically mentioned in either Schedule 12 of the NPW Act, or the JAMBA and CAMBA Agreements.

The two species most obviously affected by human disturbance in New South Wales are the Silver Gull and Little Tern. The Silver Gull has benefitted from human disturbance; Little Terns have not.

Human activities enhance estuarine habitats for Silver Gulls: they are fed scraps and refuse by fishermen and picnickers; they obtain food from dredge spoil and from sand pumping operations. Further, Silver Gulls will nest on urban structures, such as pylons and wharves, and roost in areas where shallow ponds have been created adjacent to estuaries.

Increases in Silver Gull numbers pose a threat to other native wildlife. They are well known for their habit of interfering with the feeding and breeding of other species (e.g. Hulsman 1976, 1977, 1984; Skira and Wapstra 1990; Robinson and Minton 1989; Egan 1990; Smith 1991).

The Little Tern, which is subject to pressure from the Silver Gull, is also under threat from human activities. The Little Tern is listed as 'threatened fauna' under Section 12 of the NPW Act, 1974. It has also recently been included in the list of 'Endangered Vertebrates of Australia and its Island Territories', adopted by the Council of Nature Conservation Ministers. It is listed in the JAMBA and CAMBA Agreements, and may be included in
the proposed USSR-Australia Migratory Birds Agreement.

In 1984-85, about one-fifth of the national population of Little Terns occurred along the coastline of New South Wales. However, numbers had dwindled from an estimated 340 pairs in the 1950's to 110 pairs in 1984-85. Breeding success is very low; an estimated 86% of breeding pairs fail to fledge young. Under present conditions it seems unlikely that the Little Tern population will survive (Smith 1990; NPWS, 1990). Little Terns feed in estuaries and nest on adjacent beaches. They have been unable to withstand pressure from development, recreation (off-road vehicles) and increased predation from Silver Gulls and feral vermin (dogs, cats, foxes).

8 OTHER SEABIRDS

The populations of Pied Oystercatcher, Sooty Oystercatcher, White Bellied Sea-Eagle, Brahminy Kite, Magpie Goose, Black Necked Stork, Great Egret and Cattle Egret are believed to be under a low level of threat and may require specific management considerations in the future.

9 MAMMALS

The numbers and species of mammals that have been recorded in New South Wales estuaries are few and include cetaceans (the Common Dolphin, the Bottle-nosed Dolphin and the Southern Right Whale), platypus and water rats. All marine mammals found within New South Wales waters are considered to be endangered fauna under Schedule 12 of the NPW Act. The Grassland Melomys is listed as 'vulnerable and rare' under Section 12.

The importance of estuarine habitat to the various mammal species is not well understood, but is expected to be of significance. This may be particularly true for the Water Rat, a native mammal that occurs in significant numbers within a number of estuaries (e.g. the Hawkesbury River, Sydney Harbour and Wallis Lake); dolphins, which pursue fish prey in shallow coastal areas (e.g. in Port Stephens); and the Southern Right Whale which is known to calve in shallow estuaries. The numbers of Southern Right Whale are probably increasing now that hunting pressure has eased. Hence, these whales may be seen more frequently in New South Wales estuaries in the future - provided the habitat does not become too degraded.

Seals, particularly fur seals, also frequent estuaries to feed on fish and to rest from the rigors of storms at sea.

10 FISH

Estuarine fish are not protected by national or international agreements as are migratory birds and wetlands. However, the following species are protected under the New South Wales Fisheries and Oyster Farm Act, 1935 because they are naturally scarce and their populations have been reduced to dangerously low levels:

- Elegant Wrasse
- Grey Nurse Shark
- Herbst Nurse Shark
- Blue Devilfish
- Estuary Cods
- Black Cod
- Giant Queensland Groper
- Australian Grayling

11 FLORA

Although estuarine plant species have previously been mentioned in the context of providing habitat for animals, no specific mention has yet been made of rare and endangered plants that require protection in their own right.

In fact there are very few estuarine plant species specifically protected under Schedule 13 of the National Parks and Wildlife Act 1974. Examples include the Cabbage-tree Palm and a species of orchid. However, the paucity of formally protected species does not truly reflect the number of species under imminent threat. Species such as Wilsonia backhausia, Chania fillum, some of the orchids and some succulent chaenopods also require consideration for inclusion on Schedule 13. Further details on rare and threatened estuarine flora are contained in Briggs & Leigh (1988).
REFERENCES


APPENDIX F HUMAN IMPACTS

1 INTRODUCTION

Human activities have had major adverse impacts on the habitats and ecosystems of estuaries along the New South Wales coastline (see Section 3 of Appendix H). Some activities can directly disturb, reverse or accelerate the basic geomorphic processes that have shaped estuaries, e.g. sand and gravel extraction, the reduction in freshwater discharges caused by the building of dams, increased levels of sediment inflow caused by catchment degradation. Other activities degrade estuarine water quality in particular and estuarine amenity in general.

Historically, most New South Wales estuaries have suffered from indiscriminate or poorly-planned land-use activities. A survey made in 1980 revealed that only four of 130 estuaries still had relatively pristine waters and catchment areas. Further, in 66 estuaries, less than 50% of the shoreline was in a natural state (Bell and Edwards, 1980). To reverse this trend and ameliorate past damage, firm and proper planning controls are required for estuarine waters and catchments.

This appendix describes the potential adverse effects of these activities on the estuarine environment. A number of these activities can also have beneficial effects, especially with regard to the repair and amelioration of past damage. Beneficial aspects of human activities are also described.

2 HUMAN ACTIVITIES

River Impoundments

Dams and weirs have varying effects on downstream estuarine ecosystems, depending on the size and location of the structures and the uses made of the impounded water. The main changes which have an impact on estuaries are:

- sediment and nutrient inputs;
- freshwater flow and flooding pattern;
- water quality; and
- barriers to migration.

Impoundments generally trap a high proportion of bed load and suspended sediments. Reduced sediment supply has led to serious coastal erosion problems in some parts of the world. However, reducing sediment input could be an advantage in some circumstances, particularly where catchment erosion has accelerated the filling of coastal lakes, such as Lake Macquarie in New South Wales.

Similarly, whilst input of nutrients is important in maintaining estuarine productivity, excessive nutrients may lead to eutrophication. Nutrients are affected by impoundments in different ways, depending on whether they are in the form of organic detritus, bound to sediment particles or dissolved in the water.

The reduction in freshwater flow depends on how much of the catchment is impounded, the storage capacity, and what proportion is diverted to offstream uses. The Hawkesbury is the most affected of the State’s coastal river systems, with 80 impoundments (Harris, 1984), and high use for urban purposes. Reduced freshwater flow affects the hydrology of an estuary, and allows greater penetration of saline water (see Section 8, Appendix B). Freshwater is also a major stimulus of productivity in the marine environment (Jansson, 1986 and Skreslet, 1985). Complex mixing behaviour associated with freshwater discharges has been found to foster high levels of fish larvae and other plankton as compared to purely marine areas (Grimes & Finucane, 1991).
Impoundments tend to restrict both the size and frequency of floods. Flooding is important to many freshwater wetlands, and is a stimulus to the breeding and migration of many fish species inhabiting coastal rivers and estuaries (Harris, 1984). Larger floods also flush accumulated sediments out of estuaries.

Larger impoundments can cause significant water quality changes in their own right, such as lowered temperature and oxygen levels, together with related changes in chemical balances. Downstream problems often result from the release of cold, deoxygenated water from the deeper levels of reservoirs. Toxic substances such as hydrogen sulphide may also be generated. As well as affecting the physiology of aquatic organisms, temperature and chemical changes can also affect breeding and migration behaviour (Harris, 1984). Phytoplankton blooms in reservoirs can greatly increase the turbidity of downstream waters when releases are made (Ridley and Steel, 1975).

Many fish species use both estuarine and freshwater habitats. Weirs may be barriers to migration, although species differ in their abilities to swim, leap or even climb over barriers. Some low weirs may be passable to most fish when the river is in flood. A large number of New South Wales coastal rivers have weirs built around the tidal limit to limit saline intrusion. These are potential barriers to estuarine organisms which require access to freshwater for part of their life cycle (Harris, 1984). Dams and water rediversion projects have had massive impacts on marine biota in the northern hemisphere, but little information exists for their effect on Australian estuaries. In California, the Striped Bass *Morone saxatilis* has almost disappeared from the San Francisco area due to the diversion of Sacramento and San Joaquin Rivers for agricultural and urban purposes (Stevens et al, 1989). On the Nile River, the construction of the Aswan High Dam destroyed the sardine fishery in the river’s delta (Dowider, 1988). In a comprehensive review of the impacts of river regulation, Drinkwater & Frank (1988) claim that ‘a decline in some coastal fisheries with an overall impact on the biota is generally associated with reductions in freshwater inflow’.

Fishing

Over-fishing and habitat degradation adversely affect fish stocks and the availability of this resource. Habitat degradation can be physical in nature, e.g. the smothering of seagrasses with sediments, or arise through impaired water quality.

Trawling can have a significant impact on non-commercial fish species and possibly on benthic communities (bottom dwelling organisms). Non-target and under-sized fish, which may be an important food source for birds and other animals, are inevitably killed by trawling and netting operations. Apart from these direct effects, fishing may also disturb the roosting and feeding patterns of birds.

Bottom trawling generally occurs over unvegetated bed sediments, which are disturbed to some degree. One favourable effect of trawling can be that bottom disturbance brings additional nutrients from the sediments into the waterbody, thereby increasing biological production.

Agriculture and Grazing

Changes wrought to estuarine-draining catchments by clearing, burning, cropping and grazing all increase the rate of sediment production and the amount of sediment transported into estuaries. These activities also alter habitats to the detriment of both aquatic and terrestrial wildlife.

The clearing of riverbank areas commonly causes bank erosion and collapse. Clearing also affects the hydrological balance of catchments: the frequency and severity of flooding are increased; the distribution and duration of surface runoff across the catchment is altered; changes to the groundwater table may occur.

Burning can lead to highly increased nutrient levels in surface runoff, which may result in eutrophication and possible oxygen depletion in receiving waters.

Cropping increases sediment runoff because ploughing and tilling operations both destabilise the upper soil mass and expose it to the
Agricultural runoff, apart from sediment load, can also contain high levels of toxic materials (pesticides and herbicides) and nutrients.

Grazing causes a progressive loss of tree cover because seedlings are eaten by stock. Other detrimental effects include trampling of flora, the compaction of soils, increased nutrient levels in runoff (from faecal matter) and the destabilisation of river banks (unless these areas are fenced off).

A particular agricultural practice of concern to northern estuaries is sugar cane production. This crop is grown immediately adjacent to the lower reaches of many estuaries, e.g., the Clarence River Estuary. This proximity, coupled with the relatively high demand for fertiliser, pesticides and herbicides, has the potential to lead to significant quantities of nutrients and toxic materials entering the estuary as runoff from agricultural lands. The ulceration of mullet in the Clarence River Estuary may be caused by this runoff.

Another adverse effect of agriculture is the exposure to the atmosphere of acid sulphate soils, which are common along the lower floodplains of a number of estuaries in the north of the State. Leachate from these soils can be strongly acidic and contain high concentrations of aluminium (leached from clay soils). This runoff can severely affect estuarine water quality for short periods of time (if the runoff drains to an estuary). See Section 7 of Appendix C for further details.

Forestry

Forestry operations adjacent to estuaries or in upstream catchment areas have the potential to cause significant soil erosion, with consequent increases in turbidity and sedimentation within an estuary. Forestry activities can also result in the loss of scenic amenity around an estuary. Forest roads can act as wildlife barriers, preventing or inhibiting the movement of certain native animals in estuarine catchments, whilst exacerbating the spread of exotic animals and plants.

Maritime Operations

Some estuaries provide berthing and cargo facilities for large fishing fleets; some estuaries also provide extensive facilities for coastal and international trading vessels. Maritime operations can have a number of adverse effects on estuaries. These include loss of shoreline and habitat, disturbance of fauna, oil spills and the introduction, via ballast water, of foreign organisms that may be detrimental to the health of local fauna or the health of humans consuming food items gathered from the surrounding area (Jones, 1991).

Extractive Industries

The extraction of sand, gravel or other materials from an upstream catchment area or from the floodplains or bed and banks of an estuary can have a number of adverse impacts on the estuarine environment.

Extractive industries located around the fringes or within the waterbody of an estuary can cause major damage to estuarine habitats. The tailings associated with sand and gravel extraction, whether windblown or discharged back to the estuary, may smother seagrass beds. Sand and gravel mining alter the cross-sectional area and storage characteristics of affected reaches of the estuary. This results in changes to the hydrodynamic, salinity and sediment transport processes of the estuary. In turn, these changes can lead to habitat degradation and bank erosion. Other possible adverse effects of sand and gravel extraction include the release of nutrients and heavy metals and changes to water levels (see ‘Impact of Estuary Works’, Section 5 of Appendix B). Finally, extractive operations may be noisy, visually unattractive, and the vehicular transport of the product may interfere with local traffic patterns.

Extractive industries have wrought much damage and destruction to estuarine habitats in the past. These days, such industries require planning approval under the Environmental Protection and Assessment Act, 1979 (see Appendix L). This procedure is aimed at limiting detrimental effects to acceptable levels.

Notwithstanding past problems, well designed and controlled extractive industry operations can have a number of beneficial effects. The opening up of waterway areas can increase tidal flushing and improve water quality; it may be possible to use the spoil from mining
operations to create new habitat areas (e.g. islands) or to improve existing ones.

**Reclamation and Dredging**

Reclamation is the most damaging activity associated with the development of estuarine foreshores. More often than not, mangrove and seagrass areas, which are amongst the most productive and most important habitats of an estuary (see Appendix D), are destroyed or severely degraded. The existing foreshore is buried; inter-tidal areas may be smothered by fill operations, or destroyed if used as a source of fill.

Reclamation of inter-tidal areas reduces the tidal prism, significantly at times. This in turn may alter the salinity regime and exacerbate water quality problems through reduced flushing.

Dredging can have a number of adverse effects on an estuary. Seagrass beds may be destroyed by mining the underlying sediment or degraded by increased levels of turbidity and sedimentation. Any deep holes and channels created by dredging can become stagnant or may adversely affect current patterns. Offshore dredging and sand mining near the mouth of an estuary can significantly affect tidal hydraulics and the movement of water and sediment into and out of the estuary.

However, if properly controlled, dredging - like extractive operations - can also benefit an estuary by increasing tidal exchange, enhancing water circulation, facilitating navigation and creating new wildlife habitat.

**Training Walls**

Training walls are commonly used to stabilise an estuary entrance or to confirm the location of a main channel. Whilst training walls improve the navigability of an estuary, they may have a number of adverse effects on estuarine habitats and ecosystems.

If training walls are constructed along foreshores, there is a loss of foreshore habitat and the disturbance and probable loss of inter-tidal habitat. Training walls may significantly alter the ebb and flood current patterns within an estuary. This may lead to certain backwater areas being poorly flushed. Altered current patterns may cause fish larvae to settle in inhospitable areas.

Notwithstanding these adverse effects, training walls can increase the overall flushing of the estuary by promotion of increased flows through deep channels.

**Aquaculture**

In the past, estuaries have been commonly used for oyster farming. Nowadays they are also being used for land-based prawn farming.

Oyster farming, with the oysters raised on racks in shallow estuarine waters, can have a number of adverse effects on the estuarine environment. First, oyster leases are 'out of bounds' to other waterway users (sailors, boat fishermen, etc.). Second, if oyster racks are poorly aligned to the prevailing currents, the flushing of lease areas is restricted. Realignment of oyster racks in sympathy with ebb and flood tide currents promotes both the flushing of lease areas and oyster growth.

Prawn farms have been constructed on land adjacent to a number of New South Wales estuaries, especially in the north of the State. These farms consist of an inter-connected series of large shallow ponds. ‘Fresh’ estuarine water is pumped through this system of ponds, return flows being discharged back to the estuary.

Compared with the estuary itself, prawn farms represent an intense concentration of biomass. Hence, return flows to the estuary can have very high concentrations of organic matter and other pollutants (prawns are fed with food pellets). To preserve nearby estuarine ecosystems and habitats, it is essential that estuarine waters have adequate dilutional and flushing capacity to handle these concentrated waste discharges or that discharges are adequately treated before return to the estuary.

One potential advantage of aquaculture is that the adverse effects of this form of fishing should be much more controllable - because of their concentrated and land-based nature - than 'open water' fishing. The shifting of fishing operations from the water to the land may allow more stringent fishing controls to be imposed in the estuary itself - and thereby hasten its recovery - whilst preserving the commercial 'catch'.

104
Waterfront Developments

Waterfront land is a valuable commodity. Past demand for waterfront land has led to the piecemeal reclamation of extensive foreshore areas. In turn, this has led to the destruction of natural foreshore and inter-tidal habitats and has resulted in restricted public access to foreshores. In addition, significant pollution of estuarine waters has occurred from sullage, other domestic wastes and urban runoff from waterfront developments. Waterside caravan parks with septic tank and absorption trench facilities are common sources of pollution.

Waterfront developments can also have a detrimental effect on wader populations: important habitat areas may be lost or reduced; nesting birds may be disturbed.

Well designed and sympathetic waterfront developments can increase public access to estuarine foreshores and enhance both passive and active recreational amenity.

Canal Estates

Two common and often major adverse impacts of canal estates on an estuary are the initial destruction of estuarine habitat, often wetlands or saltmarsh, and the subsequent continuing pollution and disturbance of estuarine waters by urban runoff, boating activities, etc. Canal estates, like waterfront developments in general, may have adverse effects on wader populations (loss of habitat, disturbance of nesting birds).

Conversely, well designed and constructed canal estates can facilitate the flushing of nearby estuarine areas because of the greater tidal prism associated with the canal development.

Canal estates are generally constructed on low-lying land adjacent to estuaries. Material from canal areas is excavated and used as fill to raise the residual land area. In the past, the dimensions and layout of canals were governed largely by commercial dictates: the need to maximise the number of waterfront blocks and the need to obtain sufficient fill to raise blocks above flood level.

These days, it is recognised that canal dimensions and layout should be governed by the following considerations: retention of wetlands; minimisation of adverse effects on the adjacent estuary, including sedimentation and pollution; adequate tidal flushing of canals; and provision of public access to foreshores.

Marinas and Recreational Facilities

Estuaries are popular areas for active recreational pursuits, such as swimming, boating, water skiing and fishing. These activities require various shore-based facilities, such as marinas, boat ramps and car parks. Often, these structures are built along the foreshore at the expense of mangroves and the natural fringing vegetation. In addition, dredging is sometimes required to improve boat access to marinas.

Adverse effects of boating include pollution by unburnt exhaust gasses from power boats, fuel spills and litter; disturbance to fish stocks; bank erosion, bank undercutting and increased turbidity levels caused by power boat wash; and damage to seagrass beds caused by propellers, anchors and digging for bait.

Marinas and recreational facilities can have a number of adverse effects on wader populations, including disturbance of roosts and beach nesting areas, damage to feeding areas, and reduction in food availability through the collection of bait (by fishermen) and delicacies (e.g. oysters).

Marinas and recreational facilities provide a focus for boating and recreational activities. As such, they are a valuable management tool that can be used to shepherd these activities into appropriate areas of the estuary. By providing a focus for these activities they also facilitate the control of any resulting pollution, e.g. litter, fuel spills.

Road and Bridge Construction

Roads and bridges across estuaries can have a number of adverse effects on estuarine habitats and ecosystems. Causeways across an estuary can severely restrict tidal flows and reduce the tidal prism. This in turn can lead to
increased rates of siltation and deterioration in water quality, with consequent degradation of seagrass beds and other habitats around the obstruction.

From an economic point of view, long causeways with limited waterway openings are desirable. However, the smaller the waterway opening, the greater the loss of tidal prism and the greater the adverse effects described above. In addition, limited or unsuitable waterway openings may restrict the passage of fish past the structure.

Road construction along and across estuaries often involves wetland reclamation with dredge spoil and the destruction of foreshore vegetation. These activities result in the loss of foreshore, wetland, tidal and possibly intertidal habitat.

The long-term adverse consequences of road and bridge construction can be quite dramatic. The reduced fluctuation in tidal water levels and velocities, together with highly reduced salinity levels, can lead to a progressive, but ultimately marked change to upstream habitat areas, including the loss of mangroves and the smothering of any upstream seagrass beds.

Again, careful and sensitive design that recognises the interactions between the various estuary processes can minimise these adverse effects.

**Power Generation**

The efficient generation of thermal electricity depends upon adequate supplies of high quality coal and cooling water. In New South Wales, both are found on the coastal strip between the Illawarra and Newcastle regions. Currently, 3 power stations - Vales Point, Munmorah and Eraring - with a total generating capacity of about 5800 MW, are located in the Newcastle region. These stations obtain their coal from nearby coal fields in the Hunter Valley and withdraw cooling water from nearby coastal lakes. In 1990-91, these three stations generated about one-half of New South Wales' power requirements.

Not all heat released from the combustion of coal can be converted into electrical energy. Cooling water is used to condense spent steam leaving the turbines back to water. Power stations need considerable quantities of cooling water for this purpose. Table F1 shows the amounts, source and destination of cooling water used by the three power stations near Newcastle. When operating at full capacity, the three stations require a total of some 210 m$^3$/s of cooling water. The maximum temperature increase in the cooling water at these three stations is limited to 10°C.

The possible effects of temperature increases are discussed in Section 15 of Appendix C. Other detrimental effects of the operation of power stations include:

- the death of fish which are drawn into the water intakes (SPCC, 1990); and
- air emissions from the burning of coal, which may lead to deposition of pollutants such as heavy metals in lake sediments (Batley, 1991).

<table>
<thead>
<tr>
<th>Station</th>
<th>Commencement</th>
<th>Capacity (MW)</th>
<th>Supply</th>
<th>Return</th>
<th>m$^3$/s</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vales Point A</td>
<td>1963</td>
<td>650</td>
<td>L. Macquarie</td>
<td>L. Macquarie</td>
<td>20</td>
</tr>
<tr>
<td>Vales Point B</td>
<td>1978</td>
<td>1320</td>
<td>L. Macquarie</td>
<td>L. Macquarie</td>
<td>42</td>
</tr>
<tr>
<td>Munmorah</td>
<td>1970</td>
<td>1200</td>
<td>L. Munmorah</td>
<td>L. Budgewoi</td>
<td>64</td>
</tr>
<tr>
<td>Eraring</td>
<td>1982</td>
<td>2640</td>
<td>L. Macquarie</td>
<td>L. Macquarie</td>
<td>84</td>
</tr>
<tr>
<td>Total</td>
<td>-</td>
<td>5810</td>
<td>-</td>
<td>-</td>
<td>210</td>
</tr>
</tbody>
</table>

Source: ELCOM
Flood Mitigation Works

In the past, a variety of flood mitigation works were constructed along estuaries to protect agricultural and urban areas from freshwater and coastal flooding. Such works included levees, drains and floodgates, together with the clearing and lining of stream channels to facilitate the passage of flood waters. These works can have a number of adverse impacts on estuarine habitats.

Creek, river and channel improvements aimed at facilitating the flow of floodwaters, quite apart from destroying habitat, can lead to erosion problems and downstream siltation.

Perhaps the most critical effect of flood mitigation works is the loss of wetland areas. In the past, many agricultural areas on floodplains were won by draining wetlands and restricting saltwater inflows to tidal creeks. In addition, levee banks were constructed to exclude floodwaters. All of these activities resulted in the loss of wetland areas or in markedly altered wetland regimes because of reduced replenishment by floodwaters. In addition, the loss of tidal storage led to a reduction in tidal-prism with its accompanying detrimental effects of increased siltation and exacerbation of water quality problems.

The construction of tidal barriers, such as weirs and floodgates, eventually converts upstream reaches from a brackish to a freshwater environment. In addition, these barriers impede or prevent the movement of fish and prawns and can lead to prolific weed growth upstream of the barriers. This weed growth is caused by nutrient buildup in the largely stagnant waters upstream of the barrier and may require the use of herbicides for control.

Some floodgates are designed to store floodwaters for release after main channel water flood levels have fallen. Although such gates can be left open to allow tidal flushing in non-flood times, this is generally not done. Gates tend to be kept permanently closed and are only opened when a release of water is to be made. Any residual water trapped in upstream flood channels tends to become stagnant and polluted by organic matter, with accompanying low levels of dissolved oxygen. Such releases consist of a concentrated slug of poor quality water that persists for a short period of time before being diluted by the receiving waters. Nevertheless, in a number of cases, such releases have caused disease and death to downstream fish and other aquatic organisms.

These days, the potential adverse impacts of flood mitigation works are clearly recognised. It is unlikely that significant new areas of biologically significant wetlands will be drained for agricultural or other purposes. The appropriate design of new works can preserve existing wetland areas whilst providing flood protection. Where possible, the sympathetic operation of existing works can reduce their detrimental effects.

Pest Control

Mosquitoes, midges and other insects are an irritation to nearby human populations. At times they can pose a health hazard, e.g. Ross River Fever, which is caused by an arbovirus carried by mosquitoes whose numbers can increase to epidemic proportions in stagnant accumulations of brackish water.

Insects breed in the wetland areas, saltmarshes and tidal fringes of an estuary and are an important component of a healthy and balanced estuarine ecosystem. Often there is pressure on the local council to eliminate or reduce insect nuisance by filling or draining breeding areas or by use of pesticides. All of these activities have adverse effects on the estuarine environment. Some pesticides can decimate estuarine organisms, e.g. 'Temephos' (also known as 'ABATE'), which is used to control biting midges, is toxic to crustacea, has killed large numbers of waders in Western Australia (RAOU, 1984), and has affected waterfowl in New South Wales (Rathore, 1981).

The management of insect populations in important or sensitive estuarine areas such as wetlands and saltmarshes should be a compromise between the expectations of the community and the requirements of the ecosystem.

3 WATER QUALITY CHANGES

Estuaries serve as corridors for the transit of dissolved and suspended materials from the land to the sea. Many activities in upstream
catchment areas can lead to the pollution of estuarine waters, thereby degrading the resource, habitat and amenity values of an estuary. As a consequence, oyster beds may be lost; oysters contaminated and rendered unfit for human consumption; or bathing may be prohibited because of high bacterial levels.

Pollutants can enter the estuary as point source discharges, such as sewage effluent, or as diffuse source pollutants, such as urban stormwater runoff. Common pollutants of concern to estuarine waters include toxic chemicals, suspended solids, nutrients, microbial contamination, oils, etc. (see Appendix D for details).

Point Source Pollution

Point source pollution can originate from sewage treatment works, abattoirs, sugar mills, dairy factories, dredging activities, sand and gravel extraction, gravel washing plants, land reclamation, canal estates, marinas, waterfront developments and effluent discharges from industrial operations. Oil spills are another hazardous point source of pollution. The adverse effects of point source pollution on water quality depend on the nature of the pollutant, its volume, concentration and frequency of discharge (i.e. the pollutant load), and the assimilative capacity of the estuary.

