ENGINEERS AUSTRALIA

Coastal Engineering Guidelines for working with the Australian coast in an ecologically sustainable way

3RD EDITION, 2017 UPDATE

The National Committee on Coastal and Ocean Engineering

Disclaimer
This document is prepared by the National Committee on Coastal and Ocean Engineering, Engineers Australia, for the guidance of coastal engineers and other professionals working with the coast who should accept responsibility for the application of this material.

Copies of these Guidelines are available from:
http://www.engineersaustralia.org.au/NCCOE

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PREFACE

These Guidelines have been developed by the National Committee on Coastal and Ocean Engineering (NCCOE) of Engineers Australia (EA). The 1st edition (2004) was assisted by funding from the Capacity Building Program of the Commonwealth's Coast and Clean Seas initiative while the 2nd edition was prepared with the support of Department of Climate Change and Energy Efficiency (DCCEE). Those editions have benefited from workshops and other feedback on earlier drafts/editions by practising coastal engineers and managers. This third edition is a minor update incorporating new Engineering Australia policies, more recent state policies and programs and the 5th assessment report from Intergovernmental Panel on Climate Change.

The Guidelines are directed primarily at professional engineers practising in the coastal area. It is however recognised that the Guidelines will be of value to allied professionals such as planners and managers with decision-making roles in the coastal zone. The scope of application is designed to cover Commonwealth, State and Local Government, industry, consulting and development.

Boxed checklists at key positions in the document highlight significant features and focus attention on the important issues.

This is a live document that will be regularly updated. Coastal and ocean engineers and other related professionals are encouraged to provide ongoing feedback and examples. Comments should be sent to the National Committee on Coastal and Ocean Engineering, nccoe@engineersaustralia.org.au.

CONTENTS

1 INTRODUCTION

These Guidelines have been developed by the National Committee on Coastal and Ocean Engineering (NCCOE) of Engineers Australia (EA). It is the second in a series of three guidelines produced by NCCOE. Following on from Guidelines for Responding to the Effects of Climate Change in Coastal and Ocean Engineering this publication aims at broader considerations regarding engineering in the coastal zone. A third volume (Climate Change Adaptation Guidelines in Coastal Management and Planning) provides practical assessment and advice on appropriate adaptation measures drawing on information from the first two volumes.

Initial funding provided by the Capacity Building Program of the Commonwealth's Coast and Clean Seas initiative enabled the production of a draft edition of Coastal Engineering Guidelines (1998). The 1st edition (2004) of the Guidelines incorporated significant feedback provided by a broad range of practising coastal engineers and managers. The 2nd edition includes updated material, links more closely to the climate change guidelines and incorporates two new supplements (Desalination Marine Structures and Integrated Coastal Zone Management). It, along with the other two guidelines was exposed to a wide range of practitioners at workshops and conferences around the country and feedback from those events has contributed to this update.

Coastal engineers and others charged with making planning and management decisions must be aware of their duty of care to adequately understand the physical coastal environment, how that impacts on chemical and biological matters and, finally, the engineering consequences of their decisions.

The Guidelines are directed primarily at professional engineers practising in the coastal area. It is, however, recognised that the Guidelines will be of value to allied professionals such as planners and managers with decision-making roles in the coastal zone. The scope of application is designed to cover Commonwealth, State and Local Governments, industry, consulting and development.

In exercising its responsibilities to the community and its members, Engineers Australia works by an endorsed Code of Ethics, the first sentence of which reads "*As engineering practitioners, we use our knowledge and skills for the benefit of the community ahead of other personal and sectional interest*." The Code has four tenets, the fourth of which is to "*Promote Sustainability*". Within the organisation of Engineers Australia the group with broad responsibility for sustainability is the Society for Sustainability and Environmental Engineering (SENG) who have released a Sustainability Policy containing objectives for sustainable development and a set of principles aiming at the realisation of the aspirational objectives. Both the Code of Ethics and the Sustainability Policy are reproduced in Appendix 1 (n.b. EA and SENG web sites should be checked for updates). The NCCOE believes that ecological sustainability in the coastal zone will be achieved through the application of good engineering practice and with the support of allied professions. A significant component of sustainability is the need to account for the effects of climate change and in 2014 Engineers Australia released a Climate Change Policy (also available on the SENG's web pages).