Diffuse Source Pollution

Diffuse pollution, which can be both urban and rural in nature, arises from many diverse land-use activities. Urban developments expose soil to erosion and create impermeable surfaces, such as pavements, roads and roofs, which increase the speed and volume of stormwater runoff. Materials of concern contained in road runoff include oil, heavy metals, fuels and chemicals. Further, road accidents involving trucks transporting chemicals can lead to the spill of pollutants into nearby waterways. Stormwater runoff from urban areas contains various pollutants such as litter (plastic, paper, cans), animal wastes, vegetation (grass, clippings, leaves), oil and grease, car oils, waxes, metals (filings, rust, petrol additives), bacteria and viruses, nutrients (nitrogen and phosphorus), pesticides, noxious weeds and seeds, and sediment.

Rural runoff is increased by the clearing of vegetation from catchments and the banks of waterways, road making and the tilling of soil, which together contribute substantially to the silt loads of waterways. The use of fire in agricultural and forestry practices frequently results in massive losses of topsoil following rain, with a resultant rapid siltation of receiving waters. Rural runoff can contain agricultural chemicals (nutrients, herbicides and pesticides).

Possibly the most important source of diffuse pollution of concern to estuarine water quality is stormwater runoff from urban areas. During urban construction activities, stormwater can contain very high sediment loads. When the catchment is fully developed, sediment loads become less of a problem, with trash, nutrients and bacteria assuming increasing importance. Nutrients originate from gardens and other areas where fertilisers are used. Bacteria are collected from droppings by pets and the local bird and animal populations. An additional source of both nutrients and bacteria is sewer overflows, which may originate from septic tanks or from under capacity or broken sewer lines.

4 CLIMATE CHANGE

Finally, consider the likely impact of the 'Greenhouse Effect' on estuarine habitats and ecosystems. The 'Greenhouse Effect' refers to the postulated warming of the earth caused by increasing concentrations of carbon dioxide and other gases in the atmosphere. A brief synopsis of the Greenhouse Effect is given in the Coastline Management Manual (NSW, 1990).

Although still uncertain, the current generally held scientific consensus is that such changes could result in a global warming of 1.5°C to 4.5°C over the next 30 to 50 years. Such a warming could lead to a number of changes in climate, weather and sea levels. Currently, it is not possible to predict or even infer these changes with any degree of certainty. However, it is believed that any 'greenhouse' warming will not be uniform over the earth's surface or throughout the year. Warming is expected to be greater at higher latitudes and in winter time. In Australia, it is postulated that surface temperatures may increase by 2°C in the tropics and by 3°C to 4°C in southern latitudes.
Temperature increases of these amounts may have a significant effect on extreme weather events. For example, tropical cyclones are likely to be able to penetrate a greater distance south along the New South Wales coastline.

Various estimates have been made of the sea level rise which may be caused by 'greenhouse' warming. The 'most likely results' indicate a global rise in sea level of between 0.3 m and 0.7 m over the next 100 years (NSW, 1990). More recent studies favour the lower limits of this range.

What impacts will these weather and water level changes have on the habitat and ecosystems of New South Wales estuaries? There are a number of obvious physical consequences. The saltwater/freshwater interface will move further inland; existing wetlands will be flooded more regularly and to a greater depth (they will become wetland lagoons); new wetlands will develop in low lying areas along estuaries.

These changes to water and salinity levels will cause changes to the distribution of aquatic and terrestrial flora and fauna along the estuary, with existing habitats and ecosystems tending to migrate inland.

If it gets warmer and wetter, insect populations can be expected to increase. Thus, an associated adverse effect may be increased levels of insect nuisance and health-related problems, such as Ross River Fever.

5 REFERENCES


APPENDIX G ESTUARINE MONITORING AND PROCESS MODELS

1 Introduction
2 Types of Models
3 Model Calibration and Verification
4 Hydraulic Models
5 Water Quality Models
6 Sediment Transport Models
7 Biological Models
8 Monitoring

1 INTRODUCTION

Many common land-use activities have adverse impacts on estuarine habitats, ecosystems and amenity. For example, the discharge of sewage effluent reduces bathing amenity at nearby beaches and promotes the growth of algae, which may smother nearby seagrass beds. Further, many common land-use activities lead to significant changes in the hydraulic, water quality and sediment transport processes of an estuary, e.g. sand and gravel extraction, which in turn, can adversely affect estuarine habitats, ecosystems and amenity.

In order to assess the likely impact of land-use changes on the estuarine environment, or the likely effectiveness of proposed remedial measures, it is necessary to 'simulate' or 'model' the underlying hydraulic, water quality, sediment transport and biological processes.

Use of these models is fundamental to the better management of estuaries. By treating the estuary as a 'system' and incorporating major process interactions, the models provide a means of assessing the overall response of the estuary to proposed changes. However, it must be borne in mind that these models are approximations of the real world and results obtained from them are indicative, rather than exact.

Monitoring is an integral part of both estuary management in general and the use of estuary process models in particular. Monitoring is necessary to measure the effectiveness of management measures; it is necessary to calibrate and verify process models, and so ensure reliable predictions of the impact of land-use changes.

This Appendix briefly describes the development and application of various types of estuary process models and the need for and importance of estuarine monitoring programs.

2 TYPES OF MODELS

Numerical Models

Numerical models are 'computer models' in which the underlying processes are represented by mathematical equations which are solved by computer.

The hydraulic, water quality and sediment transport behaviours of an estuary are well suited to numerical modelling. The numerical modelling of biological estuarine processes is less certain because of the complex and often uncertain nature of interactions between biological variables on the one hand (population types and numbers, habitat) and the hydraulic, water quality and sediment transport response of an estuary on the other.

In developing numerical models, simplifications are necessary, first, in developing the theoretical equations, and second, in their solution. Numerical models tend to be 'data hungry'. They require large amounts of various types of data, such as bathymetric and topographic survey data, sediment data, salinity and other water quality data. Some of these data may be available; specific monitoring programs will be required to collect others (see Section 3).
Physical Models

A physical model is merely a scaled-down model of the actual estuary. To obtain reliable results, such models must be constructed to dimensions and from materials that are in accordance with strict ‘scaling laws’. One advantage of a physical model is that it provides a direct visual indication of estuarine behaviour to onlookers. As such, observers can appreciate the impact of changes on estuarine behaviour. However, physical models are large and expensive to construct, and because of their size, may have to be destroyed after serving their immediate purpose. (A numerical model can be kept ‘on file’ in the computer for future use).

Prototype Models

The ‘best’ model to investigate the impact of the land-use changes on the estuarine environment is the estuary itself, i.e. a ‘prototype’ or full scale model. Unlike numerical and physical models, a prototype model does not suffer from the simplification or omission of processes; all estuarine processes are ‘automatically’ included together with their interactions.

Given all these advantages, why are prototype models not used exclusively? There are two important reasons. First, some land-use changes of interest may be expensive to effect, even more expensive to reverse, and possibly irreversible if they prove to have unacceptable consequences. A major sand and gravel extraction operation is a case in point. Second, many of the adverse effects that accompany land-use changes are long-term in nature, i.e. they develop slowly. Again, by the time the prototype model indicates the adverse consequences, it may prove unacceptably expensive or impossible to undo these changes.

Numerical and physical models do not suffer from these shortcomings. They are based on the simulation of changes rather than the actual measurement of them. By representing processes mathematically, a numerical model allows the time response of the estuary to be speeded up.

Nonetheless, prototype models are very useful for investigating limited effects. This is especially true with respect to biological response. A limited area of the estuary can often be isolated in which the effects of some past or on-going change can be monitored. Another example is in refining the operation of management works already in place, such as flood gates. The response of upstream biota to the tidal ingress and egress of water associated with different patterns of gate operation can readily be investigated.

3 MODEL CALIBRATION AND VERIFICATION

Important elements in the development of a reliable model are its calibration and verification. In the calibration process, various parameters of the model are adjusted to ensure a ‘good fit’ between measured and simulated results for ‘calibration events’ of interest. The adequacy of the model is then confirmed in the verification process by checking that it satisfactorily simulates the results of an independent event not used for model calibration.

It is only after a model has been calibrated and verified that it can be used with some confidence to predict the effects of proposed land-use changes on the processes it simulates. However, it must be remembered that a model is an approximation. Even when calibrated and verified, model predictions are indicative rather than exact and need to be interpreted accordingly.

The calibration and verification processes are based on a comparison between measured data and simulated results. The collection of calibration data as part of estuarine monitoring programs is discussed in Section 8 of this Appendix.

Model calibration and verification is essential for numerical and physical models. The need is somewhat different for prototype models. A prototype model automatically includes all processes of interest and their interactions. Essentially, the model is always calibrated. However, in using prototype models, care must be taken to ensure that results are measured under the conditions of interest and are not distorted by unforeseen extraneous factors.

4 HYDRAULIC MODELS

An hydraulic model simulates water levels and discharges along an estuary for varying
freshwater inflows and tidal conditions.

Apart from the need for this information in its own right, hydraulic models provide input data for water quality and sediment transport models. Water quality models require first, velocity and water level data to simulate tidally varying advective and dispersive transport, and second, discharges to evaluate the initial dilution of inflowing pollutants. Sediment transport models require velocity and water level data to simulate sediment transport (see Sections 9 and 10 of Appendix B).

Thus, an hydraulic model provides a foundation for water quality and sediment transport simulation.

In terms of spatial representation, hydraulic models can be either one-dimensional, two-dimensional or three-dimensional. One-dimensional models involve the greatest degree of spatial approximation, but are appropriate for long, relatively narrow estuaries. The estuary is represented as a series of longitudinal reaches; lateral and vertical variations of velocity and water level are not recognised. Two-dimensional models are either of ‘plan’ or ‘elevation’ type. ‘Plan’ models take into account velocity and water level variations in the longitudinal and lateral directions and are used for wide bays. ‘Elevation’ models generally take into account variations in the longitudinal and vertical directions and are used when the vertical structure of the flow is of interest, e.g. to study density driven salinity currents. Finally, three-dimensional models, which are the most complex of all, admit velocity and water level variations in all three directions.

Needless to say, the price paid for the incorporation of ‘extra’ dimensions is in increased model complexity and developmental costs. In addition, the full calibration of such models may involve a comprehensive and expensive monitoring program to gather the required data.

Because of their underlying technical complexity and data requirements, the development of numerical models of estuarine processes is a highly specialised field.

5 WATER QUALITY MODELS

Water quality models simulate the concentration of dissolved or suspended substances of interest throughout the estuary. The development of such models requires a sound and basic knowledge of the various processes that affect the water quality parameters of interest.

Water quality models are typically numerical rather than physical. Many water quality models are one-dimensional in nature. However, some are two-dimensional, and a few are three-dimensional.

The dissolved material may be either a conservative or a non-conservative substance. An example of a conservative substance is salinity. Non-conservative substances pass into and out of the water mass through various source-sink processes of a physical, chemical or biological nature. Nutrients are an example of a non-conservative substance. Estuarine nutrient concentrations are influenced by adsorption onto sediment particles, by biological uptake and release and chemical effects, as well as the usual processes of advective and dispersive transport. Note that all source-sink processes affecting the parameter of interest have to be described mathematically before they can be incorporated in a numerical model. The highly complex nature of these processes, together with the often uncertain and highly variable nature of interactions between processes, leads to additional simplifications being incorporated in water quality models.

With respect to their time scales, numerical water quality models are of two types: ‘tidally varying’ and ‘tidally averaged’.

Tidally varying models simulate water quality variations along the estuary throughout a tide cycle, i.e. such models incorporate advection on the ebb and flood tides. Tidally varying models are used to estimate short-term impacts on water quality behaviour, e.g. the effects of a new sewage effluent discharge on upstream water quality. Typically, such models are used to simulate estuarine behaviour for a period of several days to several weeks.

Tidally averaged models simulate water quality at a nominated time of the tidal cycle, e.g. at high water slack. These models are used to simulate gradual changes to estuarine water quality behaviour over a long period of months or possibly years. Over this horizon, individual
fluctuations during a tidal cycle are not of significance.

6 SEDIMENT TRANSPORT MODELS

Sediment transport models simulate the movement of sediment along an estuary under the influence of freshwater and tidal flows. These models can be used to identify locations of likely scour and deposition and predict the resultant long-term changes to estuary bathymetry.

The two sediment transport processes of interest are suspended load and bed load (see Section 10, Appendix B). One and two-dimensional numerical models of suspended and bed load transport are available; physical models are often used to investigate bed load transport.

Sediment transport models are of two types: event and long-term. Tidal behaviour is the dominant mechanism in event models, which are used to investigate the short-term consequences (i.e. over several months to several years) of some particular event, such as sand and gravel extraction at a particular location. Long-term models are used to investigate sediment behaviour over periods of several decades. In these circumstances, freshwater discharges, especially during flood times, have a marked influence on sediment transport, erosion and deposition within the estuary.

The calibration of sediment transport models is less certain than for hydraulic and water quality models. Sediment transport processes occur at a ‘slower’ rate than hydraulic or water quality processes. Sediment transport data for calibration purposes are more difficult and more expensive to gather.

7 BIOLOGICAL MODELS

Biological and ecological models are of limited potential for use in New South Wales estuaries, at least in the short-term. At present, a detailed understanding of the ecological requirements of most species of interest is not yet available, i.e. these requirements cannot yet be represented mathematically with any degree of certainty.

Several different types of models that have been developed and applied overseas may be of use to estuary management in New South Wales in the future:

- Process models: these are used for understanding ecosystem relationships and can be used to investigate the effects of either natural or human changes on an ecosystem.

- Stock management models: fisheries agencies commonly make use of fish stock management models to predict and assess the effects of harvesting regimes on fish numbers. These models are generally complex and currently employed only for the management of single species.

- Habitat models: these are used to assess changes to the distribution and abundance of organisms caused by habitat changes. Such models have been used to assess, amongst other things, the effects of estuary entrance modification works on fish larvae recruitment to estuaries and the effects of power station cooling water intakes on the entrainment of juvenile fish.

- Contaminant models: a great deal of work has been done to model the behaviour of specific chemical contaminant in aquatic environments, particularly in relation to bioaccumulation. In the United States, these models have been used to assist decision-making on dredging and spoil disposal, and in the setting of sediment quality criteria.

8 MONITORING

Monitoring is a critical component of both estuary management in general and estuary process modelling in particular. When used for management purposes, monitoring provides an on-going picture of the health and response of the estuary, e.g. water quality levels, species and numbers of fauna, area and productivity of seagrass beds, etc. To ensure reliability, estuary process models need to be calibrated and verified against measured data, e.g. water levels and discharges, salinity levels, etc.
Monitoring Programs

Estuarine monitoring programs can be involved and quite expensive. In terms of costs and difficulties, the measurement of physical parameters is easy and relatively inexpensive, whereas the measurement of biological parameters is difficult, expensive and time consuming. The difficulty and cost of monitoring chemical parameters is intermediate between these two.

To obtain the best value from estuarine monitoring programs, monitoring objectives have to be carefully defined before monitoring operations commence and the monitoring program needs to be specifically shaped to meet these objectives. Further, monitoring results need to be continuously reviewed during the program to facilitate program modification because of unexpected findings.

Typical physical parameters of an estuarine monitoring program include freshwater inflows, tidal water levels and bottom contours. These data can be collected automatically by electronic instruments. Telephone or satellite telemetry can be used to transport these data back to the office.

Chemical parameters of interest to estuarine monitoring programs include various water quality parameters such as salinity levels, dissolved oxygen, etc. (see Appendix C). Whilst a few chemical parameters can be measured satisfactorily in-situ by automatic electronic recorders (e.g. salinity), most water quality monitoring involves the collection of water samples, either by hand or automatically, followed by analysis back in the laboratory.

Basic water quality parameters that are generally measured as part of an estuarine monitoring program include salinity, turbidity, dissolved oxygen, nitrate, phosphates and toxic materials. These parameters allow an overall picture of the mixing and eutrophic status of the estuary to be established and possible threats to estuarine ecosystems from eutrophication and toxic substances to be inferred.

The monitoring of biological parameters is both difficult and expensive. Biological surveys tend to be both labour and time-intensive: surveys have to be designed to enable assessment of the multiple factors that determine population numbers or behaviour (stratified sampling); fauna may shift from habitat to habitat throughout the year and from year to year; animals have to be located and possibly trapped and measured; specimens may require detailed analysis in the laboratory.

To obtain meaningful results, estuarine monitoring programs generally need to be quite measurement intensive. Physical parameters fluctuate throughout the day (tidal effects) and throughout the year (freshwater inflows); biological parameters fluctuate even more so in response to seasonality, different stages of life-cycles, randomness, etc.

To provide a meaningful portrait of estuarine behaviour, monitoring programs must first define 'natural' variations and then isolate trends caused by adverse effects. Three to five years of measurements or more may be required to define natural variations.

Baseline Monitoring

The purpose of baseline monitoring is to provide a yardstick against which to measure the impact of land-use changes on the estuarine environment. Such a program needs to be put in place for New South Wales estuaries. As noted above, it may take 3-5 years of measurements to define the natural variation of some parameters. The parameters measured, the density of monitoring sites and the intensity of measurement will all be estuary and problem specific.

Event Monitoring

At times, it will be necessary to monitor the impact of a specific local land-use change on the estuarine environment, e.g. sand and gravel extraction. This may need to be done to confirm the effectiveness of control measures associated with the event (e.g. sill curtains to control the escape of suspended solids); to confirm model predictions, to confirm the effectiveness of an estuarine maintenance program, or it may be done for reasons of scientific interest.

In the case of event monitoring, the monitoring program would involve the measurement of
pre-event parameter levels, levels during the event itself, and post-event parameter levels. Again, objectives need to be defined and monitoring programs carefully planned if data are to be obtained effectively.
APPENDIX H TOTAL CATCHMENT MANAGEMENT

1 Introduction
2 What is Total Catchment Management?
3 The Need for Catchment Management
4 Principles of Estuary and Catchment Management
5 Catchment Management in New South Wales

1 INTRODUCTION

An estuary acts as a funnel; it gathers surface runoff from upstream catchment areas and delivers it to coastal waters. Consequently, estuarine habitats and ecosystems (and their coastal counterparts) are exposed to any detrimental changes in the volume and quality of surface runoff, i.e. to any detrimental effects of upstream land-use activities.

European settlement, which commenced some 200 years ago, has been characterised by the widespread clearing of vast areas of native vegetation and the imposition of a wide range of different land-uses, e.g. forestry, agriculture, grazing, urban development, transport, fishing, mining, etc. In many cases the new land-uses were inappropriate to natural conditions.

The widespread clearing of native vegetation has adversely affected the behaviour and the ecosystems of all coastal catchments in New South Wales. Too much water is running off the land too quickly. Moreover, this surface runoff carries with it a high sediment load and a wide variety of nutrients, toxic materials and other pollutants, all of which are delivered into estuaries and nearby coastal waters. Much of the widespread deterioration in estuarine habitats and ecosystems that is characteristic of many New South Wales estuaries has been caused by the adverse effects of land-use activities in upstream catchment areas.

To ameliorate these effects, it is necessary to recognise the interactions that exist between upstream land-use activities and the land, water, vegetation, ecosystems and other natural resources of the catchment and its estuary. It is also necessary to recognise that a wide variety of people use the catchment and its estuary for many different purposes, be they individual landholders, private companies or public organisations.

A lack of coordination, awareness and liaison by those responsible for land use management, combined with the existence of artificial administrative boundaries, has exacerbated estuarine problems resulting from poor land use management practices in the past. However, in a more general sense, it must be recognised that in many cases, past land management activities have been inappropriate for the environment, notwithstanding the fact that at any point in time managers have used the 'latest technology and resources'. With hindsight, it is easy to say that past land management practices have 'ruined the environment'. In fact, that well may be said of us in 100 years time. If we are to achieve stability and quality in our land and water systems, it is clear that a coordinated approach to land management is needed. Further, whenever possible, a conservative approach to land management should be adopted embracing limited and acceptable changes to natural systems.

Catchment Management in New South Wales has recently been formalised by the Catchment Management Act, 1989, which established procedures for the implementation of catchment management through Catchment Management Committees and Catchment Management Trusts. Total Catchment Management (TCM) provides a philosophy and administrative framework to achieve better land-use management within a catchment. This Appendix describes how TCM can be applied to ameliorate estuarine problems in New South Wales.

2 WHAT IS TOTAL CATCHMENT MANAGEMENT?

Total Catchment Management refers to the co-ordinated and balanced use of the natural resources within a water catchment area.
These resources comprise land, water, vegetation, mineral deposits, ecosystems, etc.

A water catchment provides a natural planning unit for resource management. The boundaries and characteristic pattern of water movement within a catchment are readily identified and provide a logical basis for assessing the interaction between land-use activities and the surface water and groundwater systems of the catchment.

The objectives of TCM, as outlined in the Catchment Management Act 1989, are to ensure that natural resources are managed by:

- coordinating policies, programs and activities as they relate to catchment management;
- achieving active community participation in natural resources management;
- identifying and rectifying natural resources degradation;
- promoting the sustainable use of natural resources; and
- providing stable and productive soil, high quality water and protective and productive vegetation cover within each of the State's water catchments.

A fundamental element of TCM is the need for active community participation. Although possibly minor in nature, the adverse effects caused by the many and varied individual landholders in a catchment are cumulative. To successfully manage the many sources of the resultant problem will require actions by the community at large.

3 THE NEED FOR CATCHMENT MANAGEMENT

Four distinct episodes characterised by differing patterns and perceptions of catchment land-use can be identified in Australia's history. These are briefly described because they have led to the present degraded state of New South Wales estuaries.

Pre-European

Land-use in the pre-European period was characterised by widespread gathering and hunting on a limited scale by a nomadic aboriginal society. Major adverse effects on catchments were minimal. The most significant land-use practice of this time was the use of frequent low intensity burning to encourage new grass and attract game. This led to the development of open parklike forests and woodlands, as was noted by early explorers.

The coastal catchments of the pre-European period were relatively free of erosion; runoff was largely silt-free; and rivers were deep and ran for long periods. But even in the natural state, some river erosion and deposition occurred, particularly during floods and after fires.

The estuaries of this time were characterised by generally low levels of sediment inflow and water of high clarity. Consequently, the estuary bed was relatively stable and supported large areas of seagrass and benthic fauna such as oysters. Large areas of fresh to brackish wetlands were connected to the estuary at highwater and during floods, providing extensive nursery areas for fish and crustacea.

At this time, the ocean entrances to major estuaries were permanently open to tidal flows, but the configuration of the entrances fluctuated in response to sediment removal during floods and sediment redeposition during periods of constructive ocean swell and tidal conditions. The dynamic and extensive sandy shoals and channels of ocean entrances provided ideal spawning habitat for many species of estuary dependent fish and crustacea.

The ocean entrances of minor estuaries, lagoons and lakes would often close under constructive ocean swell conditions, with the resulting beach berm excluding tidal flows and damming freshwater runoff. Fresh to brackish water conditions would prevail for extended periods, with high water levels linking the surrounding wetlands to lagoons and lakes, thereby increasing the habitat and shelter available to fish, crustacea and birds. Major flood and storm conditions would lead to the breaching of the beach berm, the purging of much of the accumulated sand from the entrance, and the reimposition of tidal conditions within the estuary, which again persisted for long periods until the entrance was once more closed.
Needless to say, under these natural conditions to which the Australian flora and fauna had adapted, wildlife was prolific. Evidence of this comes from the widespread midden deposits along the New South Wales coast and from historical accounts. Perhaps one of the most graphic reports was the diary of Bass and Flinders, who, for three consecutive days on an inshore voyage down the South Coast of New South Wales, could not accurately take their noon navigational sunsight because of flocks of migratory waterfowl.

Initial Catchment and Estuary Degradation

With European settlement, a wide range of new land uses were imposed on the natural environment: forestry, agriculture, grazing, urban development, transport and fishing. These land uses led to many changes in the natural environment. Excessive clearing and inappropriate land management led to a rapid deterioration in catchment conditions, extensive soil erosion, and increased runoff of silt laden water. Eroded and silt choked rivers, more prone to sharp, short peak discharges, resulted.

By the late 1870’s, concern emerged about the widespread destruction of forests for agricultural purposes. In 1882, the first timber reserves were proclaimed in an attempt to stem the ‘loss’ of forest areas.

The increased silt load of coastal draining rivers had a number of adverse effects on estuarine habitat and ecosystems: seagrass beds were limited to shallow water because of a reduction in light penetration; seagrass beds, bottom oysters and benthic fauna were smothered by silt; extensive mudflats developed; sandspits were replaced by mudflats, which were colonised by increased areas of mangroves; shoaling occurred in many estuarine reaches; the species balance was altered in response to habitat changes, including the proliferation of pests such as mudworm. The more rapid onset of flooding and higher peak discharges increased foreshore erosion, altered the interplay of the freshwater and coastal processes that affect the configuration of estuary entrances, and adversely affected the breeding and movement habits of fish, crustacea and birds.

Large areas of fresh to brackish wetlands were isolated from their parent estuaries by flood mitigation works or were drained to provide land for agriculture, urban development, tourism, port facilities, roads, railways, etc. Dams, together with bridges and causeways for roads and rail traffic, restricted tidal flows and isolated sections of estuaries, providing barriers not only to water flows but to the movement of fish and crustacea.

During the period of European settlement, the ocean entrances of major estuaries were stabilised by training walls to improve navigability. This often led to a reduced volume of tidal interchange, markedly differing patterns of sand shoals, mudflats and mangroves upstream of the training walls, and the loss of the nearshore spawning grounds for estuary dependent species. Dredging and trawling activities within estuaries also wrought changes to the estuarine environment.

Within those catchments having smaller estuaries and ephemeral entrance lagoons, the intensity of land use and changes to the natural environment have often been less. Such catchments have smaller floodplains and hence are of less value for agricultural purposes. Nevertheless, human activity in general and urban development in particular, has altered these catchments, the quality of their waters and the cycle of entrance opening and entrance closing.

These days, many ephemeral lagoons are artificially opened to reduce the likelihood of flooding urban lands and services inappropriately located within their catchments. This may cause severe mortality in the populations of wetland dependent species of fish and crustacea.

Continued Development with Increasing Controls

Prior to the Second World War, there was a widespread intensification of agricultural practice in Australia; horses were replaced by tractors. It was during this time that Europeans first started to come to terms with the characteristics of Australia’s climate, soils and native vegetation. A rudimentary system of natural resource management began to develop. However, catchment degradation caused by soil erosion remained uncontrolled and became increasingly self-evident. In 1936, the New South Wales and Federal Governments called a national conference on
this issue, which led to the formation of the New South Wales Soil Conservation Service in 1938.

During the pre-World War II period, estuary degradation continued at a gradual, but probably accelerated pace.

The period following World War II was characterised by rapid economic expansion with an associated large demand for natural resources. This had a number of effects on land-use practices. There were marked changes in forestry practices. The rate of harvesting native forests exceeded the rate of regeneration; clear felling became a widespread harvesting technique; plantations of exotic conifers were established to meet the increasing demand for timber. Agriculture expanded for a variety of reasons: increased mechanisation; soldier-settlement projects; the release of marginal Crown lands for agricultural purposes. Pasture improvement practices became common, including the use of introduced grasses and the regular, widespread application of fertilisers. Many new water storages were constructed on waterways to meet urban water supply needs, so reducing the volume and variation of freshwater inflow to estuaries. Urban and industrial expansion continued. Wetlands were filled for industrial and housing sites and many creeks and rivers were constricted by bridges and causeways.

The diversity and scale of estuarine problems increased dramatically in the post-World War II period, driven by the unrestrained quest for economic development. The quality of water in many rivers, estuaries and coastal areas was severely affected by urban and industrial discharges, with consequent adverse effects on estuarine habitat and ecosystems. Increasing salinity levels in many inland streams emerged as a widespread problem. During this period many organisations and individuals became concerned about environmental degradation, but the public mood favoured expansion and growth.

Nevertheless, over time and with increasing awareness of the need for catchment management, various activities were being better planned and executed. This in itself sometimes caused further changes. For example, the gradual control of soil erosion meant the reduction in silt loads entering rivers. Silt free water has a greater capacity to transport bedload sediments. Consequently, while more stable catchments were being established, stream bed configuration was still in a state of flux, often leading to streambank erosion. The extent and composition of the biotic components of our estuaries also varied in response to these changes.

Public Awareness and Cooperation: Establishing Sustainable Land and Water Use

The period since 1970 has been characterised by widespread public concern and awareness of environmental issues. Increased pressure on politicians and decision-makers has led to the introduction of comprehensive environmental legislation and policies aimed at environment protection, resource conservation and sustainable development. The Clean Waters Act, 1970, The Catchment Management Act, 1989, and the Estuary Management Policy are but some of these initiatives in New South Wales.

Thus, after 200 years of largely untrammelled land-use, it is now appreciated that all sectors of society need to cooperate in the management of natural resources.

The aim of management programs is to preserve and enhance the stability and productivity of catchments, to maintain and improve the yield and quality of surface and groundwaters, to provide a protective and productive vegetative cover, and to ensure that estuaries are productive waterbodies supporting diverse uses.

Degraded areas will require rehabilitation. Wherever possible, lands and waterways should be used within their inherent capabilities, thereby retaining options for future use.

Activities for the rehabilitation of estuaries and lagoons fall into two broad groups; continued (and improved) catchment management, and remedial works within the rivers, estuaries and lagoons themselves. Remedial works include dredging, foreshore stabilisation and revegetation, wetland re-establishment, modifications to training walls, bridges and causeways, and the multi-purpose management of dams, flood mitigation structures and other barriers to flow.
4 PRINCIPLES OF ESTUARY AND CATCHMENT MANAGEMENT

The estuary and catchment problems of today have developed over two centuries. They cannot be corrected overnight. A persistent program of work and effort extending for many years will be required.

When planning for such a long term and continuous program, it is essential that objectives be carefully thought through and are soundly based. Without clear objectives, direction will eventually be lost and work will become ineffective.

Any program for achieving better estuaries and catchments should have regard to the following broad principles.

- Land and water management are inseparable. Thus plans and programs must be developed on a whole catchment, whole river basis, of which the estuary is but one part.

- Land and water management strategies should be based on preventative maintenance, rather than disaster response. The aims should be to achieve stable catchments, enhance estuaries and also to achieve a balance between the competing demands of users throughout the catchment.

- In the management of public lands, all public authorities have the duty to put their own houses in order. This applies to the operation of all community services and facilities which affect estuaries, such as road and town drainage, water supply, logging and major development projects. Public authorities should aim for stable well managed systems which will protect and certainly not damage rivers, estuaries and their environments.

- With privately owned lands, some of the problems are historic in nature. They began a long time ago and are not the fault of the present generation. Farmers should be assisted to achieve land stability on their properties through cooperative farm advisory programs. These will involve the development of joint undertakings as a partnership between Government and farmers, with shared financial responsibilities under programs such as Landcare.

- Protection and enhancement of the natural environment are vital parts of all catchment management programs, both within specific nature conservation reserves and as general components of all land-uses.

- Funding of management programs should be shared between the Government and the local community. Programs should be on a scale which enables the community to see a steady improvement taking place. Obviously it will not be possible to commence work on the whole State simultaneously. Priority catchments and priority works within a catchment need to be identified.

- Wherever possible, the affected community should develop and initiate management decisions concerning rivers, estuaries and catchments. To balance the many different interests and values, as wide as possible a cross-section of the catchment community needs to be informed about and involved in these decision-making processes. Control of catchment management programs must be local, but operate within a framework of agreed standards and priorities which are consistent across the state. Government Agencies can assist in providing specialist advice and assistance in the design and implementation of catchment management programs.

- An integrated approach to management is vital if all the different works in the catchment are to contribute towards common objectives. Mechanisms to achieve catchment co-ordination are required, as described in the following section.

5 CATCHMENT MANAGEMENT IN NEW SOUTH WALES

Catchment management is the coordinated and sustainable use of land, water, vegetation and other natural resources on a water catchment basis to achieve a balance between resource utilisation on the one hand and nature conservation on the other.

The Total Catchment Management (TCM) process, through the coordination of management measures and mechanisms, aims to minimise the adverse impacts of land-use activities on the catchment and land-users.
Three components comprise this integrated management approach:

- the philosophy of natural resources management on a catchment basis;
- a framework that fosters the coordination and integration of management activities; and
- programs or activities undertaken at Federal, State, regional or local level to implement resource management.

Catchment Management - The Process

Within New South Wales, the TCM is based on active community participation, i.e. it is a 'bottom-up' process. TCM will only succeed if the community shares the vision and the responsibility for understanding natural resources management issues, developing action plans and implementing programs. The underlying theme of the TCM in New South Wales is that of community and government working together to address natural resources management issues. The Catchment Management Act, 1989, provides a structure that encourages and embodies this theme. There are three key levels of coordination established under the Act:

- Catchment Management Committees: These provide oversight and coordination at a regional or valley-wide level, e.g. Clarence Catchment Management Committee.
- Catchment Management Trusts: These are formed to address and take action on catchment issues and can raise revenue through applying a catchment levy, e.g. Hunter Valley Catchment Management Trust.
- State Catchment Management Coordinating Committee: This committee provides the focus and oversight for TCM in New South Wales.

There are community representatives on all three committees. The committee structure to support the TCM process is intended to be flexible; it is based on needs rather than hierarchy. The differing functions of each tier are detailed further within the Act.

Where does an Estuary Management Committee sit amongst these three tiers of catchment committees? In effect, the Estuary Management Committee is a component of a Catchment Management Committee or Trust. The Estuary Management Committee is concerned with problems in a specific area of the catchment, namely the estuary, but recognises the inter-relationship of these problems to activities elsewhere in the catchment. Estuarine problems will be amongst those issues addressed by Local Catchment Management Trusts and Catchment Management Committees. Activities and programs undertaken by TCM Committees and Trusts will have a bearing on environmental quality, health and amenity in estuaries. The Estuary Management Committee should include representatives from the relevant Catchment Management Committee or Trust.

Catchment Management - The Programs

It is the responsibility of the various Catchment Management Committees to identify, organise funding for and put in place appropriate remedial and conservation programs to enhance and protect natural resources. To identify objectives and to define an effective and coordinated suite of integrated programs to achieve these objectives may require detailed technical investigations and planning considerations. Such programs may include the following:

- action plans, such as Landcare and River Watch, developed and implemented by local community groups;
- coordinated administrative and technical support for action plans through specialist government agencies;
- community based awareness and education campaigns;
- monitoring, research and review of progress to date; and
- appropriate new or amended legislation to provide statutory backing to action plans.

Funding for TCM projects can be achieved in a number of ways which include:

- identifying and re-prioritising existing budgets in State and Local Government agencies, such as the Waterways program and revenue received from dredging royalties;
- Commonwealth funding schemes for natural resources management;
- obtaining State Government funding to address specific issues, such as the multiple use of flood mitigation barrages; and
- community funding through special levy, private contributions or community/Government joint projects, such as occurs in the case of Catchment Management Trusts.

Catchment Management - The Benefits

The success of catchment management will be judged by tangible improvement in the environmental quality of a catchment and its waterways. This improvement will be reflected in:

- improved water quality in terms of pollutant levels, and physical, chemical and biological attributes,
- increased productivity from the land, rivers and estuary, including a higher sustainable level of use by the community,
- effective vegetation cover on land, under water and within wetlands,
- successful flood management,
- maintenance and rehabilitation of ecological processes,
- greater community awareness of environmental issues within the catchment, and
- greater community involvement in natural resources management.

The 'health' of an estuary is a key indicator of TCM performance as it reflects the aggregate impact of man's activities on the catchment.

One important outcome of TCM should also be a heightened 'conservation ethic' to care for our land, water and other natural resources. It is expected that people will be impressed and motivated by seeing their neighbours and others doing something positive for natural resources management. Peer pressure can be a very powerful and motivating force.

TCM will have worked when it becomes socially unacceptable to degrade our natural resources. At that time, people's decisions will be aligned to sustainable productivity, and the many benefits of healthier, more productive and aesthetically pleasing catchments and estuaries will accrue to all Australians.
APPENDIX I  ADMINISTRATION OF CROWN LAND

1  INTRODUCTION

The Department of Conservation and Land Management (CLM), which incorporates the former Department of Lands, is responsible for administering the Crown Lands Act, 1989. This Act, which is the principle legislation dealing with Crown land in New South Wales, deals with the reservation or dedication of Crown land, the granting of leases or licences and the granting of easements over Crown land, and disposal of Crown land by way of sale or exchange. Land Assessment is a statutory requirement before Crown land is dealt with in these ways.

The majority of the intertidal and subtidal estuarine lands of New South Wales are Crown land (as well as the sea bed extending 3 nautical miles offshore). In some estuaries there is also a considerable amount of waterfront land in Crown ownership. Although estuarine Crown land does not include the waterbody itself, there are few activities on an estuarine waterway that are not dependent in some way on foreshore or subtidal land. Administration of Crown land is therefore of central importance to estuary management.

2  CROWN LAND MANAGEMENT

Legislation


Crown Land in New South Wales

The legal and functional units of Crown land in New South Wales consist of measured lots, reserves which are often defined by diagrams or descriptions, and remnant areas delineated by the boundaries of adjacent freehold lots and/or the banks of waterways. In the case of estuarine lands, a frequently used boundary is the mean high water mark.

Most Crown land units have been assigned to a particular use, whether by grant of lease or licenced tenure, by reservation for a public purpose, or by designation as a road within a Crown subdivision. In addition to the above uses, the same land often serves additional functions, such as open space, wildlife habitat, passive recreation areas and access to waterways.

Reserves

Crown land can be reserved or dedicated for specific purposes or simply reserved from sale, lease or licence. The definition of a 'reserve' under the Crown Lands Act, 1989, includes dedicated lands which are not strictly 'Crown land' but are administered in much the same way. The main difference is that dedications are more difficult to revoke than reservations.

The everyday management of Crown reserves is largely in the hands of incorporated trusts. These bodies are constituted under the Crown Lands Act, 1989, and are charged with the care, control and management of a nominated reserve or reserves. About 5000 trusts are managed by local councils. A further 1200 trusts are managed by trust boards composed of local citizens. Under the Local Government
Act 1913, local councils also have powers to manage any ‘public reserve’ (as defined in the Act) where no trust has been constituted. There are many hundreds of Crown reserves for the purpose of public recreation in this category.

Reserve trusts may, with the approval of the Minister for Conservation and Land Management, lease part or all of a reserve for an appropriate purpose. Many caravan parks on coastal waterways are managed under this form of lease.

The Minister may direct that a plan of management be prepared for a reserve. If a reserve trust exists, it usually has responsibility for the preparation of the plan. Once the plan has been publicly displayed and has been approved by the Minister, it has statutory force.

All Crown land forming the beds of rivers, lakes and estuaries, and all islands within these waterways that are not reserved for a specific purpose and not held under lease, are reserved from sale or lease generally. These areas do not constitute ‘public reserves’ as defined in the Local Government Act, and are not controlled by local councils.

This reservation was made in 1923, giving effect to the established policy that public access to Crown foreshores and submerged Crown land should not be hindered by the creation of private occupation rights. In practice, it is a simple matter to revoke the reservation over a specific area to allow the granting of a lease. However, the Crown Lands Act, 1989 gives additional protection by requiring public consultation before the approval of any new lease or licence or the sale of Crown land.

Tenures

A large variety of tenures were granted under previous Crown Lands Acts. In terms of estuaries, the main tenures of interest are Special Leases and Permissive Occupancies.

Special Leases were granted for fixed terms and for specific purposes, such as commercial boatsheds and marinas. The new Act does not establish any similar statutory form of lease. Rather, all future leases will be based on a lease agreement between the Minister for Conservation and Land Management and the lessee. Each lease is subject to the provisions of the Conveyancing Act, 1919, except as specified in the lease conditions.

A Permissive Occupancy is a licence to occupy and use Crown land, without the benefit of exclusive possession and subject to termination at will by the Minister. This form of tenure is predominant in areas below mean high water mark for purposes such as private jetties or for dredging activities. There is no provision for transfer of a Permissive Occupancy from person to person, but a form of ‘transfer’ by way of cancellation and regranting has been used in the past. The equivalent tenure under the new Act is a Licence. Licences will replace all Permissive Occupancies as they are transferred to new holders.

Estuarine Crown Land

Apart from physical and ecological differences, estuarine Crown land differs from other Crown land in the patterns of use and occupation and in the division of management responsibilities.

In the coastal watershed region of the State, areas of Crown land are highly fragmented and form only a small proportion of the total land area. Much of it is held under lease or licence for grazing or agriculture. In contrast, nearly all of the beds of estuaries are Crown land, free from any exclusive tenure. In some estuaries a significant proportion of waterside land and many islands are also Crown reserves.

Terrestrial Crown land which is not held for private purposes under lease or licence is usually reserved for a specific purpose and managed by a reserve trust appointed under the Crown Lands Act. In estuaries, management responsibilities are divided between many agencies, including local councils, the Public Works Department, the Maritime Services Board, New South Wales Fisheries and the National Parks and Wildlife Service.

Land Use Conflicts

Conflicting land-use interests arise in estuaries for a variety of reasons:

- a large proportion of waterfront land is held in private ownership;
- a strong demand for free and unrestricted public access to all public land;

126
most existing tenures do not confer exclusive possession;

- uncertain boundaries of land ownership and occupation;

- a lack of understanding of the legal/administrative system.

The main issue of concern - which is common to all estuaries - is public access to the foreshores and waterbody for recreational purposes. Many public facilities, such as boat ramps and picnic areas are located on Crown land. As a general rule it is both socially and economically desirable to maximise public access, but there may be conflicts between different types of recreational use, such as swimming, powerboating and sailing. Inappropriate land allocation can further reduce recreational access, e.g. the past practice of developing waterfront lands as sports grounds, which have no need for the exclusive use of such a location.

Provision of land to promote other interests such as nature conservation or commercial development may either restrict or enhance the public enjoyment of a waterway. Established uses such as commercial fishing and oyster farming may come under pressure with the growth of other commercial and recreational demands. The land assessment process has been developed as an aid in resolving such conflicts and achieving rational land-use allocation.

3 LAND ASSESSMENT

For the purposes of Crown land administration, land assessment serves two distinct purposes. The first is to fulfil a statutory obligation before deciding upon appropriate use for individual land parcels. The second is a broad scale planning exercise covering all of the Crown land in a defined region. Both types of assessment include an exhibition period to allow comment by the public and interested organisations, the results of which are considered before the assessment is formally approved.

Statutory Basis


Land assessment is a prerequisite before Crown land is dealt with under the Crown Lands Act 1989 by way of sale, lease, licence or exchange, by the granting of easements or by reservation or dedication for a public purpose. The Act also stipulates that a program shall be established for the assessment of Crown land, consisting of:

- the preparation of an inventory of Crown land;
- an assessment of the capabilities of the land;
- the identification of suitable uses for the land and, where practicable, the preferred use or uses.

The inventory of Crown land must contain information considered necessary to assess the capabilities of the land for the following uses:

- community or public purposes,
- environmental protection,
- nature conservation,
- water conservation,
- forestry,
- recreation,
- tourism,
- grazing,
- agriculture,
- residential purposes,
- commerce,
- industry, and
- mining.

The factors which must be considered in a land-use capability assessment are:

- The susceptibility of:
  - the land to hazards, including fire, flood, pondage, landslip, subsidence and coastal zone recession; and
  - the soil to erosion, salinity or structural decline.

- The significance of:
  - inherent natural, cultural and heritage features, including scenic attributes and adjacent waterbodies; and
  - communities of representative, rare or endangered species of flora or fauna present; and
  - minerals, extractive material, wood products, surface water, groundwater and other natural resources.
A draft land assessment must be advertised in the government gazette and a newspaper with local or state-wide circulation.

Land Assessment in Practice

The intention of the Crown Lands Act, 1989, which came into operation on 1st May 1990, is that land assessment be part of a systematic cataloguing and appraisal of all Crown land. However, it will be several years before this process is complete for the whole state. In the interim, land-use decisions must continue to be made. To date it has been necessary to carry out a large number of small land assessments, but as more regional projects are completed, there will be less need for case by case assessment.

Methodology of Land Assessment

The background to land assessment and its methodology are described in a Department of Lands publication (DOL, 1986), although there have been some modifications to these procedures since their inception. Land assessment makes use of systems which have been developed by other specialist government agencies for assessing the capability of land for particular uses, but has been adapted to reflect the broader requirements of Crown land management.

The first stage in a land assessment study is to identify the Crown land of interest and determine its legal status. The basic source of information is a set of about 6,000 parish and town maps which constitute an index of Crown land covering the whole state. This is supplemented by plans, registers, card systems, guard books (containing extracts from the government gazette) and administrative files.

Air photographs, topographic maps and special purpose maps are used to define basic units called mapping areas. An inventory card for each mapping area is used to record data on vegetation, soils, terrain, natural hazards and other factors affecting the conservation or development potential of the land.

Existing systems have been adapted for determining the suitability of land for agricultural uses, forestry or for urban development, based on topography, soil properties and natural hazards. Capabilities for residential, tourism or community purposes are based on the urban capability. Criteria for recreation, nature conservation and environmental protection have been specially developed.

A set of working policies for land assessment have been developed. These policies, while not prescriptive, provide guidance on choosing suitable and preferred land uses. Where a preferred use is identified there is generally a recommendation for further action.

4 APPLICATION OF LAND ASSESSMENT TO ESTUARIES

Selection of Study Area

As well as the bed of the waterway, an estuarine land assessment study can encompass adjacent dry land and freshwater wetlands. The choice of a study area will take account of natural boundaries, but will also depend on the distribution of Crown land, the existing patterns of land use in a region, the types of development being considered, and the administrative needs of the Department.

Definition of Mapping Areas

As a general principle the selection of mapping areas should be based on the major limiting factors of land capability. In dry land systems, vegetation, slope, terrain and soil characteristics are the main intrinsic limiting factors. Whilst these are also constraints in estuarine areas, there are other important factors, such as water depth, tidal range, currents and wave exposure.

The types of land use that are dominant in a particular estuary or part of an estuary have a large influence on how mapping areas are defined. Where the foreshore has been extensively modified by clearing, drainage or filling, there is usually a sharply defined boundary between the aquatic and terrestrial environments and the activities occurring in each.

On a natural shoreline there may be a sandy beach or a mangrove-saltmarsh community where the boundaries are more dynamic, being influenced by the tide and geomorphic
processes. In these circumstances, there is generally a greater variety of inter-meshing land-uses, both by humans (e.g. swimming, fishing) and by wildlife (e.g. feeding areas for fish and roosting areas for birds).

Within the body of a waterway the distance from the shoreline and the depth of water limit the type of activities that can be pursued and the nature of structures that can be erected. For subtidal land depth contours or any convenient lines can be used to define mapping areas.

Land Capability

The full range of land capabilities must be assessed in every case. For tidal lands, some land-uses, such as forestry or grazing, are easily eliminated using standard criteria. For developments involving erection of structures, the land capability must be interpreted on a different basis to that used in dry land systems. Structures on tidal land usually involve driving of piles and often dredging and reclamation. Characteristics such as water depth and substrate stability must be considered.

Suitable and Preferred Uses

Departmental policies such as the Coastal Crown Lands Policy, the Crown Lands Caravan Parks Policy and the Crown Land Foreshore Tenures Policy are used in conjunction with the land assessment working policies to decide on suitable and preferred uses.

Implementation of Findings

Land assessment is only the first step in allocating appropriate uses for Crown land. An assessment may recommend the existing use of the land be continued, or that the use be changed. In either case additional steps may be required, such as preparation of a plan of management or a development plan. These processes may be undertaken in cooperation with other government authorities or local councils and often involve external consultants.

Often the final stage in implementing a land-use decision is to enter into a lease or licence agreement. The completion of a land assessment study does not reduce any of the existing planning or environmental protection requirements or the need for consultation with other authorities which have statutory interests.

5 REFERENCES


1 Introduction
2 Management Principles
3 Environmental Planning and Impact Assessment
4 Land and Resource Management
5 Control of Specific Activities
6 Development Guidelines
7 References

1 INTRODUCTION

One of the aims of the New South Wales Estuary Management Policy is to ensure the long term sustainability of estuarine habitats and ecosystems. This requires the effective use of existing legal and administrative systems to manage the impacts of development and other human activities.

This Appendix presents basic principles for better estuarine management, describes how the planning and management regimes that apply to estuaries can be used to protect and improve the environment and directs the reader to additional guidelines for particular types of development.

The following four Appendices give more detail on particular aspects of estuarine management.

2 MANAGEMENT PRINCIPLES

A primary objective of this manual is to promote the protection of estuarine habitats, ecosystems and amenity, together with the sustainable use of estuarine resources. For an Estuary Management Committee or any public authority involved in estuarine management, there are certain basic principles that should guide all planning and management decisions. These can be conveniently grouped under six headings.

- General Principles,
- Habitat Protection,
- Foreshore Reserves and Recreation,
- Fisheries,
- Water Quality, and
- Development.

General Principles:

- Whenever possible, estuarine foreshores, wetlands and aquatic habitats should be preserved in their natural state.

- Habitat restoration should be undertaken wherever there is an opportunity to repair past environmental damage.

- The cultural heritage of estuaries, including Aboriginal and historic sites, should be protected by appropriate measures.

- All management and development activities by state and local government authorities should be subject to full public consultation and appropriate environmental controls.

- Any ‘activity’, ‘development’, ‘environmental planning instrument’ (as defined in the EPA Act), or any policy which is likely to affect an estuary, should be referred for assessment to appropriate authorities, including New South Wales Fisheries and the National Parks and Wildlife Service, at both the early and final planning stages.

Habitat Protection:

- Estuarine habitats should be protected by appropriate zoning and development controls; this applies particularly to saltmarshes, mangroves, seagrass beds, islands and other areas of importance to nature conservation;

- Representative and unique aquatic and terrestrial habitats should be protected and managed by reservation (i.e. designation as reserves) under the appropriate legislation.
Foreshore Reserves and Recreation:

- Existing public access to and along estuarine foreshores should be maintained and improved where possible, taking into account possible effects on ecologically sensitive areas.

- When waterfront land is rezoned, a well-marked foreshore reserve of at least 30 metres width should be established.

- Larger foreshore reserves are needed in some areas to protect ecologically sensitive areas and to provide public facilities for water-based recreation.

- Water-based and passive recreation should be given priority in the future development of foreshore reserves.

Fisheries:

- Recognised fishing grounds should not be alienated by foreshore or subtidal structures.

- Developments or activities should not interfere with commercial or recreational fishing, or with the oyster farming industry.

Water Quality:

- Water quality criteria should be based on the maintenance of the estuarine ecosystem and protection of fisheries, oyster farming and recreational amenity.

- Pollution of estuaries should be minimised, either by alternative disposal methods or by high-level treatment of wastes.

Development:

- Areas zoned for development should be separated by 'buffer zones' of adequate width from ecologically sensitive areas, especially wetlands.

- Necessary public developments should be directed to areas which will suffer the least ecological damage.

- Developments or activities should not be allowed to restrict tidal exchange, tidal inundation of low-lying lands, or fish passage.

- Developments and activities near intermittently opening coastal lagoons should be strictly controlled with the objective of maintaining a level of water quality suitable for fish and other aquatic life.

- Environmental compensation should be an integral part of the planning process for any development or activity that causes unavoidable damage to any estuarine habitat or associated habitat of importance to the estuary.

3 ENVIRONMENTAL PLANNING AND IMPACT ASSESSMENT

This section presents a brief overview of the New South Wales environmental planning system, and how it can be used to manage and conserve estuarine ecosystems and resources. More detailed information on environmental law can be found in reference books such as Farrier (1988). If practical advice on planning procedures is required, it is recommended that the planning section of the local Council be consulted.

Legislation

The Environmental Planning and Assessment Act, 1979 (EPA Act) integrates the planning of land use and natural resource development activities with measures for assessing impacts on the environment. The definition of 'environment' in the Act is human-centred, encompassing social, economic and cultural aspects, as well as ecosystems.

The Environmental Planning and Assessment Regulation 1980 (EPA regulations) provides more detail on the preparation and content of planning instruments, on the development application process itself and on environmental impact assessment criteria. This regulation also includes a schedule of 'designated developments', for which an Environmental Impact Statement (EIS) is required. Designated developments of most direct significance to estuaries include canal estates, marinas, extractive industries and aquaculture.

Environmental Planning Instruments

There is considerable flexibility in the EPA Act
which allows planning techniques to be directed at broad-ranging or narrowly focussed issues, and at different sized areas, ranging from the whole State to individual sites. There are three levels of statutory Environmental Planning Instruments:

- State Environmental Planning Policies;
- Regional Environmental Plans; and
- Local Environmental Plans.

Another level of planning is provided by Development Control Plans, which provide more detail on the matters covered by Local Environmental Plans. These are prepared and implemented by local councils.

State Environmental Planning Policies

State Environmental Planning Policies (SEPPs) are prepared by the Department of Planning for approval by the Minister. SEPPs are intended to cover matters of State significance. The most important Policy affecting estuarine areas is SEPP 14 (Coastal Wetlands).

Under SEPP 14, proposals to clear, drain, fill or construct levees on designated wetland areas, as delineated on SEPP 14 maps, require the proponent to lodge a Development Application with the local Council, together with an EIS (DOP, 1987). The local Council is the consent authority, but concurrence is required from the Director of Planning. SEPP 14 takes precedence over other planning instruments.

Regional Environmental Plans

Regional Environmental Plans (REPs) are prepared by the Department of Planning and are usually preceded by a Regional Environmental Study. This process is aimed at achieving regional planning goals. The environmental study, together with the draft REP, is displayed for public comment for a period determined by the Director of Planning. The draft plan, with any necessary amendments, is then submitted to the Minister for approval.

REPs which include important estuarine areas are the North Coast, Hunter and Illawarra REPs (DOP, 1988; DOP, 1989; DEP, 1986) and the Lower South Coast Draft REP (DOP, 1991).

An REP may use a variety of mechanisms for achieving its objectives, including:

- establishing guidelines and criteria which must be followed by councils when preparing Local Environmental Plans;
- making specific amendments to local planning instruments;
- specifying matters that councils must consider when deciding development applications; and
- establishing general land use planning policy.

Local Environmental Plans

A Local Environmental Plan (LEP) is prepared by the local Council and is the basis for most land-use control. An LEP may apply to any area of land from a single parcel to an entire local government area. LEPs establish zonings with permissible land uses, prohibited uses and development controls for each zone. LEPs can be used to rezone a small area or otherwise amend an existing plan.

LEPs can also be used to identify and conserve heritage items, including historic sites and buildings, and establish appropriate development controls.

A local environmental study must be undertaken before an LEP is prepared, unless the Director of Planning waives this requirement. The Director often does this when the LEP constitutes a small amendment to an existing plan. The environmental study, together with the draft LEP, must be publicly displayed for a minimum of 14 days. After any changes made in response to public comment, the draft LEP is submitted to the Department of Planning for gazetted by the Minister.

When a major LEP or a rezoning proposal is being considered for any area within or adjoining an estuary, it is desirable that a local environmental study be prepared. The study should address the following matters, where applicable:

- mapping of all estuarine wetlands, including saltmarshes, mangroves, seagrasses and intertidal sand and mud flats;
- compiling an inventory of recorded animal and plant species, including the likely
occurrence of any endangered or threatened species, or species having regional or local significance;

- assessment of the conservation requirements of habitat areas;

- assessment of existing and potential recreational use, including boating, fishing and passive recreation;

- assessment of additional areas which should be reserved or acquired for improved foreshore access;

- the need for a foreshore building line;

- listing and discussion of heritage features;

- assessment of commercial fishing activities and the value of the industry to the local and regional economy;

- assessment of oyster farming and its commercial value;

- consideration of environmental problems caused by past and continuing land uses;

- assessment of potential impacts of future development on ecological processes, water quality, public amenity and on the fishing and oyster industries.

Development Control Plans

A Development Control Plan (DCP) is a policy document which may be prepared and adopted by a Council to provide more detailed guidelines for applying the controls contained in an LEP. A DCP is a formal statement of council policy, but does not have the same statutory force as an LEP.

A DCP may cover any part of a local government area, including unzoned waterways, providing that the governing LEP contains a provision requiring consent for development in the unzoned area. Before a DCP can be adopted, it must be displayed for public comment for a minimum period of 21 days.

The DCP applying to Lake Macquarie is an example of a plan specifically designed to control lake and foreshore development (LMCC, 1989). A DCP can be a useful means of informing the public of the Council’s goals for estuarine management. It may also provide practical guidelines on the processes involved in gaining approval for a development. A DCP may include:

- the recommendations of Estuary Management Plans;

- general environmental goals, such as water quality standards;

- detailed standards for siting and design of developments of specified types or in particular locations;

- policies and guidelines for use by Council when assessing the environmental impact of developments and activities;

- policies for consulting with government authorities on development applications;

- specified information that must be supplied with development applications;

- requirements for developments to comply with other guidelines, e.g. the Estuarine Habitat Management Guidelines (NSW Fisheries, 1991);

- advice on additional approvals required from government authorities for specific types of developments;

- strategies for the provision of public amenities and services; and

- strategies for the proposed acquisition of public open space.

Environmental Impact Assessment

The EPA Act provides two sets of procedures for environmental impact assessment:

- under Part IV, when consent is required for a 'development'; and

- under Part V, when consent is not required under Part IV, but the proposed 'activity' needs the approval of a government Minister or public authority.

Both 'development' and 'activity' are similarly defined in the EPA Act. They include building and earth works, the use of land or buildings,
and the subdivision of land. The applicable LEP or other planning instruments determine whether or not a particular proposal requires development consent.

When considering development applications, the 'consent authority', which is usually the local Council, must consider a wide range of matters before making a decision, including environmental factors. All development applications must be accompanied by information on the likely environmental impact. In most cases this takes the form of a 'statement of environmental effects', which may be brief and simple or quite lengthy and complex, depending on the type of development proposed.

Certain types of development are listed in the EPA regulations as 'designated development'. For these developments a more structured form of assessment is required in the form of an Environmental Impact Statement (EIS). The EPA regulations currently specify over 30 types of designated development, including:

- canal estates providing more than 10 residential allotments;
- marinas providing mooring or dry storage for more than 30 boats or repair facilities for 5 or more boats;
- extractive industry, such as dredging for sand or gravel; and
- farms for the cultivation of fin-fish, crustacea, molluscs or seaweed which inundate an area exceeding 2 hectares.

A planning instrument may create additional categories of designated development by referring to the type, purpose or location of development. An example is SEPP 14, which requires an EIS for certain types of development in specified coastal wetland areas. A Local Environmental Plan could use this method to ensure that any development on a visually or ecologically sensitive site is subject to the most rigorous assessment of environmental impact.

Part V of the Act provides a different set of environmental assessment procedures. Any Minister or public authority that carries out an activity or approves an activity is a 'determining authority'. Where more than one approval is required, the Minister for Planning may choose one authority to be the 'nominated determining authority'. This is usually the authority with the most relevant technical expertise, or which is undertaking or supervising the project.

Each determining authority has a duty to 'examine and take into account to the fullest extent possible' the likely environmental impact of the activity. Where the impact of the activity on the environment is likely to be significant, an EIS must be obtained.

Environmental Impact Statements

The EPA regulations (clauses 34 and 57) detail the matters that every EIS must cover. Amongst other things, these include a full description of the project and the existing environment likely to be affected, an analysis of the likely impacts and proposed measures to protect the environment.

The person or organisation proposing to undertake such a project is responsible for preparing the EIS. They must consult with the Director of the Department of Planning, who will provide a written statement of more specific requirements for the EIS and advice as to which other government agencies should be consulted.

The consent authority for a development, or the nominated determining authority for an activity, is responsible for the public exhibition of an EIS. All submissions must be considered before a decision is made.

4 LAND AND RESOURCE MANAGEMENT

In addition to the environmental planning procedures under the EPA Act, a number of other agencies have responsibilities to manage and protect the land, waterways and other natural resources of estuaries and their catchments. These responsibilities relate to:

- provision of public infrastructure to support land and resource development;
- management of publicly-owned land;
- reservation and management of land for conservation, recreation and other purposes;
- development of management plans for publicly-owned land and resources; and
- integrated planning for estuaries and catchments.

Table J1 lists the responsible public agencies and the legislative basis of their management functions and controls.

Public Infrastructure

Public infrastructure includes services required for transport and urban development, as well as facilities for maritime operations and public recreation. Although these developments have negative impacts on estuarine habitats and amenity (see Appendix F), they can also be used to remedy existing problems and increase the recreational and tourism potential of estuaries. Public infrastructure of significance to estuary management includes the following services:

- Roads and Bridges,
- Drainage and Sewerage,
- Fishing Ports,
- Recreational Boating Facilities, and
- Navigation Aids.

(a) Roads and Bridges

Most public roads are owned and maintained by local Councils, whilst the Roads and Traffic Authority is responsible for main roads and highways. Techniques used in the construction and maintenance of roads and bridges are important for reducing the incidence of erosion and water pollution.

Downstream water quality can be improved by the use of sediment traps, stabilisation of roadside batters, sealing of existing gravel roads and better road maintenance procedures. Bridges over estuarine waterways should be located and designed to minimise bank erosion and other detrimental environmental impacts.

(b) Drainage and Sewerage

Most urban stormwater drains discharge directly into streams and estuaries. There are various pollution control measures that can be incorporated into new and existing drainage systems to minimise the load of debris, sediment, nutrients and other chemicals reaching the waterway. These measures include artificial wetlands, detention basins, grassed swales, sediment traps and gross pollutant traps (Water Board, no date).

Proper disposal of sewage is essential for the protection of public health and the reduction of water pollution. Measures to reduce water pollution include the reticulation of unsewered areas, the adoption of higher standards of treatment, pretreatment or recycling of trade wastes, and reuse of effluent for irrigation or industrial purposes.

Sewerage and some stormwater systems in the Sydney/Illawarra/Blue Mountains and Newcastle areas are managed by the Water Board and Hunter Water Corporation respectively. Elsewhere local government manages the sewerage and stormwater systems with assistance from the Public Works Department in the design, construction and operation of sewerage works.

The Environment Protection Authority sets conditions for effluent discharge and is implementing a new licensing system which requires commitment by each authority to a pollution reduction program over the period of the licence.

(c) Fishing Ports

The Public Works Department is responsible for the construction and maintenance of port facilities for commercial fishing fleets (SCP Fisheries Consultants, 1985). Many ports are located in estuaries which also require entrance stabilisation works and/or maintenance of navigation channels. Extensive hydraulic and environmental studies are carried out to determine the effects of any necessary training walls or dredging. Under the Fishing Ports Program, 24 ports and associated facilities at 29 locations have been constructed over the last 35 years (Public Works, 1990).

(d) Recreational Boating Facilities

Provision of boating access to waterways is mainly a function of local government, which must balance the benefits of recreation and tourism against possible negative impacts on other waterway users and sensitive habitats.
### Table J1  Main Agencies and Legislation Associated with Estuarine Management, New South Wales

<table>
<thead>
<tr>
<th>Agency</th>
<th>Legislation</th>
<th>Functions and Controls</th>
</tr>
</thead>
<tbody>
<tr>
<td>Councils</td>
<td>Environmental Planning and Assessment Act 1979</td>
<td>Environmental protection and tree preservation, Zoning of land use, Protection of heritage items, Development standards, Conditions of development consent, Environmental impact assessment, Building controls, Management of public reserves, public wharves and bathing areas, Dredging</td>
</tr>
<tr>
<td></td>
<td>Local Government Act 1919</td>
<td></td>
</tr>
<tr>
<td>Dept. of Conservation and Land Management</td>
<td>Crown Lands Act 1989</td>
<td>Sale, lease or licence of Crown land, Crown reserves administration, Protection of 'public land'</td>
</tr>
<tr>
<td></td>
<td>Soil Conservation Act 1938</td>
<td>Tree clearing</td>
</tr>
<tr>
<td>Dept. of Planning</td>
<td>Environmental Planning and Assessment Act, 1979</td>
<td>Coastal Lands Acquisition, State Environmental Planning Policies, Regional Environmental Studies, Regional Environmental Plans</td>
</tr>
<tr>
<td>Environment Protection Authority</td>
<td>Pollution Control Act 1970*</td>
<td>Licensing of pollution sources, Point source pollution, Control of excessive noise</td>
</tr>
<tr>
<td></td>
<td>Clean Waters Act 1970</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Noise Control Act 1975</td>
<td></td>
</tr>
<tr>
<td>Maritime Services Board</td>
<td>Maritime Services Act 1935</td>
<td>Boat registration, Boat driver licensing, Navigation rules, Speed restrictions, Moorings, Aquatic licences</td>
</tr>
<tr>
<td></td>
<td>Navigation Act 1901</td>
<td></td>
</tr>
<tr>
<td>NSW Fisheries</td>
<td>Fisheries and Oyster Farms Act 1935</td>
<td>Removal of mangroves, Permission or notification of dredging and reclamation, Use of explosives, Free passage for fish, Provision of fish passage facilities, Protection of fishing grounds, Licensing of commercial fishing, Regulation of recreational fishing, Leases for oyster farming, Licensing of aquaculture, Management of Aquatic Reserves</td>
</tr>
<tr>
<td>Public Works Dept.</td>
<td>Rivers and Foreshores Improvement Act 1948, Public Works Act 1912</td>
<td>Dredging, excavation, reclamation or structures</td>
</tr>
</tbody>
</table>

* formerly known as the State Pollution Control Commission Act 1970
The Public Works Department provides technical and financial assistance to local authorities for preconstruction activities, the construction or upgrading of safe anchorage breakwaters, public wharves and waterway improvements, and on the management of these public assets. The Department also undertakes maintenance and upgrading programs for breakwaters and training walls and facilitates the development of marinas on Crown land.

(e) Navigation Aids

The provision of channel markers and other aids to navigation is the responsibility of the Maritime Services Board.

Management of Publicly-owned Land

For the purposes of this section, publicly-owned land includes Crown land and land owned by local Councils and state government authorities.

The beds of estuaries are mainly Crown land, most of which is not held or reserved for any particular purpose. Consequently there is no authority with exclusive management control.

The Department of Conservation and Land Management (CLM) administers the provisions of the Crown Lands Act for protection of ‘public land’, which includes Crown land and certain other types of reserves. The matters covered include:

- illegal removal of plants, earth, stone or other materials;
- dumping of vehicles or other rubbish;
- trespass by persons or animals; and
- unauthorised structures.

The power to grant leases or licences for private or commercial uses of Crown land below high water mark is divided between CLM (for most purposes), NSW Fisheries (oyster leases) and the Maritime Services Board (moorings). These authorities are responsible for ensuring that the lease or licence conditions are observed.

As well as acting as trustees for many Crown reserves, local Councils have authority under the Local Government Act to manage ‘public reserves’, which includes council-owned reserves and any land reserved or dedicated by the Crown for ‘public health, recreation, enjoyment’ or similar purposes, and for which there is no appointed trust. Councils may establish community management committees to manage particular parks and reserves.

Councils also have powers to construct and maintain facilities such as public baths, public wharves, seawalls and navigation channels. The Public Works Department may act as constructing authority for these and other works.

There are often large areas of publicly-owned land adjacent to estuaries or within their catchments. Main roads and highways are owned and maintained by the Roads and Traffic Authority. Railway land, including bridges and causeways, is managed by the State Rail Authority. The authorities responsible for electricity generation and supply own significant areas of land adjacent to coastal lakes and estuaries.

Land required for port facilities for maritime trade is acquired and managed by the Maritime Services Board.

Reserves Systems

There are various legislative means by which land may be reserved for different purposes and managed by public authorities or trusts. The reserves of importance for estuarine management are listed and described below, and include large areas within the catchment which affect estuarine water quality, waterfront reserves for public recreation, and reserves within the estuarine waterbody itself:

- Crown Reserves,
- Council Reserves,
- Aquatic Reserves,
- National Parks, Nature Reserves and Historical Sites,
- State Recreation Areas, and
- State Forests.

(a) Crown Reserves

The Department of Conservation and Land Management may reserve Crown land for a variety of purposes, including public recreation and environmental protection. Crown reserves are managed by local Councils or trust boards.
The latter are comprised of members of the public and representatives of government agencies (see Appendix I for more information).

(b) Council Reserves

Local Councils may purchase land for reserves or require land to be transferred to them as a condition of subdivision approval. The latter method has been used to create many foreshore reserves. Council reserves are mainly used for open space and recreation or for drainage, but some contain valuable areas of wetland and other remnants of native vegetation.

(c) Aquatic Reserves

New South Wales Fisheries may declare an area of Crown land below high water mark to be an Aquatic Reserve (sometimes termed a 'Marine Reserve' where coastal waters are included). This allows either total protection of all aquatic animals, or zoning of allowable fishing activities according to a Management Plan. There are 8 existing Aquatic Reserves in the State, of which the largest is the Solitary Islands Marine Reserve of 85,000 hectares (O'Donnell, 1992).

(d) National Parks, Nature Reserves and Historic Sites

National Parks, Nature Reserves and Historic Sites are owned and managed by the National Parks and Wildlife Service. National Parks and Nature Reserves are intended to preserve representative samples of natural ecosystems in order to ensure the long-term survival of native species and their habitats. The needs of the public for natural recreation are also considered, but Nature Reserves give a higher priority to nature conservation objectives. Historic sites preserve areas and structures of significance to the history of the State.

National Parks are often important in maintaining the water quality in estuaries by protecting large areas of the catchment. There are also a small number of areas where a National Park or Nature Reserve includes the bed of an estuary or coastal lagoon, such as Myall Lakes National Park and Wamberal Lagoon Nature Reserve. Because the National Parks and Wildlife Act does not protect fish or other marine life (apart from birds and marine mammals), complementary fisheries regulations are required to give protection to animal species in these intertidal or subtidal reserves.

(e) State Recreation Areas

Although the Department of Conservation and Land Management presently controls some State Recreation Areas, the major SRAs on the coast are managed by the National Parks and Wildlife Service. The management objectives for these areas are similar to those for National Parks.

(f) State Forests

Forest management is important for catchment protection, as well as the provision of recreational opportunities. State Forests often cover a significant proportion of the catchment area of estuaries. The majority of land in NSW reserved as State Forests is within the coastal catchments, because the higher rainfall in the coastal region is better able to support productive forests. Areas within State Forests can be set aside as Flora Reserves for the protection of special floristic values.

Management Plans

Management plans can be used to address many issues, including land-use planning, the allocation of natural resources and nature conservation. They usually specify management objectives and strategies. The regulatory mechanisms by which management plans may be enforced are discussed in Section 5 of this Appendix. Typical areas or issues encompassed by management plans include:

- Reserves,
- Floodplains,
- Coastline Hazard,
- Fisheries,
- Threatened Species, and
- Oil Spills.

(a) Reserves

For each type of reserve described above, a management plan can be prepared and adopted under the relevant legislation. In most cases there is provision for public display of a draft plan and consideration of comments before the
plan is finalised. Once a plan is formally adopted, it is generally binding on the management agency.

(b) Floodplains

The Government’s Floodplain Development Manual recommends that Councils form Floodplain Management Committees to oversee floodplain management studies and to develop Floodplain Management Plans (NSW Govt, 1987). In the case where a floodplain extends over more than one local government area, two or more Councils may form a joint committee.

Floodplain Management Plans usually involve zoning and development controls through the planning process to address the question of future development of floodplains. Measures to address problems from existing floodplain development may include structural (retarding basins, levees, floodways, channel improvements) and non-structural (voluntary purchase or house raising) options.

Structural works alter the hydrology of a floodplain system and have the potential for major impacts on the downstream estuary. Such impacts are addressed through the floodplain management study process.

(c) Coastline Hazard

The Government’s Coastline Management Manual recommends that Councils form Coastal Management Committees to address the problems of coastline hazards (e.g. beach erosion, shoreline recession, coastal entrance stability, degradation of coastal vegetation, sand drift, coastal inundation, slope and cliff stability and stormwater erosion). The role of Coastal Management Committees is to oversee hazard definition studies and to prepare coastline management plans (NSW Government, 1990).

Coastline management plans involve both structural measures (breakwaters, sea walls, etc.) and non-structural measures (zoning, voluntary purchase, planned retreat, etc.). A number of these management measures can effect estuarine habitats, ecosystems and amenity. Thus, in those areas where both a coastline hazard management plan and an estuary management plan are developed, there needs to be an integration and coordination of activities and approaches.

(d) Fisheries

New South Wales Fisheries prepares management plans for commercial fisheries, protection of endangered species and activities such as intertidal harvesting of invertebrates. As well as preserving species that are important for commercial and recreational fishing, management plans are also implemented to protect vulnerable aquatic ecosystems.

(e) Threatened Species

The National Parks and Wildlife Service produces management plans which address research needs and strategies for conserving the habitat of flora and fauna of concern. Management plans for particular species are discussed in Appendix M.

(f) Oil Spills

Oil spills, especially from shipping, can be controlled by a number of methods, including dispersants and floating booms. Dispersants are themselves toxic to aquatic life, and need to be used with care.

The Environment Protection Authority (formerly the State Pollution Control Commission) has published guidelines for the control of oil spills (SPCC, 1981). In addition the EPA has produced a number of ‘Coastal Resource Atlases’ for different sections of the New South Wales coastline, including bays and estuaries. These provide an inventory of ecological, recreational and economic resources likely to be affected by oil spills, with guidelines on the control measures which are appropriate for different areas. An example is the Coastal Resource Atlas for Broken Bay, Pittwater and the Hawkesbury River (EPA, 1992).

Integrated Planning

Given the number and diverse objectives of agencies involved in management of estuaries and their catchments, there is an obvious need for coordination. There are two main mechanisms for bringing local and state government agencies together with community
members to achieve integrated planning of coastal catchments and estuarine areas.

(a) Catchment Management

Catchment Management Committees (CMCs) combine the advantages of community and landholder representation with the support of government agencies. Their task is to raise community awareness and involvement in the problems of land and water resource management (see Appendix H for more details).

CMCs serve as vehicles for disseminating information on catchment management problems and solutions. They also coordinate the allocation of funding for community projects under State and Federal programs such as Landcare.

(b) Estuary Management

As described in the main body of this manual, the role of Estuary Management Committees is to achieve the integrated and coordinated management of estuaries and coastal lakes on an individual waterbody basis. Estuary Management Committees need to be aware of the existence of other committees with overlapping objectives, and should seek to cooperate by joint membership and information sharing.

5 CONTROL OF SPECIFIC ACTIVITIES

The environmental planning system does not effectively deal with all activities which affect the quality of the estuarine environment, particularly where degradation is caused by the cumulative effects of many small individual actions. Other legislation, enforced by specialist agencies, is used to regulate and control many of these activities.

Some activities, such as dredging, are subject to the full environmental assessment provisions of the Environmental Planning and Assessment Act, but also require approvals under other legislation.

Most Acts of Parliament allow for the making of regulations for specified purposes. Regulations cover such details as what activities are allowed or prohibited in certain areas, the procedures for obtaining permits and the equipment which may be legally used for these activities.

Fishing

NSW Fisheries has responsibility for the management of fish and fishing activities in all State waters. The Fisheries and Oyster Farms Act and the regulations administered by NSW Fisheries cover such matters as:

- fishing closures over certain areas and times;
- limits on intertidal collecting of invertebrates for bait or food;
- restrictions on numbers of fish taken and minimum sizes;
- restrictions on the type of fishing gear allowed;
- licensing of commercial fishers and boats;
- protected species; and
- Aquatic Reserves (see section 4).

Recreational Boating

The regulations on recreational boating are administered by the Waterways Authority of the Maritime Services Board, and deal with the following matters:

- registration of boats;
- licensing of boat drivers;
- navigation rules;
- speed restrictions;
- private and commercial moorings; and
- ‘aquatic licences’ which allow activities that may interfere with other waterway users, e.g. boat races and seaplane operations.

Pollution Control

The Environment Protection Authority enforces the main pollution control regulations, including:

- licensing of discharges to waterways;
- licensing of air pollution discharges; and
- limits on noise levels.

The Maritime Services Board administers regulations to prevent vessels discharging pollutants into waterways, and to limit noise levels.
The proper use of pesticides and other agricultural chemicals is important for minimising adverse effects on water quality. NSW Agriculture administers the pesticide regulations, which are mainly designed to protect the health of users and the general public.

Aboriginal Sites

The National Parks and Wildlife Service is responsible for protecting all sites of significance to Aboriginal culture, whether on public or private land. Approval is required to disturb, damage, deface or destroy an Aboriginal site or relic (NPWS, 1986).

Tree Clearing

The Soil Conservation Act 1938 allows maps to be prepared of environmentally sensitive areas which then become ‘protected land’ (CLM, 1991). The categories of protected land include steep slopes, areas subject to land degradation, and all land within 20 metres of the banks of prescribed streams. The latter includes the estuarine reaches of rivers. Permission is required from the Department of Conservation and Land Management to destroy or remove trees on protected land.

Many Councils have a Tree Preservation Order which requires permission to be obtained to remove, lop or otherwise damage trees over a certain size. Cutting of mangroves below high water mark must be authorised by NSW Fisheries.

Dredging and Reclamation

Dredging may be carried out for a number of different purposes. Any dredging of commercially valuable material, whether for sale or for reclamation works, is classified as ‘extractive industry’ and requires the preparation of an Environmental Impact Statement (see Appendix L for further details).

Any dredging or reclamation in an estuary, even for a minor purpose such as maintaining access to a jetty, requires the permission of a number of authorities, including:

- Council (if development consent is required);
- Department of Conservation and Land Management (if Crown land is affected);
- NSW Fisheries;
- Public Works Department;
- Maritime Services Board; and
- Environment Protection Authority.

Use of Explosives

Permission must be obtained from NSW Fisheries for underwater blasting. Approval is generally only given when it is required for an essential public service. Conditions are applied to minimise the chance of fish kills, or disruption to fishing activities.

Obstructions to Waterways

Under the Rivers and Foreshores Improvement Act, 1948, a permit is required for any activity which could detrimentally affect the flow of a river or lake and for any excavation or removal of material from the bed or within 40 metres of the banks. These provisions are administered by the Maritime Services Board where the bed is vested in that Board, the Public Works Department in other tidal waterways and by the Department of Water Resources elsewhere. NSW Fisheries requires that any structure crossing a waterway should be designed so as not to obstruct fish passage. Any proposed structure which will completely block the flow of water, such as a dam or weir, must incorporate a fish ladder or other passage facilities.

Endangered Fauna Protection

Under the Endangered Fauna (Interim Protection) Act, 1991, any development or activity that is likely to have a significant detrimental effect on the habitat of endangered fauna, i.e. is likely to adversely affect its essential behavioural patterns, will require from the National Parks and Wildlife Service a licence to take or kill endangered fauna.

6 DEVELOPMENT GUIDELINES

This section lists publications produced by government agencies to assist developers and decision makers in planning, designing and assessing projects and in fulfilling the various
regulatory requirements. Other useful brochures and booklets are often available from local Councils. New South Wales Fisheries has produced guidelines which specifically address development conditions and other strategies to protect estuarine habitats (NSW Fisheries, 1991).

Urban Development:
- Urban erosion and sediment control (SCS, 1978);
- Design of soil conservation works (SCS, 1987);
- Roadworks (DMR, 1984);
- Pollution from urban stormwater (SPCC, 1989);
- Stormwater management (IEA, 1985; Water Board, n.d.);
- Acid sulphate soils (SCS, 1990).

Extractive Operations and Dredging:
- Environmental assessment of extractive industry (DOP, 1989).

Marinas:

Canal Estates:
- Planning guidelines (DOP, 1990a);
- Design guidelines (DOP, 1990b);
- Conditions and guidelines (Public Works, 1992).

Aquaculture:
- Prawn and fish farming (DOP, no date).

10 REFERENCES


DOP, no date. ‘Prawn Farming’, Circular No. E2, NSW Department of Planning.


DOP, (1991). ‘Lower South Coast Regional Environmental Study and Draft Regional Environmental Plan No. 2’, NSW Department of Planning.


Public Works, (1990). 'Coast and Rivers Programs', Public Works Department of NSW.


SPCC, (1981). 'Guidelines for Controlling Oil Spills in Maritime Waters of New South Wales', State Pollution Control Commission of NSW.


Water Board, (no date). 'Hard Rain', Water Board.
APPENDIX K MANAGEMENT OF WATER QUALITY

1 Introduction
2 Principles and Objectives
3 Legislative Basis of Water Quality Management
4 Management Guidelines for Point Source Pollution
5 Management Guidelines for Diffuse Source Pollution
6 Management Guidelines for Coastal Lagoons
7 References

1 INTRODUCTION

This appendix reviews the legal controls and other mechanisms that can be used to manage water pollution in New South Wales estuaries. The relevant legislation providing legal weight to pollution control in New South Wales is also described. The management of water quality is a key aspect of the management of estuarine habitats. Reduced biological productivity, the accumulation of toxic materials such as heavy metals in the food chain, and the death of estuarine fauna are but some of the adverse effects of impaired water quality (see Appendix C for details).

2 WATER QUALITY POLICY

The goal of the New South Wales draft Water Quality Policy is:

'To manage the State’s water resources in a sustainable manner to meet agreed human and environmental needs, and for optimum social, environmental and economic benefit. Consistent with this, water quality will be protected from degradation and improved.'

As a broad guiding principle, the pollution of estuaries is to be avoided wherever possible. Point source wastes should be disposed of elsewhere or undergo high levels of treatment before discharge to estuaries; diffuse source pollutant loads should be reduced through better management practices or by treatment before entering estuaries.

3 LEGISLATIVE BASIS OF WATER QUALITY MANAGEMENT

The Clean Waters Act, 1970, was designed to provide a framework for the control of water pollution in New South Wales. Under Sections 16 and 17 of the Act, it is an offence for a person to pollute any waters, or to cause or permit any waters to be polluted, unless a licence is held and any conditions of the licence are obeyed. According to the Act, both 'waters' and 'pollute', in relation to any waters, are defined in wide-ranging terms (see Glossary).

Point Source Pollution

Under the provisions of the Clean Waters Act 1970 and the Pollution Control Act 1970, any point source discharge of pollutants to waterways must be licenced by the Environment Protection Authority (EPA). The conditions of the licence specify the water quality standards the effluent must meet, e.g. maximum suspended solids levels, and any relevant operational criteria, e.g. maximum rates and duration of discharge. Licences are renewed annually. Licence conditions encourage the installation of effective pollution control equipment and implementation of new processes as advances in technology occur.

All development plans prepared under the provisions of the Environmental Planning and Assessment Act, 1979, that involve the installation, construction or modification of any apparatus, equipment or works for the discharge, treatment or storage of pollutants require approval by the EPA. Over the last 20 years, the system of point source control has been particularly effective in reducing pollution of the state's waterways.

Under Section 34 of the Fisheries and Oyster Farms Act, it is an offence to allow any solid or liquid matter injurious to fish, their food, spawning grounds or spawn to enter any waters.
Diffuse Source Pollution

Under the Clean Waters Act, 1970, the regulation of diffuse source pollution is less effective. The Catchment Management Act, 1989, was developed to address a number of issues including the management of water pollution from diffuse sources. Control is exercised by local Catchment Management Committees and Catchment Management Trusts, both of which aim at achieving active community participation in voluntary measures to reduce pollution (see Appendix G).

The Soil Conservation (Further Amendment) Act, 1986, requires owners or holders of timber rights to make application for permission to destroy or injure trees growing on 'protected land'. 'Protected land' includes environmentally sensitive land, or land affected or liable to be affected by soil erosion, siltation or land degradation.

Agricultural pesticides are controlled under the Pesticides Act, 1978, which stipulates that all pesticides are to be used in accordance with label directions. Precautionary statements on the label, particularly those relating to the aquatic environment must be followed. In potentially damaging situations, the least toxic pesticides should be used. Pesticide containers should be disposed of in an environmentally acceptable way.

The EPA is currently developing a set of 'Water Quality Goals and Objectives for New South Wales' (SPCC, 1990a), that will further involve Catchment Management Committees in the management of water quality. Stage 1 of this process consists of the setting of goals and objectives, together with the statewide classification of all waters on the basis of water quality. In Stage 2 of this process, which will involve community participation, the classification of waters will be reviewed by Catchment Management Committees who will advise the EPA of any necessary modifications.

The 'Water Quality Goals and Objectives for New South Wales' will specify specific water quality guidelines for each category of waters. Catchment Management Committees and Estuary Management Committees will then be able to apply these guidelines to their local estuary. Both established activities and proposed developments can be assessed in the light of these goals and objectives.

4 MANAGEMENT GUIDELINES FOR POINT SOURCE POLLUTION

Sewage and Industrial Effluent

Residential sub-divisions incorporating artificial waterways must be fully sewered, preferably with a connection to a reticulated town sewerage system, as discussed under Waterfront Developments (see below).

The disposal of sewage and industrial effluent into estuarine waters is highly undesirable.

In the first instance, alternative means of disposal should be investigated as a means of controlling pollution from these sources. In the case of sewage effluent, options include land disposal of treated effluent (e.g. for watering golf courses) or ocean disposal.

The disposal of industrial effluent to any waters is undesirable, particularly effluents containing toxic or persistent substances. Land disposal or the high-temperature incineration of toxic wastes is preferable. As yet, a high-temperature incinerator has not been constructed in New South Wales. Discharge to sewer is an option, but has a number of possible problems. First, the effluent may not be acceptable because of interference with sewage treatment processes. Second, sewage treatment processes may not effectively remove the offending industrial pollutants. Finally, any untreated or residual pollutants will be discharged along with the treated sewage effluent, generally into a waterbody. Notwithstanding these problems, a number of industrial effluents are acceptable for discharge to sewer and are amenable to sewage treatment processes.

If estuarine disposal of either sewage or industrial effluent is the only viable option, the outfall location should be chosen to minimise adverse impacts on the estuary. Factors to be taken into account include the capacity of the estuary to accept the pollutant (i.e. the dilutional capacity and advective and dispersive transport processes of the estuary), together with the location of fishing grounds, fish nurseries, oyster leases and water bird feeding grounds, and the use of the estuary for recreational pursuits. If disposal to an estuary is necessary, consideration should be given to flood-tide storage and ebb-tide release to
maximise flushing. An hydraulic model will generally be necessary to investigate the movement and concentrations of sewage and industrial effluent discharged into an estuary (see Appendix G). Other controls, including discharge monitoring, may also be necessary.

Urban Runoff

Stormwater outfalls should be located at points of maximum flushing. Outfalls should generally not discharge into artificial waterways and should be located a sufficient distance from the canal entrance to ensure that the effluent is not carried back into the waterway system by tidal currents. Discharge into dead-end canals must be avoided.

The use of toxic substances such as herbicides and pesticides which may drain into the artificial waterways via urban runoff should be avoided. The careful use of garden fertilisers in accordance with the manufacturer’s instructions should minimise adverse affects on water quality.

Canal Estates

The two principles for controlling water pollution associated with canal estates are first, to ensure that the canals themselves are well-flushed and second, to minimise pollution from the associated dwellings and infrastructure.

Only estuarine waters with a permanent opening to the sea are suitable for canal estates. Shallow coastal lagoons with an intermittently open entrance are not suitable.

Proponents of canal estate developments have to satisfy the Public Works Department that the size and configuration of the canals will not adversely affect tidal hydraulics and sediment processes in the main estuary, and that the canals themselves will not be subject to excessive erosion or sedimentation. As part of these studies the flushing behaviour of the canals should be investigated and quantified. A numerical or physical model of the canal system will be necessary for this task.

Septic tank and pit disposal systems are unacceptable for sewage disposal at canal estates. Typically, water tables are high and land fill is of a sandy nature; contamination of canal waters with effluent readily occurs under these conditions. A necessary condition for the development of canal estates should be the provision of full sewerage, preferably with connection to a reticulated town sewerage system. If this is not possible, sewage re-use or land application of treated effluent at an adequate distance from the estuary should be considered.

Consideration will also need to be given to stormwater runoff from canal estates. Where appropriate, gross pollutant traps, sedimentation ponds and artificial wetlands should be constructed to intercept sediment and nutrient loads in stormwater runoff. Stormwater outfalls should be located to ensure maximum flushing not only from the canals, but from the estuary itself. Where possible, outfalls should be located outside the canal network. Even when this is done, consideration needs to be given to the likelihood and consequences of stormwater being carried back into the canals on the ebb tide.

Marina and boat harbour facilities are often constructed in conjunction with canal estates. These areas can generate significant water pollution. To ensure adequate flushing, marinas and boat harbours should be located outside the canal system or as close as possible to the entrance of the system. Other methods of pollution control within the facilities are discussed below.

The gardens of canal estate dwellings provide a potential source of canal pollution by pesticides, herbicides, fertilisers and organic matter. Sediment removal from stormwater runoff will reduce pesticide, herbicide and nutrient loads. Source control of these pollutants can only be effected by changing community behaviour. This can only be done through community education programs.

Dredging and Extractive Operations

Dredging and extractive operations can increase suspended sediment loads and may remobilise any contaminants in the sediments.

To minimise these effects - and it should be noted that they cannot be prevented - tailings
should be pumped to settlement ponds. Settlement ponds adjacent to the waterway must be constructed above mean high water mark. These ponds must be protected against inundation by a flood of a specified annual exceedance probability, usually 10%, i.e. the flood that has a 10% chance of occurrence in any year. This is to ensure that entrained silt from dredging operations is not returned to the waterway by small floods. In some situations this level of flood protection may not be adequate, e.g. where valuable estuarine habitats are at risk, or where the nature of the silt makes it particularly hazardous to the aquatic environment. In these circumstances, an appropriate level of flood protection should be determined in consultation with officers of the New South Wales Fisheries.

Catch drains should be constructed to divert clean rainfall runoff around and away from the settlement ponds.

Where dredging or extractive industry operations are likely to generate high silt levels, floating 'silt curtains' made from geotextile fabric should be used to enclose the dredge and dredge head and so minimise the escape of silt laden water.

Marinas and Recreation Facilities

Marinas, boat harbours and other recreational facilities can generate significant water pollution of various types.

Marinas must provide pump-out facilities for the disposal of sewage and sullage from berthed vessels. Ideally, pump out facilities should be connected to a reticulated sewerage system. Facilities must be provided for disposal of bilge and ballast water.

All fuelling, maintenance or servicing of boats involving potential pollutants (including de-fouling and anti-fouling compounds) must be restricted to a designated boat servicing area which does not drain into the waterway (to prevent contamination of the waterway). In the case of marinas associated with canal estates, the boat servicing area should preferably be located outside the canal system.

Precautions must be taken to avoid fuel spills. Drip trays must be provided for fuel bowsers and all pumps, hoses and pipes must be checked regularly for weaknesses and leaks.

Waterfront Developments

The principal water pollution problems with waterfront developments are siltation, especially from steep sites, and pollution by stormwater runoff and sewage.

The most positive means of control is by limiting waterfront development. Only those developments that particularly rely on the waterway should be permitted, e.g. marinas. Developments for which the waterway is an attractive but non-essential amenity, e.g. housing, should be banished from the immediate waterside by a buffer zone.

When construction is on a steep waterfront site, the developer may be required to install and maintain silt traps prior to the area being grassed and stabilised (see Section 5 of this Appendix).

Waterfront developments must be fully sewered, preferably with a connection to a reticulated town sewerage system. If this is not possible, the preferred disposal option is the use of treated effluent for irrigation (at an adequate distance from the estuary), evaporation or exfiltration. Ocean discharge of tertiary treated effluent is acceptable if land disposal is not practicable. Septic tank and pit disposal facilities are unacceptable means of sewage disposal for waterfront developments.

Land Reclamation

Water quality problems of concern with land reclamation include increased suspended solids levels, the leaching of toxic and other pollutants from the fill, and possible alterations to the salinity regime and flushing behaviour of the estuary.

Silt cloth (geotextile fabric) can be used to minimise siltation during fill operations. Foreshore erosion is a potential problem once fill operations are complete. Material to be used as fill for land reclamation should be carefully investigated. Contaminated material or material likely to leach potentially toxic substances should not be used.
Hydraulic, water quality and sediment transport models may be needed to assess the likely impact of the altered configuration and bathymetry of the estuary on flushing, salinity and sediment behaviour.

**Road, Bridge and Dam Construction**

The major water quality problems associated with these operations are increased levels of erosion and siltation during the construction process and a reduction in estuarine flushing associated with the loss of tidal prism caused by these structures.

Silt traps may be required during construction operations and before new earthworks have been grassed and stabilised.

Hydraulic models will be required to assess the impact of these structures on the flushing behaviour of the estuary.

### 5 MANAGEMENT GUIDELINES FOR DIFFUSE SOURCE POLLUTION

**Stormwater**

Where appropriate, gross pollutant traps, sedimentation ponds and artificial wetlands should be constructed to reduce the amounts of sediment, trash and nutrients entering the waterway. Wetlands stocked with emergent macrophytes are quite effective in the uptake of both nutrients and toxic materials.

Erosion control measures should be put in place at urban construction sites to reduce sediment loads in urban stormwater runoff. Contractors should submit erosion control plans to the Department of Conservation and Land Management (formerly the Soil Conservation Service) for comments and approval. In the ACT, control of construction activities now extends down to the level of individual dwellings. The Department of Conservation and Land Management has prepared an instructive video on erosion control at construction sites.

Both the Environment Protection Authority and the Department of Conservation and Land Management have published manuals for the management and control of stormwater runoff (SPCC, 1989; SCS, 1978).

Where appropriate, consideration should be given to the chemical treatment of stormwater flows to reduce bacterial levels, suspended solids or nutrients. However, it is noted that artificial wetlands by themselves are quite effective at nutrient removal and suspended solids reduction, and when used in conjunction with large expanses of clean open water, are quite effective at bacterial control (sunlight kills the bacteria).

When siting stormwater outlets, factors which must be taken into consideration include the assimilative capacity of the estuary and the existing uses of the waterway, including fishing, oyster farming and recreation.

**Agricultural Runoff**

Close attention should also be given to the runoff from agricultural areas, which may contain excessive levels of sediments, nutrients and pesticides. The Soil Conservation Services of the Department of Conservation and Land Management should be consulted when necessary to reduce problems of soil movement; the Department of Agriculture should be consulted in regard to farm management. Wetlands of significance should be fenced to prevent access by stock.

An adequate foreshore buffer strip (of at least 30 metres width) must be retained to reduce siltation of the waterway. The Department of Conservation and Land Management should be consulted concerning the width of the strip.

In areas where contamination of watercourses is likely, fertilisers must be applied with care.

The role of the remnant areas of uncleared Crown land in the protection of water quality should be considered before any new uses for agriculture or forestry are allowed.

### 6 MANAGEMENT GUIDELINES FOR COASTAL LAGOONS

Water quality in coastal lagoons is sensitive to a number of factors, including entrance opening, nutrient inflows from sewage, urban...
runoff and from the use of fertilisers, and the use of toxic chemicals and anti-fouling paints.

When lagoon entrances are opened by dredging, settlement ponds must be provided to prevent entrained silt being returned to the lagoon from dredge spoil.

The use of toxic pesticides in the catchment area must be in accordance with the requirements of the Pesticides Act, i.e. application must be strictly in accordance with directions.

In areas where contamination of watercourses is likely, fertilizers should be applied with care.

Nutrient concentrations (particularly forms of nitrogen and phosphorus from surface runoff and domestic effluent) must be minimised to prevent the excessive growth of algae, both microscopic (phytoplankton) and large attached algae. Stormwater from roads, car parks and other paved surfaces must be channelled away from the lagoon wherever possible.

Where the catchment is urbanised or is zoned for urban development, sewerage works with disposal outside the catchment area are a prerequisite. The preferred option for sewage disposal is discharge of treated effluent to land at an adequate distance from the lagoon (for irrigation, evaporation or exfiltration). Ocean discharge of secondary treated effluent may be acceptable if land disposal is not practicable.

Dissolved oxygen levels in lagoon waters must be substantial and should not fluctuate too widely. Long term levels which fall below 4-5 mg/l and short-term levels below 2 mg/l are undesirable.

The handling of potential chemical pollutants, such as boat fuels and anti-fouling paints, must be avoided within lagoons.

Caravan parks and service amenities must be fully sewered and placed beyond the foreshore buffer zone.

7 REFERENCES


1 INTRODUCTION

Sand and gravel extraction from an estuary and its floodplains can have major adverse effects on estuarine habitats and ecosystems. These include the destruction of foreshore and intertidal areas, the smothering of seagrass beds, reduced water quality and marked changes to the hydraulic and sediment transport processes of the estuary.

For these reasons, extractive industry operations in New South Wales are subject to the provisions of the Environmental Planning and Assessment Act, 1979 (EPA Act). This Act requires that proponents obtain development consent or approval from the appropriate consent authority before extractive operations commence. As part of this process, it is necessary that the environmental impact of the proposed operation be assessed, often in the form of an Environmental Impact Statement (EIS).

This Appendix describes the Environmental Impact Assessment for extractive industries, be they located in estuaries or elsewhere. First, potential adverse and beneficial effects of extractive industries in estuaries are identified, together with the agencies responsible for their control.

2 ENVIRONMENTAL EFFECTS

Some ten regulatory authorities are responsible for various facets of extractive industry management in New South Wales (see Table L1). The large number of authorities reflects the diverse nature of impacts of sand and gravel extraction. Table L2 summarizes the adverse and beneficial environmental effects associated with sand and gravel extraction and indicates the regulatory and advisory authority responsible for the management of these effects.

### Table L1 Public Authorities Responsible for Various Aspects of Extractive Industries Management, New South Wales

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>PWD</td>
<td>Public Works Department</td>
</tr>
<tr>
<td>DWR</td>
<td>Department of Water Resources</td>
</tr>
<tr>
<td>Councils</td>
<td>Local Councils</td>
</tr>
<tr>
<td>Fisheries</td>
<td>New South Wales Fisheries</td>
</tr>
<tr>
<td>DOP</td>
<td>Department of Planning</td>
</tr>
<tr>
<td>NPWS</td>
<td>National Parks and Wildlife Service</td>
</tr>
<tr>
<td>EPA</td>
<td>Environment Protection Authority</td>
</tr>
<tr>
<td>MSB</td>
<td>Maritime Services Board</td>
</tr>
<tr>
<td>CLM</td>
<td>Department of Conservation and Land Management</td>
</tr>
<tr>
<td>RTA</td>
<td>Roads and Traffic Authority</td>
</tr>
</tbody>
</table>
## Table L2  Adverse and Beneficial Impacts of Extractive Industries in Estuaries

<table>
<thead>
<tr>
<th>ENVIRONMENTAL IMPACT</th>
<th>LOCATION</th>
<th>REGULATORY &amp; ADVISORY AUTHORITIES</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Waterways</td>
<td>River Banks</td>
</tr>
<tr>
<td>ADVERSE(^a)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bank Erosion</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Channel Instability</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Increased marine salt intrusion</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Changed tidal levels</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Changed flood behaviour</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Coastal erosion</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Turbidity</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Damage to fish hauling grounds and shellfish</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Damage to habitat (wetlands, shoals and seagrass)</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Reduced pollutant assimilation (deeper waters)</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Loss of wetlands and littoral rainforests</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Loss of agricultural land</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Noise</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Aesthetic damage to landscape</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Decreased conservation values</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Restricted public access</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Maintenance cost devolved to the public</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Infrastructure costs</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>BENEFICIAL(^a)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Improvement in navigability</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Improvement in tidal flushing</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Increased waterway area for recreation, fish and wildlife</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Placement of sand for coastal beach nourishment</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Wetland and Island formation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Scenic/recreational lake formation</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Public access improvement [where included as a condition of development consent]</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Reduction in flood risk</td>
<td>Yes</td>
<td></td>
</tr>
</tbody>
</table>

\(^a\) Under Section 90 of EPA Act, local councils are required to consider all of the above adverse and beneficial effects, together with social and economic issues, in deciding on development applications.

\(^b\) Where lakes connect to an estuary.
3 ENVIRONMENTAL IMPACT

Purpose

The basic purpose of the environmental impact assessment (EIA) process for estuarine-based extractive industries is to ensure that they do not cause unacceptable adverse effects to estuarine habitats and ecosystems or to other estuarine activities.

The EIA process has been established by Government to ensure that appropriate assessments are carried out as an integral part of the decision-making process.

Consent or Determining Authorities

In New South Wales, the consent or determining authority for extractive industries will either be a Local Council or a State Government Authority.

Under Part IV of the EPA Act, extractive industries are listed as 'designated developments' and require the preparation and public exhibition of an Environmental Impact Statement (EIS). The Local Council is the consent authority when the local planning instrument or an applicable Regional Environmental Plan requires consent under Part IV of the Act.

Under Part V of the EPA Act, a State Government Authority becomes the determining authority when consent of the local council is not required under Part IV of the Act and the State authority either authorises or carries out an extractive operation. The State authority must first determine if the extractive industry is likely to have a significant environmental impact. If this is the case, the State authority must prepare or cause to be prepared and publicly exhibited an EIS prior to determining whether or not the proposed activity should be approved.

Permit Authorities

In addition to obtaining consent or approval for the project, the proponent must also obtain statutory permits.

These permits signify that the various Government Departments and Agencies are satisfied that any adverse consequences of relevance to their jurisdictions have been evaluated and found to be acceptable. The permit may only involve a declaration by the Authority that it does not object to the project. Alternatively, the permit may be quite detailed and impose stringent conditions on the proponent. Generally, Permit Authorities require the full findings of an Environmental Impact Statement to be available before a permit is issued. Table L3 shows the ten 'permitting authorities', their governing legislation and the type of permit required.

Environmental Impact Statement

Where an EIS is required under Parts IV and V of the EPA Act, the development proponent must initially write to the Director of Planning requesting formal requirements of its form and content. The EIS must be prepared in accordance with these requirements, which are drafted specifically for each individual development. The Department of Planning has also published a general set of guidelines regarding the preparation of EIS's for extractive industries which provide useful information (DOP, 1989).

During preparation of the EIS, the proponent should also hold discussions with the local council and a range of State Government departments to ensure that the EIS satisfactorily addresses their specific statutory responsibilities and requirements. The list of formal EIS requirements determined by the Director of Planning will also indicate which State authorities should be contacted by the proponent.

The public exhibition of an EIS, the assessment of impacts by the consent or determining authority and the decision-making process, must all be in accordance with the provisions of the EPA Act and regulations. The matters which consent authorities must consider when deciding on development applications are listed under Section 90 of the EPA Act.

An often necessary, important, and at times costly component of many EIS's for estuarine-based extractive industries is the development and use of numerical models to simulate the
Table L3  Details of Consenting Authorities and Statutory Permits for Estuarine-Based Extractive Industries

<table>
<thead>
<tr>
<th>Authority</th>
<th>Legislation</th>
<th>Permit</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Soil Conservation Act</td>
<td>Control of tree removal.</td>
</tr>
<tr>
<td>Local Councils</td>
<td>Environmental Planning and Assessment Act</td>
<td>Consent Authorities under Part IV.</td>
</tr>
<tr>
<td>Department of Water Resources</td>
<td>Rivers and Foreshores Improvement Act</td>
<td>Permit to undertake excavation.</td>
</tr>
<tr>
<td>Department of Public Works</td>
<td>Rivers and Foreshores Improvement Act</td>
<td>Permit to undertake excavation.</td>
</tr>
<tr>
<td>Fisheries</td>
<td>Fisheries and Oyster Farms Act</td>
<td>Concurrence or approval for dredging or reclamation works, cutting of mangroves.</td>
</tr>
<tr>
<td>Department of Mineral Resources</td>
<td>Crown Lands Act</td>
<td>Approval to issue extractive licences by CLM.</td>
</tr>
<tr>
<td>Maritime Services Board</td>
<td>Navigation Act</td>
<td>Conditions on works affecting navigation.</td>
</tr>
<tr>
<td>Environment Protection Authority</td>
<td>Noise Control Act</td>
<td>Noise limit licence.</td>
</tr>
<tr>
<td></td>
<td>Clean Waters Act</td>
<td>Discharge licence.</td>
</tr>
<tr>
<td></td>
<td>Wilderness Act</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Endangered Species (Interim Protection) Act</td>
<td>Licence to take or kill endangered fauna.</td>
</tr>
</tbody>
</table>

effects of extraction on tidal hydraulics, flood behaviour, salinity, water quality, sediment movement, bed and bank stability, etc. (see Appendix G for details).

The Approval Process

The approval process is typically an involved and lengthy procedure because of the number of authorities to be consulted, the differing requirements and procedures of each authority, and the technical complexity and diversity of issues to be addressed.

There are four distinct phases in the approval process for an extractive industry:

- formulation of a proposal by the proponent,
- agreement by the landowner to proceed,
- obtaining development consent/approval, and
- obtaining the necessary permits.

In practice, the proponent usually follows a procedure involving the definition of the requirements of each consent or permit authority, the investigation of the resource, the design of proposed works, the undertaking of EIS studies, and compliance with monitoring requirements.

All authorities should be consulted as early as possible in the project formulation phase so that their requirements can be efficiently incorporated into the investigation and design phases of the project.

Formulation of a Proposal

In this phase, the proponent identifies a resource proposed for development. The
identification of suitable resources can be undertaken by a private developer or by a government authority.

Private developers are encouraged to liaise with the appropriate consent and permit authorities early in the proposal formulation phase. These authorities may highlight difficulties or problems of which the developer is unaware.

In some cases, State authorities will identify suitable or preferred resources for development and invite tenders from the private sector. The Regional Environmental Plans of Sydney and Penrith Lakes (DOP, 1986a, 1986b) include examples of sand and gravel resources so identified. In other cases, State authorities have developed and marketed the product themselves, e.g. the Lake Budgewoi sand deposits, which are marketed by the Department of Conservation and Land Management.

When State authorities have identified resources and invited tenders for their development, the authorities will generally have made a preliminary assessment of the environmental impact to ensure that there are no major impediments to development. Private tenderers will still be required to assess the environmental consequences of extractive operations. However, the scope of these studies will depend upon the extent and detail of the preliminary environmental studies made by the State authority.

Agreement by the Landowner

At some stage during or after the formulation process, the proponent needs to obtain agreement with the landowner to use the site for extractive industry. In the case of privately owned land, this agreement is a normal commercial matter between the proponent and landholder. However, in the case of Crown land, the 'owner' for the purposes of negotiating approval is the Department of Conservation and Land Management (CLM). In this case, the normal procedure for obtaining agreement is as follows:

- the resource is identified by CLM, or by another public authority, or a private operator;
- CLM undertakes a 'Land Assessment' of the site to determine whether extractive use is acceptable in terms of land management (as required by the Crown Lands Act, 1989);
- CLM selects the operator ('proponent') who will undertake the extraction, usually by a process of public competition;
- the proponent undertakes the usual EIS procedure, as described below, and may also be required to prove the value of the resource by drilling, etc. A temporary licence may be issued for this purpose;
- the proponent is then given consent to submit a development application;
- if development approval is granted, CLM can issue a lease or licence which specifies royalty rates, requirements for site rehabilitation, or any other conditions.

Development Consent/Approval

Once an application has been lodged with the consent or determining authority, the environmental impact assessment process begins, which if successful leads to approval under the EPA Act. In most cases, extractive industries will require consent under Part IV of this Act. Key steps in this process and the interactions between proponent and consent authority are shown in Table L4.

Permitting Process

Once planning approval is obtained, together with the required statutory permits, approval can then be effected, with or without conditions.

Note that for Crown land, the Minister for Conservation and Land Management is not obliged to issue a lease or licence, notwithstanding the proponent having received landowners consent and development approval under the EPA Act. The issue of a lease or licence for extraction from Crown lands is subject to a Land Assessment Study by CLM.
### Table L4  Steps in the Development Consent/Approval Process

<table>
<thead>
<tr>
<th>Applicant</th>
<th>Consent or Determining Authority</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prepare and submit Development Application to Consent Authority, or application to determining authority, together with an EIS if required.</td>
<td>Assess application. Public exhibition of EIS. Public comments. Review comments. Notify applicant of any required changes. Make necessary changes. Development approval given, possibly including conditions, or refused.</td>
</tr>
</tbody>
</table>

### 4 IMPACT ASSESSMENT

In gaining planning approval for a proposed extractive industry, the proponent will need to demonstrate that the development will not adversely affect the physical and biological systems of the estuary. This will normally form part of the EIS procedure.

The removal of sand and gravel from the bed or banks of an estuary or its floodplain can significantly affect four estuarine processes:

- estuarine hydraulics, i.e. the water level and discharge behaviour of the estuary in response to ocean tide and freshwater flows (including floods),
- estuarine water quality, including salinity behaviour,
- estuarine fluvial processes, i.e. sediment erosion and deposition processes and the transport of sediment along the estuary, and
- estuarine ecosystems, i.e. the aquatic and terrestrial plants and animals using the estuary and its surrounds as habitat.

At the crudest level, removal of sand and gravel will alter either the cross-sectional area available for flow (both tidal and flood) and possibly the storage characteristics of the affected reach. These changes will influence water level and discharge behaviour. Extractive operations, be they water based dredging or land-based earth removal, can increase turbidity through higher levels of suspended fine material that may settle out with detrimental effects to aquatic habitat.

It should be noted that all of the above four systems interact. The hydraulic system influences water movement, and hence water quality behaviour and sediment transport. Altered patterns of sediment transport, erosion and deposition, together with changes to salinity or water quality behaviour, may adversely affect estuarine habitats and ecosystems.

Assessing the impact of sand and gravel extraction on these systems is a technically demanding task. The impact of these changes is often best assessed by means of 'estuary process models', which are first used to simulate the behaviour of these systems for the current estuarine bathymetry and circumstances, and then used to assess the impact of the proposed bathymetric or topographic changes accompanying sand and gravel extraction. Detailed biological studies are required to determine the likely impacts on aquatic and terrestrial flora and fauna. Estuary Process Models are discussed in Appendix G.
5 REFERENCES


APPENDIX M  MANAGEMENT OF THREATENED FAUNA

1 Introduction
2 Available Data
3 Biological Surveys
4 Waders
5 Little Terns
6 Osprey
7 Platypus
8 Australian Grayling
9 Areas of Research
10 References

1 INTRODUCTION

A number of fauna species found in New South Wales estuaries have been listed as threatened, endangered or rare (see Appendix E). These animals are managed under several international and national agreements and several pieces of State legislation (see Appendix E). Particular attention needs to be paid to the conservation of habitats and ecosystems of importance to these species.

Management plans have been prepared for a number of threatened species, but not all. This Appendix provides a brief overview of existing plans of management. It does not specifically address all threatened species, although aspects of management strategies described here are often appropriate to a number of species. The management guidelines of this Appendix should be read in conjunction with the more general guidelines for the management of estuarine activities of Appendix J.

2 AVAILABLE DATA

In assessing the impact of human activities and developments on an estuary, it is essential to realise the importance of wildlife to the estuarine system. In the preparation of Local Environmental Plans, Environmental Impact Statements and Fauna Impact Statements, it will be necessary to assemble information on species type and distribution in the estuary of interest. Some of this information may be available on environmental databases; other information can be obtained from experts or by surveys (see Section 3).

There are three environmental databases that may provide useful information about estuarine species:

- ERIN, the Environmental Resources Information Network initiated by the Commonwealth Department of Arts, Sport, the Environment, Tourism and Territories;
- NRIC, the National Resource Information Centre managed by the Department of Primary Industries and Energy; and
- ERMS, the Environmental Resource Mapping Scheme managed by the New South Wales National Parks and Wildlife Service.

Not only should these databases be consulted for available information, but any additional biological information collected for EIS purposes (e.g. species distribution, population size, etc.) should be lodged with one of the above authorities for incorporation into a database to assist with future management decisions.

3 BIOLOGICAL SURVEYS

Notwithstanding the existence of the above databases, the management of endangered estuarine species is often hampered by a lack of basic information concerning population numbers, needs and preferences. Thus, an essential aspect of better management is the need to undertake biological surveys to obtain such data, to identify preferred feeding and breeding sites, to assess the impact of specific developments, etc.
In those estuaries harbouring threatened species, such surveys are regarded as an essential component of both the environmental assessment process for proposed developments and the preparation of Local Environmental Plans. Under the new Endangered Fauna (Interim Protection) Act, 1991, a Fauna Impact Statement (FIS) is required for any development or activity that is likely to significantly affect the habitat of protected fauna.

The design and undertaking of such surveys and the interpretation of the results is a specialist exercise. The National Parks and Wildlife Service should be consulted on these matters.

4 WADERS

The Australian Government is a signatory to a number of international agreements aimed at the protection and conservation of wading birds (see Section 2 of Appendix E).

Because of the number of estuaries of significance to waders within the state, the New South Wales government has a particular role to play in their protection. Sites of significance are listed in order of priority in Table M1. Two New South Wales estuarine areas have already been declared as areas of international importance under the Ramsar Convention: Towra Point Nature Reserve adjacent to Botany Bay and Kooragang Nature Reserve adjacent to the Hunter River estuary. Additional estuaries are likely to be nominated because of their large wader populations. Twenty-three coastal wetlands of significance to waders in New South Wales have already been identified (see Table M1).

Table M2 shows a list of wader species ranked in order of priority for conservation. The welfare of the Hooded Plover is of particular concern. Recently, this species was listed by the Council of Nature Conservation Ministers as a 'vulnerable species'.

Five major issues have been identified in relation to the conservation of waders (Smith, 1991; NPWS, 1991):

- poor representation of wader habitat in reserves;
- habitat degradation in estuaries and increasing pressure for further developments detrimental to wader habitat;
- excessive disturbance of beach-nesting sites, inter-tidal feeding grounds and high tide roosts;
- pollution of coastal wetlands; and
- poor knowledge of use of inland wetlands by waders, particularly in relation to the effects of river regulation.

The management objective for waders in New South Wales is to prevent and reverse the long-term decline in population numbers brought about by habitat degradation and direct disturbance to birds. To this end, the following guidelines should be adhered to:

- Surveys should be undertaken to identify specific feeding, roosting and nesting sites used by waders. In particular, beach surveys should be made to identify specific nesting sites used by beach nesting species, such as the Hooded Plover, the Beach Stone-Curlew, the Pied Oystercatcher and the Red-Capped Plover. The National Parks and Wildlife Service should be consulted before undertaking such surveys.

- The impact of specific land-use developments on wader numbers should be monitored to provide a basis for future management decisions. The National Parks and Wildlife Service should be consulted before undertaking such monitoring programs.

- To ensure appropriate protection of wader habitats, there needs to be negotiation and cooperation between the various agencies, organisations and individuals responsible for estuarine land-use planning.

- Where a land-use development will unavoidably degrade existing wader habitat, alternative habitat should be created by the developer. Further, the effectiveness of the new habitat needs to be monitored. The developer should consult with the National Parks and Wildlife Service on both these matters.

- Important beach nesting areas should be closed to public access during the breeding season. Works that involve major disturbances to breeding areas should not be undertaken during the breeding season.
Table M1  Priority Sites for Waders in New South Wales

<table>
<thead>
<tr>
<th>Priority 1</th>
<th>Priority 2</th>
<th>Priority 3</th>
<th>Priority 4</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>11. Lake Macquarie</td>
<td>20. Long Reef</td>
</tr>
<tr>
<td></td>
<td></td>
<td>13. Hawkesbury River Wetlands</td>
<td>22. Lake Illawarra</td>
</tr>
<tr>
<td></td>
<td></td>
<td>15. Ulladulla Coastline</td>
<td></td>
</tr>
</tbody>
</table>


Note: Sites listed north to south under each priority. Only coastal wetlands listed; insufficient information to determine priorities among inland wetlands.

Table M2  Priority Wader Species for Conservation

<table>
<thead>
<tr>
<th>Priority 1</th>
<th>Priority 2</th>
<th>Priority 3</th>
<th>Priority 4</th>
<th>Priority 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>7. Sooty Oystercatcher</td>
<td></td>
<td>17. Sanderling</td>
<td>23. Pectoral Sandpiper</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>19. Ruff</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>


Note: Species listed in taxonomic order under each priority.

Measures should be undertaken to reduce the risk of pollution to important feeding sites. This may involve the exclusion of certain high risk activities. Where the presence of such activities is unavoidable, contingency plans should be prepared to deal with inadvertent pollution events, such as toxic spills.

5  LITTLE TERNs

The survival of the Little Tern in New South Wales is at extreme risk (see Section 17 of Appendix E).

The Little Tern is listed as an endangered species by the Council of Nature Conservation Ministers, it is listed under Schedule 12 of the New South Wales National Parks and Wildlife Act, 1974, and it is listed in Annexes to the JAMBA and CAMBA treaties (see Appendix E). Concern for the species has led to the preparation of a national conservation strategy, presently in draft form and not yet released. (Hill, in press), and a draft Management Plan prepared by the New South Wales National Parks and Wildlife Service (NPWS, 1990).

The broad management objective for the Little Tern is to prevent it from becoming an extinct breeding species in Australia, with the most
immediate objective being to increase the number of young being fledged each year.

If the Little Tern is to survive in New South Wales, the following management guidelines will need to be stringently adopted.

- Important breeding sites need to be protected and managed primarily for Little Terns. This may involve:
  
  (a) Careful management of nesting habitats, e.g. clearing sites of encroaching vegetation, shifting nests to safer areas, artificially incubating eggs, creating artificial nesting sites and chick shelters, etc.

  (b) Protection of and minimising disturbance to breeding birds by limiting the access of vehicles, people and predators.

  (c) The appointment of wardens to supervise nesting areas.

  (d) Signposting to alert the public to the importance of breeding areas.

  (e) Reducing Silver Gull populations within the vicinity of Little Tern colonies by siting waste depots away from Little Tern breeding areas and eliminating ponded water areas where gulls can roost.

- Important inter-tidal feeding sites need to be protected from potential threats which include pollution, changes to estuarine drainage patterns, reclamation of tidal areas, damming of tidal creeks and loss of habitat (seagrass beds, mangroves and saltmarshes).

- Oil spills have a major adverse effect on feeding sites. Contingency plans to protect important feeding areas in particular and estuarine areas in general from oil spills are necessary.

- Beach users should be made aware of the plight of the Little Tern through public education programs, e.g. signs around important habitat sites explaining these matters. The cooperation and support of beach users are essential to management success.

- It is essential to monitor population numbers and breeding success on a regular basis. The National Parks and Wildlife Service should be consulted on necessary monitoring programs.

6 OSPREY

In New South Wales the Osprey is confined to coastal districts north of the Hunter River. The current breeding population is only about 50 pairs. The major threat to the Osprey is loss or degradation of habitat caused by urban development. The broad management objective is to prevent the Osprey from becoming extinct in New South Wales. Management Guidelines are as follows:

- It is essential that Osprey nests and nest trees be protected. This can be done by incorporation of appropriate areas as reserves under the National Parks and Wildlife Act, Conservation Agreements, Regional Environmental Plans or by protective zoning in a Local Environmental Plan.

- Important feeding sites require identification, mapping and protection (mullet is a common food item). The impact of proposed developments on these sites needs to be thoroughly assessed. The National Parks and Wildlife Service should be consulted on these matters.

- The effective protection of Osprey breeding and feeding sites will require liaison and cooperation between a considerable number of government and public organisations, e.g. Maritime Services Board, New South Wales Fisheries, Department of Conservation and Land Management, Department of Planning, Department of Water Resources, Coastal Committee, Heritage Council, Catchment Management Committees and relevant local and county councils.

- Public education and management is required to assist in the protection and management of Ospreys.

- Population size and breeding success needs to be monitored on a regular basis. The National Parks and Wildlife Service should be consulted before undertaking such surveys.
7 PLATYPUS

Platypus inhabit the upper reaches of some estuaries. The principal management objective is to ensure that existing platypus populations are not threatened by further habitat degradation. Management guidelines are as follows:

- Platypus populations and the water quality of their habitats should be monitored regularly. The National Parks and Wildlife Service should be consulted before undertaking such surveys.

- The impact of specific projects on Platypus numbers and the water quality of their habitat should be monitored for use in future management strategies.

- Land acquisition may be necessary for the protection and management of Platypus habitats.

- Wherever possible, the construction of works affecting Platypus habitats (e.g. river improvement and flood mitigation works) should be commenced and finished either prior to the Platypus breeding season (October to March) or after the young have left their burrows and are dispersing (March to May).

- Potential sources of oil spills, pesticides and other toxic substances should be identified and contingency plans for dealing with inadvertent spills should be developed by appropriate authorities.

- Farmers should be encouraged to maintain riparian riverbank vegetation and to limit stock grazing and watering along riverbanks where Platypus occur.

- Careful attention should be given to sand and gravel extraction operations in or close to Platypus habitats. Extracted materials and topsoil should be stored in flood-free locations; all affected riverbanks should be restored and revegetated with native species; snags within waterways should not be removed, or if removed, should be stored for replacement in the river channel on completion of works.

- Power boats should be discouraged from using river reaches that are important Platypus habitats.

- The extent of illegal gill net and drum net fishing in Platypus habitats should be assessed and if necessary controlled by stricter law enforcement. The effects of commercial and recreational fishing on platypus populations need to be investigated.

- Netting for fish or eels should not be permitted in Platypus habitats.

- The effective protection of Platypus and their habitats will require liaison and cooperation between a considerable number of government organisations and agencies, e.g. New South Wales Fisheries, National Parks and Wildlife Service, Department of Planning, Department of Conservation and Land Management, Roads & Traffic Authority, Department of Water Resources, Electricity Commission, Public Works Department, and the Environment Protection Authority.

- Public education will be an important element in the successful protection of Platypus.

8 AUSTRALIAN GRAYLING

The Australian Grayling is the sole surviving species of a unique Southern Hemisphere family of fishes. The New Zealand Grayling is now extinct. The Australian Grayling's distribution is limited to the south-east coast of New South Wales, Victoria and Tasmania.

Whilst adult Grayling are essentially freshwater inhabitants, it is thought that larval Grayling drift downstream into estuarine or ocean waters, and that juvenile Grayling ascend rivers probably about six months after hatching.

Guidelines for management of Grayling populations are as follows:

- Non-destructive surveys should be undertaken to identify population numbers on a regular basis;

- Those waterways known to contain Grayling populations must receive special protection from both in-stream and in-catchment
activities which lead to habitat loss, habitat
degradation and reduction in water quality;
and
- new barriers to the migration of Grayling,
such as weirs, must not be placed on
waterways harbouring Grayling and any
barriers already in place on these waterways
should be modified or removed to enable the
passage of Grayling and other species.

9 AREAS OF RESEARCH

There are a number of key areas that require
research to establish the effects of human
disturbance on estuarine fauna, especially
threatened species. This information is
essential to adequately assess the long-term
detrimental effects of human development and
to put effective management plans in place.
Areas of specific research include:

- monitoring the migration of birds along
costal areas;

- measurement and classification of the
nutrient status of estuaries to identify
patterns of nutrient cycling relevant to
costal wildlife;

- investigation of the effects of toxic
substances such as pesticides on bird
populations, including any increased
sensitivity at critical life cycle stages, e.g.
nesting;

- increased understanding of local movements
by birds within and between selected key
habitats;

- investigation of the hazards to non-target
species of biting-insect control with insecti-
cides;

- an examination of the effects of fishing on
bird populations, e.g. reduction in fish
stocks, effects of bait collection in inter-tidal
areas, etc.;

- effects of benthic invertebrate distributions
on the distribution and diet of waders;

- the general effects of environmental change
(e.g. logging, river regulation, etc.) on the
numbers and productivity of benthic
invertebrates and the associated effects on
the feeding regime of waders; and

- use of population genetics to understand the
biology of coastal wildlife.

10 REFERENCES

Hill, R. (in press). 'A Strategy for the
Conservation of the Little Tern in Australia'.
Australian National Parks and Wildlife Service.

the Little Tern (Sterna albifrons) in New South
Wales'. Species Draft Management Plan No.
1, New South Wales National Parks and
Wildlife Service.

Waders (Suborder Charadrii) in New South
Wales'. New South Wales National Parks and
Wildlife Service.

Smith, P., (1991). 'The Biology and
Management of Waders (Suborder Charadrii) in
New South Wales'. New South Wales National
Parks and Wildlife Service.
APPENDIX N  ESTUARY REHABILITATION

1 Introduction
2 Sedimentation
3 Eutrophication
4 Entrance Shoaling
5 Entrance Closure
6 Loss of Waterway Area
7 Loss of Wildlife Habitat
8 Foreshore Erosion
9 Restricted Foreshore Access

1 INTRODUCTION

An essential part of an Estuary Management Plan is the definition of a set of environmental objectives for the estuary. Whilst, the impact of future land-use activities can be controlled by planning and regulatory requirements, what about existing land-use activities? In many cases, environmental objectives will not be met because of existing problems.

Several options are available for the control of existing problems. First, it may be possible to 'undo' some of the damage and let the estuary recover naturally. This can be achieved through controls to limit or prohibit certain detrimental activities. The declaration of an important roost site for waders as a reserve is one such example. However, in many cases, it will not be possible to 'undo' past damage in this way. In these circumstances, 'rehabilitation works' may provide a means of reducing existing problems and achieving the desired environmental objectives.

In general, rehabilitation works can never return the estuary to the way it was. At best they ameliorate a problem; they make conditions better than they were.

In assessing the need for such works, the usual factors of costs, benefits, effectiveness and affordability need to be addressed. However, there is a more fundamental issue that also needs to be considered, namely the effect of the proposed works on the interacting estuarine processes that form the estuarine 'system'. In solving one problem with 'rehabilitation works', care must be taken not to create new problems and not to exacerbate existing ones. Thus, a 'systems approach' is essential in considering the effectiveness and effects of rehabilitation works.

In general, most estuaries have changed significantly during the time of European settlement. Detrimental changes include increased shoaling in channels, embayments and entrances; excessive algal growth that decays to form a malodorous 'black ooze'; reduced flushing; increased turbidity levels; high bacterial counts; reduced visual amenity because of litter and poorly sited or unattractive developments; loss of or disruption to both terrestrial and aquatic habitat; and declining fishery production.

In many cases, these changes have been gradual and associated with ever-increasing levels of urban development along the estuarine fringe. In some cases, the changes may have been relatively rapid and caused by industries located along the estuary.

This Appendix presents examples of estuarine management issues, together with a brief description of the advantages and disadvantages of potential management works. The comments made here are indicative only. The effectiveness of any rehabilitation works are site and problem specific and must be investigated as such.
Extensive urbanisation and land development has greatly increased the rate of sediment supply to estuaries. Much of this sediment is transported to the estuary via stormwater discharges. 'Urban' sediment, which is often fine in size and rich in organic matter, is quite different from the naturally occurring 'clean' sandy sediments (see Appendix H). Whilst the replacement of sandy areas with muds favours the growth of mangroves (Dunstan, 1990), the decay of excessive levels of green algae can deposit a layer of malodorous black ooze on the bed of the estuary (Cheng, 1981; King, 1988).

In most estuaries, it is generally neither financially feasible nor biologically wise to undertake large scale dredging programs to remove sediments.

However, it is possible to reduce incoming sediment before it reaches the estuary. This can be done by reducing sediment loads at source or by removing sediment from stormwater discharges (by settling or by filtration).

An essential part of any sediment control program is the identification of all sources of sediment. A significant proportion of sediments may come from upland areas and be difficult to control, e.g. soil loss from agricultural areas. Notwithstanding the use of sediment removal devices, the implementation of sound soil conservation practices - both in urban and rural areas of the catchment - is essential if future sedimentation problems are to be controlled (see Appendix H).
Reduction at Source

Within urban areas, reduction of sediment inflows at source is generally only effective for specific sites generating high sediment yields, e.g. building sites, road construction sites, etc. In these circumstances, filter sediment traps (see below) are typically used to reduce sediment load.

The reduction of sediment yield from agricultural areas will only come about through better land-use management practices. There is some indication that this is occurring under the auspices of Total Catchment Management programs, but it will take a long time before agricultural sediment inflows are significantly reduced at source.

General management guidelines for diffuse source pollutants, including sediment inflows, are discussed in Section 5 of Appendix K.

Gross Pollutant Traps

Gross pollutant traps are designed to remove litter, debris and coarse sediments from urban stormwater flows. This is done by screening to remove litter and coarse debris and by settling to remove coarse sediments. Gross pollutant traps are ineffective in removing medium and fine-sized sediments. Because of their small size, there is scope for the incorporation of gross pollutant traps into existing stormwater drainage systems.

Filter Sediment Traps

Filter sediment traps are small structures that use a filter material such as gravel, geotextile fabric or straw bales to filter out sediment. Typically, the filter medium clogs quickly and removal efficiencies fall. Such structures are generally only useful as temporary measures until more permanent devices are installed or the source of the sediment is controlled. Filter sediment traps are commonly used to control sediment loss from construction sites.

Settlement Ponds

Settlement ponds enable medium-sized and possibly fine-sized sediment to settle out of stormwater inflows. The ponds generally have to be relatively large in size to trap a high proportion of the sediments.

Settlement ponds can be either 'wet' or 'dry'. 'Wet' ponds trap a proportion of the stormwater runoff (and its associated sediment and dissolved contaminants) after runoff has ceased, and so physically reduce the volume of stormwater entering the estuary. 'Dry' ponds drain after stormwater runoff ceases; only settled sediment is left behind.

Artificial Wetlands

Artificial wetlands generally consist of extensive shallow ponds containing water on a permanent or semi-permanent basis. The ponds are planted with vegetation of appropriate types. Wetlands remove sediment from stormwater by a mixture of settling and filtration. The lengthy residence time associated with large pond size facilitates settling; the vegetation acts as a filter. Artificial wetlands also remove a considerable proportion of dissolved nutrients through uptake by vegetation and adsorption onto sediment particles, and can be quite effective in reducing bacterial levels.

To be effective, wetland areas generally need to be large. However, significant benefits can be achieved with well designed and well maintained ponds of small size ('mini-wetlands'). Apart from sediment and nutrient removal, artificial wetlands have a number of other benefits: they provide habitat for wildlife and they can serve recreational and educational needs (parkland).
Eutrophication causes the excessive growth of aquatic plants, which can be free-floating algae of microscopic size (phytoplankton), large attached algae (e.g. seaweeds), or rooted plants such as seagrasses or reeds (macrophytes). Growth is stimulated by increased levels of nitrogen, phosphorus and other aquatic nutrients (see Section 9 of Appendix C). Nutrient levels in estuarine waters have increased in response to the widespread use of fertilisers in agricultural areas and home gardens, and inflows of stormwater and treated sewage effluent from urban areas.

The problems of excessive plant growth can be manifested in several ways. First, the increased growth of macrophytes may lead to the 'clogging' of waterways and 'choking' of embayments, so reducing recreational amenity. Second, the increased growth of phytoplankton can lead to an 'algal bloom' (see Section 9 of Appendix C). Under bloom conditions, the algal mass can reach a size such that the water cannot supply sufficient dissolved oxygen for respiration. In these circumstances, fish can die of asphyxiation and plants may die through lack of nutrients. The subsequent anaerobic decay of organic matter can result in the production of foul smelling hydrogen sulphide ('rotten egg gas').

Before attempting to control eutrophication, it is essential that all sources of nutrient inflows be identified and that the limiting nutrient(s) be identified. Failure to do so may lead to the imposition of expensive controls on one source of nutrients when the problem is sustained by another less controllable source (e.g. agricultural runoff).
Reduction at Source

It may be possible to reduce the inflow of nutrients to an estuary by more careful management practices, especially in agricultural areas.

Nutrient Removal

Eutrophication can be controlled by nutrient removal. Often a significant proportion of aquatic nutrients is adsorbed, or attached to, sediment particles, especially to medium and fine sediments. Thus, sediment traps can be used to remove nutrients from stormwater (see Section 2). Alternatively, wetlands are also effective at nutrient removal (see Section 2). Treated sewage effluent is a common and significant source of nutrient inflow to many estuaries. Nutrient removal processes at the treatment works can be used to reduce nutrients from this source. Alternatively, it may be possible to dispose of the effluent on land or divert it to another less sensitive location.

Harvesting

Harvesting involves the harvesting, baling and removal of aquatic vegetation, typically macrophytes (large rooted plants). A floating mechanical device - specific to the waterway and problem - is generally designed and constructed to harvest and bale the plants. Harvesting is achieved by means of cutters, rakes, suction heads, etc. In New South Wales, extensive harvesting is undertaken at Lake Illawarra and Tuggerah Lake.

If harvesting is to be an effective means of nutrient removal from the waterbody, it is important to foster plant growth. To this end, it may be necessary to dedicate and maintain shallow areas for macrophyte growth. In some circumstances, it may be necessary to create additional shallow areas for this purpose.

The ecological consequences of harvesting need to be carefully evaluated before embarking on a dedicated harvesting program. Although the aquatic ecosystem has been severely distorted by nutrient inflows and uptake by plants, the method or the time of harvesting may be important to certain fauna.

Beach Cleaning

Certain wind and tidal conditions may cause the extensive build-up of weed on estuarine shores (the wrack zone). 'Sea grass' (Zostera spp) is especially susceptible to removal and deposition along estuarine shores. If substantial, these accumulations can interfere with access to the water and reduce recreational amenity. Such material can be removed by means of a tractor-hauled beach-cleaner. Long, unobstructed sandy foreshores lend themselves to this means of removal.

It should be noted that the wrack zone is part of the natural estuarine environment. The ecological consequences of beach cleaning should be evaluated and programs designed accordingly.
4 ISSUE: Shoaling of Estuary Entrances

The shoaling of estuary entrances results from a complex interaction of coastal and estuarine processes (see Section 9 of Appendix B and NSW Government, 1990, for details). Historically, entrance shoals hindered navigation when coastal shipping was an important means of transport. These days, entrance shoals are of concern because of hindrance to commercial fishing and recreational vessels and because shoals may reduce estuary flushing and exacerbate water quality problems.

Entrance shoals are typical of Lake and River estuaries. In New South Wales, only Drowned River Valley Estuaries are not characterised by such shoals. Entrance shoals are 'dynamic' in that their configuration continually waxes and wanes in response to the ever-changing interplay of coastal, estuarine and meteorological processes. If the shoals are dredged, they will reform in a relatively short time.

The satisfactory management of entrance shoals requires considerable investigation of the freshwater, tidal and longshore sediment transport processes (see NSW Government, 1990, for details). Failure to undertake the necessary studies can lead to unforeseen erosion and deposition and marked changes to estuary shoaling patterns. The analysis and design of entrance control works is best left to experts.

MANAGEMENT OPTIONS:
1. Training Works
2. Dredging
3. Sand By-Passing
4. Do Nothing
Training Works

Most major river estuaries along the New South Wales coast are characterised by the presence of 'training walls'. These structures improve navigation in several ways: by causing the entrance shoal to form in deeper water offshore; by stabilising the location of the entrance channel; and by orientating the channel to incoming waves. These works are more appropriately termed 'training breakwaters'. In some estuaries, internal training walls are used to stabilise deepwater channels and improve navigability.

By themselves training works rarely provide a complete solution to the problem of entrance shoaling. Supplementary dredging is nearly always required.

Training works have a number of detrimental effects on estuarine ecosystems, including loss of foreshore and possibly inter-tidal habitat, altered current patterns that may cause floating fish larvae to settle in inhospitable areas of the estuary, and altered flushing characteristics that may lead to poorer water quality in backwater areas.

Dredging

Historically, a fleet of ocean-going dredges was used to maintain navigable water depths in New South Wales estuaries. Most entrances were dredged annually. With the decline in coastal shipping, the requirement for this expensive service declined and the dredging fleet gradually diminished.

A disadvantage of Training breakwaters is that they interfere with the longshore movement of sand and may cause beach erosion. Dredging does not suffer from these disadvantages. Moreover, dredging is a flexible management measure: dredging strategies can be adapted to changing management objectives and patterns of estuary use. Further, dredging has the added benefit that dredge spoil can be used to create new habitats, e.g. islands for beach nesting birds or new inter-tidal areas. However, dredging tends to be required on a more-or-less regular basis, and tends to be expensive, especially if extensive areas are involved and frequent dredging is required.

Sand By-Passing

Sand by-passing refers to the pumping of sand around training walls. It can be a very effective way of maintaining longshore drift whilst minimising the updrift build-up and downdrift erosion caused by entrance training walls.

Do Nothing

'Do Nothing' is certainly the most appropriate option until the problem has been properly investigated. It is then necessary to weigh the benefits and advantages against the costs and disadvantages. If the scale is evenly poised or tilted towards the latter, 'do nothing' may still be the most appropriate option.
5 ISSUE:
The Opening and Closure of Entrances to Lake Estuaries

MANAGEMENT OPTIONS:
1. Building Control Measures
2. Entrance Opening
3. Control of Shoaling

Many Lake Estuaries (or lagoons) along the New South Wales coastline have entrances that are only intermittently open to the ocean. At other times, the entrance is partially or completely blocked by sand shoals or a sand barrier (see NSW Government, 1990).

Entrance closure is a natural phenomenon that results from complex interactions between freshwater, tidal and longshore sediment transport processes (see NSW Government, 1990). Extreme care needs to be given to the design and operation of works aimed at 'improving' entrance behaviour. Failure to do so may exacerbate existing problems or create new ones. The analysis and design of entrance control works are tasks best left to experts.

The opening of a closed entrance can have adverse effects. Typically, lagoon water levels fall, and may expose large reaches of the shore or even the bed of the lagoon. If the sediments contain organic matter they may be both unsightly and malodorous.

Similarly, entrance closure can also have a number of detrimental effects on the amenity of a lagoon. Partial or complete closure generally causes lagoon water levels to rise. This in turn may interfere with the operation of stormwater drains or septic tank systems along surrounding flat foreshores. Entrance closure leads to a reduced flushing of the lagoon and may exacerbate water quality problems (see Section 6 of Appendix K).
Building Control Measures

Surprisingly, many of the problems caused by entrance closure can be addressed by building controls and planning measures. For example, the use of septic tanks in areas of high water table is likely to lead to pollution of the estuary with septic tank effluent. The provision of sewerage or septic pumpout systems will control this problem. In some instances, the re-siting of developments situated on low, poorly drained lands may be the most cost-effective control measure.

Entrance Opening

Considerable care needs to be given to the consequences of opening an entrance which is normally closed. On the one hand it might not be financially feasible or practical to create an opening; on the other hand it may trigger significant adverse ecological consequences. Lagoon water levels will be lowered, perhaps exposing unsightly and strong smelling bed sediments. However, where an Estuary Management Plan indicates that entrance opening is justified, this is normally done by excavating a pilot channel across the ocean barrier. To be effective, the difference in water levels between the lagoon and the ocean needs to be considered, as does the state of tide when 'break through' occurs.

Entrance opening and closure works need not be expensive. To cut a pilot channel may only require a bulldozer and an excavator. Similarly, a bulldozer can 'close' such a channel by pushing in sand. Thus, a system of entrance opening and closure in response to defined lagoon conditions may be a viable and cost-effective management measure. Such a procedure could be used to ameliorate water quality problems and unacceptable growths of noxious weeds. The outgoing water will drain pollutants with it; exposure of the shores and bed to the air will kill aquatic weeds. It may be possible for marine biologists to devise a strategy of controlled opening and closure that is in harmony with or even enhances the biological needs of fish and prawns.

Control of Shoaling

The dredging of entrance shoals often provides a cost-effective means of entrance management. For lagoons where the average entrance condition is generally satisfactory, a mobile dredging plant can be used to improve tidal flushing during those limited times of excessive shoaling. For other lagoons where the average entrance condition is generally unsatisfactory, more extensive and longer duration dredging may be required. In these circumstances, the construction of training works to reduce longshore transport may be useful.
Preserving the Tidal Prism

In the past, the foreshores of many estuaries were reclaimed for a variety of purposes: housing and industrial developments, solid waste landfill sites, carparks, playing fields, fisheries infrastructure, etc.

Not only did these developments reduce the biological capacity of the estuary through loss of habitat, they also physically reduced the tidal prism of the estuary, i.e. the volume of water that flows in and out of the estuary each tide cycle (see Section 7 of Appendix B). This in turn reduces tidal velocities and leads to shoaling. It also results in reduced flushing and can exacerbate water quality problems.

In addition, tidal barrages, flood control levees and causeways have been constructed along many New South Wales estuaries. The blocking effect of tidal barrages is often complete; the blocking effect of flood control levees is also more or less total, although most levees incorporate culverts to allow local drainage waters to escape to the estuary. Causeways may incorporate culverts to allow some upstream penetration of tidal waters.

In all the above cases, these structures not only reduce the tidal prism, they also inhibit or prevent the upstream migration of fish and other aquatic fauna and reduce available habitat.

<table>
<thead>
<tr>
<th>MANAGEMENT OPTIONS:</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Development Controls</td>
</tr>
<tr>
<td>2. Increasing Waterway Surface Area</td>
</tr>
<tr>
<td>3. Dredging</td>
</tr>
</tbody>
</table>
Development Controls

In most cases, it is impossible physically or financially 'undo' the loss of waterway area through reclamation and the construction of barrages, levees, etc. As a management measure, it is important to retain the existing tidal prism and to carefully investigate the consequences of any future developments that would further reduce the prism.

The existing tidal prism can be most effectively preserved or increased by development controls, e.g. causeways should be provided with culverts of adequate size to facilitate tidal flows; structures within the tidal zone should be supported on piles rather than solid fill; it may be possible for floodgates in flood control levees to be left open to admit tidal inflow and outflow.

Increasing Waterway Surface Area

The most effective way of increasing the tidal prism of an estuary is to increase the surface area of tidal waters. This can be achieved by converting reclaimed areas back into wetlands, or by creating tidal lakes in upstream tidal reaches. Chipping Norton, where tidal lakes some 120 ha in extent have been created along the upper tidal reaches of the Georges River, is an example of a tidal lakes scheme.

Dredging

Dredging of bottom sediments can also increase the tidal prism of an estuary. Bottom dredging increases the tidal range (and tidal prism) by allowing waters to move in and out of the estuary faster. However, bottom dredging is generally not as effective at increasing the tidal prism as increasing waterway surface area.
Estuaries provide a variety of habitats for wildlife. Habitats around the shores of the estuary include mangrove areas, salt marshes, beaches, inter-tidal flats and seagrass meadows (see Appendix D). In a number of estuaries, many of these habitats have been lost or degraded through foreshore reclamation, sand and gravel extraction and altered hydraulic regimes.

The loss of natural foreshore through reclamation is a major cause of reduced and degraded habitats. Mangrove and saltmarsh areas have been reclaimed for solid-waste dumps, sports ovals, housing developments, etc. Not only is there a direct loss of habitat and tidal prism (see Section 6), but ensuing urban activities often interfere with the use of the remaining habitat by wildlife (see Appendix M).

Sand and gravel extraction, unless closely controlled, can destroy or degrade terrestrial, inter-tidal and sub-tidal habitats (see Appendix L for details concerning the Management of Extractive Industries). The freshwater and tidal regimes of many estuaries have been significantly altered by various works (see Section 6). Changes to the freshwater and tidal regimes of an estuary affect both estuarine habitats and the creatures that use them.
Alternative Sites for Development

The most direct way to stop the loss of habitat is to direct developments to alternative sites. In areas of critical habitat, this may be essential for the survival of threatened species.

Creation of New Habitat Areas

There is considerable scope to create new habitat areas and rehabilitate degraded ones.

Dredge spoil can be used to create dedicated islands for beach nesting birds, the breeding success of which is currently reduced by human activities on estuary foreshores. Dredge spoil can also be used to create additional shallows, inter-tidal areas and wetlands.

The creation of wetland areas not only provides additional habitat, but if well designed, wetlands can be used to remove sediment and nutrients from urban and possibly rural stormwater flows.

It may be possible to foster the colonisation of new seagrass areas or the recolonisation of degraded areas by replanting seagrasses.

The creation of buffer strips and areas of riparian vegetation along upper estuary areas, especially where adjacent areas are used for agriculture, will assist in reducing sediment and nutrient inflows from these areas.
ISSUE:
Foreshore Erosion

The occurrence of significant areas of bank erosion is a natural feature characteristic of many estuaries. Unfortunately, foreshore erosion has often been exacerbated by human activities (see Appendices F and H). There are a number of adverse effects associated with bank erosion: infrastructure, such as roads and buildings, may be placed at risk; remnant bands of foreshore vegetation may be lost; recreational, aesthetic and habitat values may be impaired; the eroding bank is a source of fine-grained sediment that may settle out in sheltered embayments, margins or wetlands, thereby further changing habitat and recreational values.

In planning counter measures, it is essential that the causes, agents and mechanisms of foreshore erosion are understood. The ‘cause’ of erosion is the basic reason for its occurrence, e.g. natural river migration, changes in discharge or sediment load over time, site-specific activities, such as clearing, excavation, etc. The ‘agents’ of erosion are those processes that physically remove the sediment from the eroding site, e.g. flood or tidal currents, boat or wind waves. Finally, the ‘mechanisms’ of erosion deliver the sediment to the ‘agents’, e.g. bank slumping, piping, undercutting at base of bank, etc.

Failure to fully investigate the causes, agents and mechanisms of erosion may lead to the design and construction of ineffective ‘improvement’ works, if indeed improvement works are needed.

MANAGEMENT OPTIONS:
1. Do Nothing
2. Relocation of Assets
3. Foreshore Stabilisation
4. Foreshore Reinstatement
Do Nothing

In some cases, it may be preferable to let the natural erosive processes occur, thereby increasing the waterway area (and possibly inter-tidal and foreshore habitats).

Relocation of Assets

This measure involves shifting infrastructure and other assets away from areas at risk of erosion. This could be done by physical relocation or by public purchase and demolition of any buildings. In the latter circumstances, the publicly acquired land should be developed for a use compatible with erosion hazard.

Foreshore Stabilisation

The three common means of foreshore stabilisation are vegetation, revetments and regrading.

(a) Vegetation

In addition to controlling erosion, foreshore vegetation has a number of other benefits: it may enhance fishery habitat, provide wildlife habitat, screen riverside developments and provide shade. Wherever possible, natural vegetation should be retained on foreshores and riverbanks. Direct clearing of vegetation should be controlled; developments should be separated from the foreshore by buffer strips, which contain a 'sacrifice strip' along the foreshore to accommodate long-term erosion and a 'habitat strip' to provide habitat for plant communities.

Vegetation stabilises foreshores in the following ways: emergent plants dissipate wave energy and trap sediment; ground cover minimises rilling; root mats reinforce soil strength; transpiration removes soil moisture, lowers water tables and so increases bank stability. The effectiveness of vegetation increases with the density and landwards extent of the vegetative cover. Riverbank vegetation will not control erosion on the outside of bends during river meandering. In these circumstances, the seat of erosion is at the toe of the bank, usually beneath plant roots.

In revegetating areas, it is important that appropriate natural vegetation of local origin is used. In this way, genetic integrity of the area is maintained.

(b) Revetments

Revetments are structural 'walls' that provide a barrier between the waters of an estuary and the land. They may be constructed to stabilise the bank material, to resist erosion of the bank face or to restrict undercutting at the toe of the bank. Revetments are described in detail in the Coastline Management Manual (NSW, 1990).

(c) Bank Regrading

Regrading involves cutting back a steep eroding bank to a more gentle slope (say 1 vertical: 4 horizontal), grassing and planting with shrubs and trees. Several points should be noted about this method of erosion control. First, regrading may involve removal of existing trees and shrubs to the detriment of short-term stability and wildlife habitat. Second, if the erosion agent is bank undercutting, regrading will not be successful unless a rock toe is provided. Further, if a rock toe is to be provided, why not take advantage of the existing vegetation - supplemented by additional planting if necessary - and avoid the expense of regrading.

Where a rock toe is not economically justified, supplementary planting of the existing bank with natural shrubs may be the most appropriate solution, possibly combined with drainage works where high water tables are a problem.

Regrading is warranted in those situations where open park-like settings are required with easy pedestrian access down the bank. Where regrading is adopted as a control measure, the design must be subject to a full slope stability analysis. The incorporation of horizontal benches in the design will allow steeper bank slopes to be used.

Foreshore Reinstatement

Another means of controlling erosion is to rebuild the foreshore with fill material. This approach is most suitable for foreshores of low elevation. Material used as fill needs to be carefully selected. If the fill is sacrificial, the material must be suitable for foreshore exposure throughout the fill deposit. Alternatively, if the area is stabilised against erosion, e.g., by training works, poorer quality fill can be used.
There are a number of opportunities and problems associated with foreshore reinstatement. Opportunities include the establishment of wider foreshore reserves, the creation of wetlands and other areas of desirable habitat, and the improvement of foreshore appearance through 'soft' visual features, such as vegetated gentle slopes, rather than the abrupt features of revetments.

Possible problems include loss of waterway area, loss of inter-tidal or underwater habitat, and the temptation to use unsuitable material as fill.

As a general guideline, reclamation should not extend beyond the limits of the historical shoreline (which can be determined from old maps). Moreover, it is necessary to consider the effect of the changed shoreline on flow patterns and fluvial processes in other areas. Often dredge tailings are a readily available and inexpensive source of fill material. However, the reclamation of foreshores with dredge tailings cannot be justified on these grounds alone. Rather, the reclamation must be in terms of wider issues such as amenity and use, and the natural dynamics of estuarine systems.
<table>
<thead>
<tr>
<th>ISSUE:</th>
<th>MANAGEMENT OPTIONS:</th>
</tr>
</thead>
</table>
| Restricted Foreshore Access | 1. Land Purchase  
2. Siting Controls  
3. Development Setback  
4. Foreshore Design |

These days, with increased leisure time and interest in outdoor recreation, the foreshores of estuaries have become popular sites for both passive and active recreational activities. Unfortunately, these uses are often limited by past development decisions that have restricted access to foreshore lands. The management of this problem is more a matter of ensuring that current and future development decisions do not perpetuate past mistakes (i.e. planning considerations) rather than ameliorating these mistakes.
Land Purchase

The purchase and removal of offending developments, together with the development of the area for recreational purposes, is one means of redressing past mistakes and improving foreshore access. This solution tends to be expensive if implemented on a large scale; waterfront properties tend to be highly valued. Nevertheless, the purchase of several properties can markedly increase access to the foreshore, which can then serve as a focus for water-based recreation.

Siting Controls

Siting controls are aimed at ensuring that future developments do not physically or visually alienate the public from the foreshore. Foreshore land needs to be regarded as a scarce public resource and managed as such. Careful thought needs to be given to the location of infrastructure in public foreshore reserves: is it necessary for the desired recreational use? Could it be satisfactorily located further away from the foreshore? Amenities not related to recreational use should not be located in small foreshore reserves.

Development Setback

Development setback is another planning control. It is aimed at ensuring that future developments are set back far enough from the foreshore to provide a public foreshore reserve adequate for future recreational needs. When Crown land is subdivided, a public foreshore reserve should be retained. Similarly, a condition for the rezoning of private foreshore lands should be the deeding of a public foreshore reserve to council. Where the foreshore is eroding, the public lands should include a sacrificial buffer strip. The width of the foreshore strip should be such that public use is not inconvenienced or restricted by adjacent developments.

Foreshore Design

Careful foreshore design can facilitate public use and recreation in areas of limited foreshore access. In small foreshore reserves, consideration should be given to encouraging only one or two key activities, probably passive in nature, e.g. picnicking. More active recreational pursuits should be encouraged in large areas where there is less likelihood of inter-activity interference.

Suitable pedestrian access to the foreshore is essential if foreshore recreation is to be encouraged. Ground slopes of gentle batter, access ramps and stairways can be used. One potential problem area is the land-water interface. Revetments form a 'hard' barrier that can limit access to the beach and to intertidal areas. Wherever conditions allow, unrestricted access should be retained between the foreshore bank and the foreshore beach.

10 REFERENCES


<table>
<thead>
<tr>
<th><strong>GLOSSARY OF TECHNICAL TERMS</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Algae</strong></td>
</tr>
<tr>
<td><strong>Advective Transport</strong></td>
</tr>
<tr>
<td><strong>Aerobic Bacteria</strong></td>
</tr>
<tr>
<td><strong>Algal Bloom</strong></td>
</tr>
<tr>
<td><strong>Amenity</strong></td>
</tr>
<tr>
<td><strong>Amphibian</strong></td>
</tr>
<tr>
<td><strong>Amphipods</strong></td>
</tr>
<tr>
<td><strong>Anaerobic Bacteria</strong></td>
</tr>
<tr>
<td><strong>Angiosperms</strong></td>
</tr>
<tr>
<td><strong>Animal</strong></td>
</tr>
<tr>
<td><strong>Annual Exceedance Probability</strong></td>
</tr>
<tr>
<td><strong>Aquaculture</strong></td>
</tr>
<tr>
<td><strong>Arbovirus</strong></td>
</tr>
<tr>
<td><strong>Balanced Development</strong></td>
</tr>
<tr>
<td><strong>Baseline Monitoring</strong></td>
</tr>
<tr>
<td>Term</td>
</tr>
<tr>
<td>-------------------------------------------</td>
</tr>
<tr>
<td>Bed Load</td>
</tr>
<tr>
<td>Benthos, Benthic Organisms</td>
</tr>
<tr>
<td>Bio-deposition</td>
</tr>
<tr>
<td>Biological Oxygen Demand</td>
</tr>
<tr>
<td>Biomass</td>
</tr>
<tr>
<td>Biota</td>
</tr>
<tr>
<td>Bird</td>
</tr>
<tr>
<td>Cetaceans</td>
</tr>
<tr>
<td>Chemoautotroph</td>
</tr>
<tr>
<td>Crown Land</td>
</tr>
<tr>
<td>Degradation</td>
</tr>
<tr>
<td>Denitrification</td>
</tr>
<tr>
<td>Detritivores</td>
</tr>
<tr>
<td>Detritus</td>
</tr>
<tr>
<td>Diatoms</td>
</tr>
<tr>
<td>Diffuse Source Pollution</td>
</tr>
<tr>
<td>Term</td>
</tr>
<tr>
<td>-------------------------------------------</td>
</tr>
<tr>
<td>Discharge</td>
</tr>
<tr>
<td>Dispersive Transport</td>
</tr>
<tr>
<td>Dissolved Oxygen</td>
</tr>
<tr>
<td>Diurnal</td>
</tr>
<tr>
<td>Ebb Tide</td>
</tr>
<tr>
<td>Ecologically Sustainable Development</td>
</tr>
<tr>
<td>Ecosystem</td>
</tr>
<tr>
<td>Eddies</td>
</tr>
<tr>
<td>Elevated Half-Tide Levels</td>
</tr>
<tr>
<td>Endangered Fauna (In the context of the National Parks and Wildlife Act, 1974)</td>
</tr>
<tr>
<td>Entrance Bar</td>
</tr>
<tr>
<td>Environmental Impact Statement (In the context of the Environmental Planning &amp; Assessment Act, 1979)</td>
</tr>
<tr>
<td>Epibenthic Organisms</td>
</tr>
<tr>
<td>Epib iota</td>
</tr>
<tr>
<td>Epiphytic</td>
</tr>
<tr>
<td>Estuarine Processes</td>
</tr>
<tr>
<td>Estuarine Resources</td>
</tr>
<tr>
<td>Term</td>
</tr>
<tr>
<td>-------------------------------</td>
</tr>
<tr>
<td>Estuary</td>
</tr>
<tr>
<td>Estuary Management Process</td>
</tr>
<tr>
<td>Eutrophication</td>
</tr>
<tr>
<td>Event Monitoring</td>
</tr>
<tr>
<td>Fauna</td>
</tr>
<tr>
<td>(In the context of the National Parks and Wildlife Act, 1974)</td>
</tr>
<tr>
<td>Fauna Impact Statement</td>
</tr>
<tr>
<td>(In the context of the Endangered Fauna (Interim Protection Act), 1991)</td>
</tr>
<tr>
<td>Fish</td>
</tr>
<tr>
<td>(In the context of the Fisheries &amp; Oyster Farms Act, 1935)</td>
</tr>
<tr>
<td>Flocculate</td>
</tr>
<tr>
<td>Flood Mitigation Works</td>
</tr>
<tr>
<td>Flood Tide</td>
</tr>
<tr>
<td>Fluvial</td>
</tr>
<tr>
<td>Fluvial Processes</td>
</tr>
<tr>
<td>Fluvial Sediments</td>
</tr>
<tr>
<td>Foreshore</td>
</tr>
<tr>
<td>Technical Term</td>
</tr>
<tr>
<td>--------------------------------</td>
</tr>
<tr>
<td>Fortnightly Tides</td>
</tr>
<tr>
<td>Geomorphology</td>
</tr>
<tr>
<td>Gravitational Circulation</td>
</tr>
<tr>
<td>Habitat</td>
</tr>
<tr>
<td>Half-Tide Level</td>
</tr>
<tr>
<td>Heavy Metals</td>
</tr>
<tr>
<td>Herbivores</td>
</tr>
<tr>
<td>Humic Acid</td>
</tr>
<tr>
<td>Hydraulic Regime</td>
</tr>
<tr>
<td>Hydrolyse</td>
</tr>
<tr>
<td>Hydrophobic</td>
</tr>
<tr>
<td>Hypersaline</td>
</tr>
<tr>
<td>Induration</td>
</tr>
<tr>
<td>Intertidal</td>
</tr>
<tr>
<td>Invertebrate</td>
</tr>
<tr>
<td>Isohaline</td>
</tr>
<tr>
<td>Term</td>
</tr>
<tr>
<td>------</td>
</tr>
<tr>
<td>Land Assessment</td>
</tr>
<tr>
<td>Large-Scale Boundary Effects</td>
</tr>
<tr>
<td>Levee</td>
</tr>
<tr>
<td>Littoral Zone</td>
</tr>
<tr>
<td>Littoral Drift Processes</td>
</tr>
<tr>
<td>Macrolagaceae</td>
</tr>
<tr>
<td>Macrophytes (aquatic)</td>
</tr>
<tr>
<td>Mammal (aquatic)</td>
</tr>
<tr>
<td>Mammal</td>
</tr>
<tr>
<td>Mangroves</td>
</tr>
<tr>
<td>Marine Mammal</td>
</tr>
<tr>
<td>Marine Sediments</td>
</tr>
<tr>
<td>Mollusc</td>
</tr>
<tr>
<td>Native Plant (aquatic)</td>
</tr>
<tr>
<td>Neap Tides</td>
</tr>
<tr>
<td>Term</td>
</tr>
<tr>
<td>-------------------------</td>
</tr>
<tr>
<td>Nematode</td>
</tr>
<tr>
<td>Numerical Model</td>
</tr>
<tr>
<td>Pelagic Organisms</td>
</tr>
<tr>
<td>Phase Lag</td>
</tr>
<tr>
<td>Physical Model</td>
</tr>
<tr>
<td>Phytoplankton</td>
</tr>
<tr>
<td>Pinnipeds</td>
</tr>
<tr>
<td>Pneumatophores</td>
</tr>
<tr>
<td>Point-Source Pollution</td>
</tr>
<tr>
<td>Pollute</td>
</tr>
<tr>
<td>Polychaete</td>
</tr>
<tr>
<td>GLOSSARY OF TECHNICAL TERMS - Cont’d</td>
</tr>
<tr>
<td>--------------------------------------</td>
</tr>
<tr>
<td><strong>Poorly-Mixed Estuary</strong></td>
</tr>
<tr>
<td><strong>Protected Amphibian</strong></td>
</tr>
<tr>
<td>(In the context of the National</td>
</tr>
<tr>
<td>Parks and Wildlife Act, 1974)</td>
</tr>
<tr>
<td><strong>Protected Fauna</strong></td>
</tr>
<tr>
<td>(In the context of the National</td>
</tr>
<tr>
<td>Parks and Wildlife Act, 1974)</td>
</tr>
<tr>
<td><strong>Protected Native Plant</strong></td>
</tr>
<tr>
<td>(In the context of the National</td>
</tr>
<tr>
<td>Parks and Wildlife Act, 1974)</td>
</tr>
<tr>
<td><strong>Prototype Models</strong></td>
</tr>
<tr>
<td><strong>Public Lands</strong></td>
</tr>
<tr>
<td><strong>Receiving Waters</strong></td>
</tr>
<tr>
<td><strong>Recruitment</strong></td>
</tr>
<tr>
<td><strong>Reptile</strong></td>
</tr>
<tr>
<td>(In the context of the National</td>
</tr>
<tr>
<td>Parks and Wildlife Act, 1974)</td>
</tr>
<tr>
<td><strong>Residual Sediment Flux</strong></td>
</tr>
<tr>
<td><strong>Revetments</strong></td>
</tr>
<tr>
<td><strong>Riparian Vegetation</strong></td>
</tr>
<tr>
<td><strong>Runoff</strong></td>
</tr>
<tr>
<td><strong>Salinity</strong></td>
</tr>
</tbody>
</table>

190
<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Salinity Limit</td>
<td>The landward limit of salinity intrusion along an estuary. The location of the salinity limit changes with freshwater discharge, high freshwater inflows moving the limit downstream, whilst low flows allow salt and the salinity limit to migrate upstream.</td>
</tr>
<tr>
<td>Saltation</td>
<td>The movement of sediment particles along the bed of a waterbody in a series of 'hops' or 'jumps'. Turbulent fluctuations near the bed lift sediment particles off the bed and into the flow where they are carried a short distance before falling back to the bed.</td>
</tr>
<tr>
<td>Saltmarsh</td>
<td>A coastal wetland subject to tidal flooding and vegetated by grasses, herbs and low shrubs that are tolerant of high salinity.</td>
</tr>
<tr>
<td>Salt Wedge</td>
<td>The wedge-shaped body of saltwater that underlies freshwater in poorly-mixed estuaries.</td>
</tr>
<tr>
<td>Sand Bypassing</td>
<td>The pumping of marine sediments from the updrift side of an estuary mouth to the downdrift side, thereby preventing excessive entrance bar formation.</td>
</tr>
<tr>
<td>Sediment Load</td>
<td>The quantity of sediment moved past a particular cross-section in a specified time.</td>
</tr>
<tr>
<td>Semi-diurnal</td>
<td>A twice-daily variation, e.g. two high waters per day.</td>
</tr>
<tr>
<td>Shear Strength</td>
<td>The ability of the bed to accommodate flowing water without the movement of bed sediments. The shear strength of the bed depends upon bed material, degree of compaction, armouring, etc.</td>
</tr>
<tr>
<td>Shear Stress</td>
<td>The stress exerted on the bed of an estuary by flowing water. The faster the velocity of flow, the greater the shear stress.</td>
</tr>
<tr>
<td>Shoals</td>
<td>Shallow areas in an estuary created by the deposition and build-up of sediments.</td>
</tr>
<tr>
<td>Sirenid</td>
<td>Dugong.</td>
</tr>
<tr>
<td>Slack Water</td>
<td>The period of still water before the flood tide begins to ebb (high water slack) or the ebb tide begins to flood (low water slack).</td>
</tr>
<tr>
<td>Spring Tides</td>
<td>Tides with the greatest range in a monthly cycle, which occur when the sun, moon and earth are in alignment (the gravitational effects of the moon and sun act in concert on the ocean).</td>
</tr>
<tr>
<td>Storm Surge</td>
<td>The increase in coastal water levels caused by the barometric and wind setup effects of storms. Barometric setup refers to the increase in coastal water levels associated with the lower atmospheric pressures characteristic of storms. Wind setup refers to the increase in coastal water levels caused by an onshore wind driving water shorewards and piling it up against the coast.</td>
</tr>
</tbody>
</table>
## Glossary of Technical Terms - Cont’d

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stratigraphy</td>
<td>That branch of geology dealing with the ordering of rocks into their relative ages.</td>
</tr>
<tr>
<td>Sub-Aerial Sand Barrier</td>
<td>A sand barrier with crest level above high tide; usually vegetated.</td>
</tr>
<tr>
<td>Super-Elevation</td>
<td>See Storm Surge.</td>
</tr>
<tr>
<td>Surface Pollutants</td>
<td>Floating pollutants that do not mix effectively with water, e.g. oil.</td>
</tr>
<tr>
<td>Surfactants</td>
<td>Substances that reduce the surface tension of water and promote ‘wetting’.</td>
</tr>
<tr>
<td>Suspended Sediment Load</td>
<td>That portion of the total sediment load held in suspension by turbulent velocity fluctuations and transported by flowing water.</td>
</tr>
<tr>
<td>Swale</td>
<td>A topographic depression in a dune system that may retain water.</td>
</tr>
<tr>
<td>Tailings</td>
<td>The residue of mined ores after the target mineral has been extracted.</td>
</tr>
<tr>
<td>Tidal Amplification</td>
<td>The increase in the tidal range at upstream locations caused by the tidal resonance of the estuarine waterbody, or by a narrowing of the estuary channel.</td>
</tr>
<tr>
<td>Tidal Celerity</td>
<td>The speed of travel of the tidal wave along estuaries. Celerity depends upon the depth of water; the deeper the water, the greater the celerity.</td>
</tr>
<tr>
<td>Tidal Delta</td>
<td>The build-up of shoals in the lower reaches of an estuary due to the gradual accumulation of marine sands transported into the estuary through its entrance.</td>
</tr>
<tr>
<td>Tidal Distortion</td>
<td>The distortion of the tidal variation of water levels in shallow estuaries caused by the differences in the celerity of rising (faster) and falling (slower) water levels.</td>
</tr>
<tr>
<td>Tidal Exchange</td>
<td>The proportion of the tidal prism that is flushed away and replaced with ‘fresh’ coastal water each tide cycle.</td>
</tr>
<tr>
<td>Tidal Excursion</td>
<td>The distance travelled by a water particle from low water slack to high water slack and vice versa.</td>
</tr>
<tr>
<td>Tidal Lag</td>
<td>The delay between the state of the tide at the estuary mouth (e.g. high water slack) and the same state of tide at an upstream location.</td>
</tr>
<tr>
<td>Tidal Limit</td>
<td>The most upstream location where a tidal rise and fall of water levels is discernible. The location of the tidal limit changes with freshwater inflows and tidal range.</td>
</tr>
<tr>
<td>Term</td>
<td>Definition</td>
</tr>
<tr>
<td>-------------------------------------------</td>
<td>-----------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Tidal Loops</td>
<td>Inter-connecting channels between two tidal systems or across a large delta. Tidal Loops can generate a complicated pattern of residual flows that facilitate advective and dispersive transport.</td>
</tr>
<tr>
<td>Tidal Planes</td>
<td>A series of water levels that define standard tides, e.g. 'Mean High Water Spring' (MHWS) refers to the average high water level of Spring Tides.</td>
</tr>
<tr>
<td>Tidal Prism</td>
<td>The total volume of water moving past a fixed point on an estuary during each flood tide or ebb tide.</td>
</tr>
<tr>
<td>Tidal Propagation</td>
<td>The movement of the tidal wave into and out of an estuary.</td>
</tr>
<tr>
<td>Tidal Pumping</td>
<td>The generation of Elevated Half-Tide Levels because of the greater celerity of the flood tide compared to the ebb tide.</td>
</tr>
<tr>
<td>Tidal Range</td>
<td>The difference between successive high water and low water levels. Tidal range is maximum during Spring Tides and minimum during Neap Tides.</td>
</tr>
<tr>
<td>Tidal Trapping</td>
<td>The process whereby a discrete body of water is trapped over shallow shoal areas on the flood tide and separated from other water moving up the estuary. This facilitates mixing.</td>
</tr>
<tr>
<td>Tidally Averaged Models</td>
<td>Models that predict estuarine behaviour over periods greater than a tidal cycle, i.e. the temporal resolution is of the order of days, weeks or months.</td>
</tr>
<tr>
<td>Tidally Varying Models</td>
<td>Numerical models that predict estuarine behaviour within a tidal cycle, i.e. the temporal resolution is of the order of minutes or hours.</td>
</tr>
<tr>
<td>Tides</td>
<td>The regular rise and fall in sea level in response to the gravitational attraction of the sun, moon and planets.</td>
</tr>
<tr>
<td>Total Catchment Management</td>
<td>&quot;The coordinated and sustainable use of land, water, vegetation and other natural resources on a water catchment basis so as to balance resource utilisation and conservation&quot;.</td>
</tr>
<tr>
<td>Training Walls</td>
<td>Walls constructed at the entrances of estuaries to improve navigability.</td>
</tr>
<tr>
<td>Turbidity</td>
<td>A measure of the ability of water to absorb light.</td>
</tr>
<tr>
<td>Velocity Shear</td>
<td>The differential movement of neighbouring parcels of water brought about by velocity gradients. Velocity shear causes dispersive mixing, the greater the shear (velocity gradient), the greater the mixing.</td>
</tr>
<tr>
<td>Vertebrate</td>
<td>Animal with a backbone, e.g. fish, birds.</td>
</tr>
<tr>
<td>Water Quality</td>
<td>The suitability of the water for various purposes, as measured by the concentration or level of a wide variety of contaminants.</td>
</tr>
</tbody>
</table>
Waters
(In the context of the Clean Waters Act, 1970)

"Any river, stream, lake, lagoon, swamp, wetlands, unconfined surface water, natural or artificial watercourse, dam or tidal waters (including the sea) or part thereof, and includes waters stored in artificial works, water in water mains, water pipes and water channels, and any underground or artesian water, or any part thereof".

Well-Mixed Estuary

Estuary characterised by strong vertical mixing and weak or non-existent vertical salinity gradients.

Wildlife
(In the context of the National Parks and Wildlife Act, 1974)

"Fauna and native plants".

Wind Shear

The stress exerted on the water’s surface by wind blowing over the water. Wind shear causes the water to ‘pile up’ against downwind shores and generates secondary currents.

Wrack Zone

That area of the foreshore where flotsam and jetsam are deposited.
## GLOSSARY OF SCIENTIFIC NAMES

### 1. MAMMALS

<table>
<thead>
<tr>
<th>COMMON NAME</th>
<th>SCIENTIFIC NAME</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bottle-nosed Dolphin</td>
<td><em>Tursiops truncatus</em></td>
</tr>
<tr>
<td>Common Dolphin</td>
<td><em>Delphinus delphis</em></td>
</tr>
<tr>
<td>Dugong</td>
<td><em>Dugong dugon</em></td>
</tr>
<tr>
<td>False Water Rat</td>
<td><em>Xeromys myoides</em></td>
</tr>
<tr>
<td>Grassland Melomys</td>
<td><em>Melomys burtoni</em></td>
</tr>
<tr>
<td>Platypus</td>
<td><em>Ornithorhynchus anatinus</em></td>
</tr>
<tr>
<td>Southern Bush Rat</td>
<td><em>Rattus fuscipes</em></td>
</tr>
<tr>
<td>Southern Right Whale</td>
<td><em>Eubalaena australis</em></td>
</tr>
<tr>
<td>Water Rat</td>
<td><em>Hydromys chrysogaster</em></td>
</tr>
</tbody>
</table>

### 2. BIRDS

<table>
<thead>
<tr>
<th>COMMON NAME</th>
<th>SCIENTIFIC NAME</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bar-Tailed Godwit</td>
<td><em>Limosa lapponica</em></td>
</tr>
<tr>
<td>Beach Stone-Curlew</td>
<td><em>Burhinus neglectus</em></td>
</tr>
<tr>
<td>Black Duck</td>
<td><em>Anas superciliosa</em></td>
</tr>
<tr>
<td>Black-necked Stork</td>
<td><em>Xenorhynchus asiaticus</em></td>
</tr>
<tr>
<td>Black Swan</td>
<td><em>Cygnus atratus</em></td>
</tr>
<tr>
<td>Black-Tailed Godwit</td>
<td><em>Limosa limosa</em></td>
</tr>
<tr>
<td>Brahminy Kite</td>
<td><em>Haliastur indus</em></td>
</tr>
<tr>
<td>Broad-billed Sandpiper</td>
<td><em>Limbicola falcinellus</em></td>
</tr>
<tr>
<td>Brown Honeyeater</td>
<td><em>Lichmera indistincta</em></td>
</tr>
<tr>
<td>Bush Stone-Curlew</td>
<td><em>Burhinus grallarius</em></td>
</tr>
<tr>
<td>Caspian Tern</td>
<td><em>Hydroprogne caspia</em></td>
</tr>
<tr>
<td>Cattle Egret</td>
<td><em>Ardeola ibis</em></td>
</tr>
<tr>
<td>Chestnut Teal</td>
<td><em>Anas castanea</em></td>
</tr>
<tr>
<td>Common Sandpiper</td>
<td><em>Tringa hypoleucos</em></td>
</tr>
<tr>
<td>Common Tern</td>
<td><em>Sturna hirundo</em></td>
</tr>
<tr>
<td>Crested Tern</td>
<td><em>Sturna bergii</em></td>
</tr>
<tr>
<td>Curlew Sandpiper</td>
<td><em>Calidris ferruginea</em></td>
</tr>
<tr>
<td>Double-banded Plover</td>
<td><em>Charadrius bicinctus</em></td>
</tr>
<tr>
<td>Eastern Curlew</td>
<td><em>Numenius madagascariensis</em></td>
</tr>
<tr>
<td>Great Egret</td>
<td><em>Egretta alba</em></td>
</tr>
<tr>
<td>Great Knot</td>
<td><em>Calidris tenuirostris</em></td>
</tr>
<tr>
<td>Greenshank</td>
<td><em>Tringa nebularia</em></td>
</tr>
<tr>
<td>Grey Plover</td>
<td><em>Pluvialis squatarola</em></td>
</tr>
<tr>
<td>Grey-tailed Tattler</td>
<td><em>Tringa brevipes</em></td>
</tr>
<tr>
<td>Grey Teal</td>
<td><em>Anas gibberifrons</em></td>
</tr>
<tr>
<td>Gull-billed Tern</td>
<td><em>Sterna nilotica-Gelochelidon</em></td>
</tr>
<tr>
<td>Hardhead</td>
<td><em>Athyra australis</em></td>
</tr>
<tr>
<td>Hooded Plover</td>
<td><em>Charadrius rubricollis</em></td>
</tr>
<tr>
<td>Japanese Snipe</td>
<td><em>Gallinago hardwickii</em></td>
</tr>
<tr>
<td>Kelp Gull</td>
<td><em>Larus dominicus</em></td>
</tr>
<tr>
<td>Large Sand Plover</td>
<td><em>Charadrius leschenaultii</em></td>
</tr>
</tbody>
</table>
2. **BIRDS** - Cont’d

<table>
<thead>
<tr>
<th>COMMON NAME</th>
<th>SCIENTIFIC NAME</th>
</tr>
</thead>
<tbody>
<tr>
<td>Little Penguin</td>
<td><em>Eudyptula minor</em></td>
</tr>
<tr>
<td>Little Tern</td>
<td><em>Sterna albifrons</em></td>
</tr>
<tr>
<td>Long-toed Stint</td>
<td><em>Calidris subminuta</em></td>
</tr>
<tr>
<td>Lotusbird</td>
<td><em>Irediparra gallinacea</em></td>
</tr>
<tr>
<td>Magpie Goose</td>
<td><em>Anseranus semipalmata</em></td>
</tr>
<tr>
<td>Mangrove Warbler</td>
<td><em>Gerygone laevis</em></td>
</tr>
<tr>
<td>Marsh Harrier</td>
<td><em>Circus aeruginosus</em></td>
</tr>
<tr>
<td>Mongolian Plover</td>
<td><em>Charadrius mongolus</em></td>
</tr>
<tr>
<td>Osprey</td>
<td><em>Pandion haliaetus</em></td>
</tr>
<tr>
<td>Pacific Golden Plover</td>
<td><em>Pluvialis fulva</em></td>
</tr>
<tr>
<td>Painted Snipe</td>
<td><em>Rostratula benghalensis</em></td>
</tr>
<tr>
<td>Pectoral Sandpiper</td>
<td><em>Calidris melanotus</em></td>
</tr>
<tr>
<td>Pelican</td>
<td><em>Pelecanus conspicillatus</em></td>
</tr>
<tr>
<td>Pied Oystercatcher</td>
<td><em>Haematopus longirostris</em></td>
</tr>
<tr>
<td>Reef Heron</td>
<td><em>Egretta sacra</em></td>
</tr>
<tr>
<td>Ruff</td>
<td><em>Philomachus pugnax</em></td>
</tr>
<tr>
<td>Sanderling</td>
<td><em>Calidris alba</em></td>
</tr>
<tr>
<td>Sharp-tailed Pectoral</td>
<td><em>Calidris melanotes</em></td>
</tr>
<tr>
<td>Silver Gull</td>
<td><em>Larus novaehollandiae</em></td>
</tr>
<tr>
<td>Sooty Oystercatcher</td>
<td><em>Haliaeetus fuliginosus</em></td>
</tr>
<tr>
<td>Terek Sandpiper</td>
<td><em>Tringa terek</em></td>
</tr>
<tr>
<td>Terns and gulls</td>
<td><em>Family Laridae</em></td>
</tr>
<tr>
<td>Wandering Tattler</td>
<td><em>Tringa incana</em></td>
</tr>
<tr>
<td>Whistling Kite</td>
<td><em>Haliaeetus sphenurus</em></td>
</tr>
<tr>
<td>Whimbrel</td>
<td><em>Numenius phaeopus</em></td>
</tr>
<tr>
<td>White-bellied Sea-eagle</td>
<td><em>Haliaeetus leucogaster</em></td>
</tr>
<tr>
<td>White-fronted Chat</td>
<td><em>Ephthianura albifrons</em></td>
</tr>
<tr>
<td>White-fronted Tern</td>
<td><em>Sterna striata</em></td>
</tr>
<tr>
<td>White-winged Tern</td>
<td><em>Sterna leveoptera</em></td>
</tr>
<tr>
<td>Wood Sandpiper</td>
<td><em>Tringa glareola</em></td>
</tr>
</tbody>
</table>

3. **REPTILES**

<table>
<thead>
<tr>
<th>COMMON NAME</th>
<th>SCIENTIFIC NAME</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carpet Python</td>
<td><em>Morelia spilotes</em></td>
</tr>
<tr>
<td>Eastern Water Dragon</td>
<td><em>Physignathus lesueurii</em></td>
</tr>
<tr>
<td>Land Mullet</td>
<td><em>Egernia major</em></td>
</tr>
<tr>
<td>Leathery Turtle</td>
<td><em>Dermochelys coriacea</em></td>
</tr>
<tr>
<td>Red-bellied Black Snake</td>
<td><em>Pseudechis porphyriacus</em></td>
</tr>
<tr>
<td>Yellow-bellied Sea Snake</td>
<td><em>Pelarmis platurus</em></td>
</tr>
</tbody>
</table>
## GLOSSARY OF SCIENTIFIC NAMES - Cont’d

<table>
<thead>
<tr>
<th>COMMON NAME</th>
<th>SCIENTIFIC NAME</th>
</tr>
</thead>
<tbody>
<tr>
<td>Australian Bass</td>
<td>Macquaria novaemaculeata</td>
</tr>
<tr>
<td>Australian Grayling</td>
<td>Prototroctes maraena</td>
</tr>
<tr>
<td>Black Cod</td>
<td>Epinephelus damelii</td>
</tr>
<tr>
<td>Blackfish or Luderick</td>
<td>Girella tricuspidata</td>
</tr>
<tr>
<td>Blue Devilfish</td>
<td>Paraplesiops bleekeri</td>
</tr>
<tr>
<td>Bullrout</td>
<td>Notesthes robusta</td>
</tr>
<tr>
<td>Carp gudgeon</td>
<td>Hypseleotris sp.</td>
</tr>
<tr>
<td>Dusky Flathead</td>
<td>Platytcephalus fuscus</td>
</tr>
<tr>
<td>Elegant Wrasse</td>
<td>Anampses elegans</td>
</tr>
<tr>
<td>Estuary Cod</td>
<td>Epinephelus sp. (E. suillus, E. malabaricus)</td>
</tr>
<tr>
<td>Fantail Mullet</td>
<td>Valamugil georigii</td>
</tr>
<tr>
<td>Flathead Gudgeon</td>
<td>Philypnodon grandiceps</td>
</tr>
<tr>
<td>Flat-tail Mullet</td>
<td>Liza argentea</td>
</tr>
<tr>
<td>Giant Queensland Groper</td>
<td>Promicrops lanceolatus</td>
</tr>
<tr>
<td>Glass Perchlet</td>
<td>Velambasssis jacksoniens</td>
</tr>
<tr>
<td>Golden-Lined Whiting</td>
<td>Sillago analis</td>
</tr>
<tr>
<td>Grey Nurse Shark</td>
<td>Carcharias taurus</td>
</tr>
<tr>
<td>Herbst Nurse Shark</td>
<td>Odontaspis ferox</td>
</tr>
<tr>
<td>King George Whiting</td>
<td>Sillaginoides punctata</td>
</tr>
<tr>
<td>Large-Toothed Flounder</td>
<td>Pseudorhombus arsius</td>
</tr>
<tr>
<td>Long-Tailed Catfish</td>
<td>Euristhmus lepturus</td>
</tr>
<tr>
<td>Mosquito Fish</td>
<td>Gambusia affinis</td>
</tr>
<tr>
<td>Mullahoway</td>
<td>Argyrosomus hololepidotus</td>
</tr>
<tr>
<td>Pacific Blue Eye</td>
<td>Pseudomugil signifer</td>
</tr>
<tr>
<td>River Garfish</td>
<td>Hyporhamphus ardelio</td>
</tr>
<tr>
<td>Sampson Fish</td>
<td>Seriola hippos</td>
</tr>
<tr>
<td>Sand Mullet</td>
<td>Myxus elongatus</td>
</tr>
<tr>
<td>Sand Whiting</td>
<td>Sillago ciliata</td>
</tr>
<tr>
<td>Sea Garfish</td>
<td>Hyporhamphus australis</td>
</tr>
<tr>
<td>Silver Biddy</td>
<td>Gerres subfasciatus</td>
</tr>
<tr>
<td>Silver Trevally</td>
<td>Pseudocaranx dentex</td>
</tr>
<tr>
<td>Snapper</td>
<td>Pagrus auratus</td>
</tr>
<tr>
<td>Southern Herring</td>
<td>Harengula abbreviata</td>
</tr>
<tr>
<td>Striped Catfish</td>
<td>Potosus lineatus</td>
</tr>
<tr>
<td>Striped Sole</td>
<td>Aseraggodes macleayanus</td>
</tr>
<tr>
<td>Tailor</td>
<td>Pomatomus saltator</td>
</tr>
<tr>
<td>Tarwhine</td>
<td>Rhabdosargus sarba</td>
</tr>
<tr>
<td>Trumpeter Whiting</td>
<td>Sillago maculata</td>
</tr>
<tr>
<td>Yellowfin Bream</td>
<td>Acanthopagrus australis</td>
</tr>
<tr>
<td>Yellow Perchlet</td>
<td>Ambasssis marianus</td>
</tr>
<tr>
<td>Yellowtail</td>
<td></td>
</tr>
<tr>
<td>COMMON NAME</td>
<td>SCIENTIFIC NAME</td>
</tr>
<tr>
<td>-------------------</td>
<td>-------------------------</td>
</tr>
<tr>
<td>Greasyback Prawn</td>
<td><em>Metapenaeus bennettae</em></td>
</tr>
<tr>
<td>King Prawn</td>
<td><em>Penaeus plebejus</em></td>
</tr>
<tr>
<td>School Prawn</td>
<td><em>Metapenaeus macleayi</em></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>COMMON NAME</th>
<th>SCIENTIFIC NAME</th>
</tr>
</thead>
<tbody>
<tr>
<td>Copper Jewel</td>
<td><em>Hypochrysops apelles</em></td>
</tr>
<tr>
<td>Dull Jewel</td>
<td><em>Hypochrysops epicurus</em></td>
</tr>
<tr>
<td>Glistening Blue</td>
<td><em>Theclinesthes scintillata</em></td>
</tr>
<tr>
<td>Illidge’s Ant-blue Butterfly</td>
<td><em>Acrodipsas illidgei</em></td>
</tr>
<tr>
<td>Painted Skipper</td>
<td><em>Hesperilla picta</em></td>
</tr>
<tr>
<td>Saltpan Blue</td>
<td><em>Theclinesthes sulphitius</em></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>COMMON NAME</th>
<th>SCIENTIFIC NAME</th>
</tr>
</thead>
<tbody>
<tr>
<td>Black Mangrove</td>
<td><em>Bruguiera gymnorrhiza</em></td>
</tr>
<tr>
<td>Broad-leaf Paperbark</td>
<td><em>Melaleuca quinquenervia</em></td>
</tr>
<tr>
<td>Cabbage-tree Palm</td>
<td><em>Livistona australis</em></td>
</tr>
<tr>
<td>Common Reed</td>
<td><em>Phragmites australis</em></td>
</tr>
<tr>
<td>Cottonwood Hibiscus</td>
<td><em>Hibiscus tilliaceus</em></td>
</tr>
<tr>
<td>Cumbungi</td>
<td><em>Typha australis</em></td>
</tr>
<tr>
<td>Eelgrass</td>
<td><em>Zostera sp.</em> (Z. capricorni, Z. muellerii) and <em>Heterozostera tasmanica</em></td>
</tr>
<tr>
<td>Grey Mangrove</td>
<td><em>Avicennia marina var. australasica</em></td>
</tr>
<tr>
<td>Large-Leaved Mangrove</td>
<td><em>Bruguiera gymnorrhiza</em></td>
</tr>
<tr>
<td>Milky Mangrove</td>
<td><em>Excoecaria agalocha</em></td>
</tr>
<tr>
<td>Paddleweed</td>
<td><em>Halophila sp.</em> (H. ovalis and H. decipiens)</td>
</tr>
<tr>
<td>Paperbark</td>
<td><em>Melaleuca sp.</em></td>
</tr>
<tr>
<td>Red Mangrove</td>
<td><em>Rhizophora stylosa</em></td>
</tr>
<tr>
<td>Red Samphire</td>
<td><em>Sarcocornia quinqueflora</em></td>
</tr>
<tr>
<td>Ribbon Weed</td>
<td><em>Vallisneria gigantea</em></td>
</tr>
<tr>
<td>River Mangrove</td>
<td><em>Aegiceras corniculatum</em></td>
</tr>
<tr>
<td>Salt Couch</td>
<td><em>Sporobolus virginiticus</em></td>
</tr>
<tr>
<td>Scrambling Clerodendron</td>
<td><em>Clerodendrum inerme</em></td>
</tr>
<tr>
<td>Sea Tassel</td>
<td><em>Ruppia spp.</em></td>
</tr>
<tr>
<td>Spider Mangrove</td>
<td><em>Rhizophora stylosa</em></td>
</tr>
<tr>
<td>Strapweed</td>
<td><em>Posidonia australis</em></td>
</tr>
<tr>
<td>Swamp Mahogany</td>
<td><em>Eucalyptus robusta</em></td>
</tr>
<tr>
<td>Swamp Oak</td>
<td><em>Casuarina glauca</em></td>
</tr>
<tr>
<td>Water Thyme</td>
<td><em>Hydrilla verticilata</em></td>
</tr>
</tbody>
</table>