The challenges and problems of achieving ecologically sustainable development in the coastal zone arise from its great economic, environmental and social attractiveness and hence the great pressures that the community places on the coastal zone environment. Proper management of Australia's extensive coastline and its resources requires knowledge and understanding of the complex and highly variable physical interactions of the atmosphere, ocean and adjacent lands, over wide time scales, and their linkages to the many chemical and biological components of the environment. The discipline of Coastal Engineering combines this scientific knowledge with the practical knowledge needed to plan and implement the infrastructure needs and expectations of society. These needs span a diverse range across industry, commerce, recreation and conservation. Clearly, any decision-making in the active coastal zone requires such knowledge and expertise to understand the environmental processes that are constantly shaping the coastline, to appreciate the natural variability in the coastal system and to quantify the sometimes significant risks to life, property and the environment itself. Indeed, such knowledge is even more important where it is intended that environmental values be preserved or enhanced. The projected impacts of climate change add a further layer of complexity to these issues. Coastal planning, management and development processes therefore demands robust proper professional advice on engineering-related matters.

This publication attempts to present a comprehensive Australia-wide approach to ecologically sustainable engineering-related practice in the coastal zone. The document is designed to form a core reference that has overall applicability and includes several supplements covering more specific topics in detail..

These Guidelines are concerned firstly with ensuring that those who offer engineering advice are cognisant of their specific responsibilities. However, others who are charged with making planning and management decisions also must be aware of their own duty of care to adequately understand the physical coastal environment, how that impacts on chemical and biological matters and, finally, the engineering consequences of their decisions. The issues covered within the Guidelines include government policy, professional ethics, the nature of the coastal environment and development within it, coastal engineering methodology including recommended investigation procedures and project planning for economic sustainability. **The Guidelines are not designed to dictate the detailed procedures to be followed** (as would a handbook or technical manual, several of which are included in the references under Coastal Engineering Methodology and elsewhere), but rather identify the types of processes and the considerations, particularly environmental, required when practising in the coastal zone. Boxed checklists are provided throughout the Guidelines to highlight significant features and focus attention on the important issues. The first of these is given below.

Although the material in these Guidelines has been arranged in a logical order, it is likely that many readers will have specific requirements for which a more targeted approach would be warranted. The following checklist suggests how such an approach might be made.

Checklist – Using the Guidelines

- **Is there a specific issue covered by one of the Supplements? If so, start there.**
- **Whether covered by Supplement or not, have the issues itemised in the checklist for Chapter 5, Coastal Development, been addressed?**
- **Has the methodology of Chapter 6, Coastal Engineering Methodology, been appropriately adopted? Refer to the checklists for each section of that chapter.**
- **Are the geological, meteorological, oceanographical, geomorphological, ecological processes understood in sufficient depth? Refer to Chapter 4 Coastal Environment and its checklist.**
- **Is the activity being carried out ethically, according to any pertinent Code and according to relevant National and State Policies and Programs? Refer Chapter 2, Ethics. Responsibilities and Duty of Care, Chapter 3, Coastal Zone Policy, Chapter 7, Standards, Codes and Quality Assurance, Appendix 1 and relevant section of Appendix 2. Additionally check with appropriate authorities for currency.**
- **Has advice been sought from organisations or individuals with appropriate expertise if not available in-house?**

2 ETHICS, RESPONSIBILITIES AND DUTY OF CARE

The need for ethical behaviour by engineers practising their profession in the coastal zone is as relevant as for any other profession. Ethical professional practice is particularly important because poorly planned or insensitive projects in the coastal zone have the potential to cause long-lasting, extensive and expensive ecological and environmental damage. They can also adversely affect social, cultural, aesthetic, indigenous and natural heritage values. Coastal climates are highly variable and extremely demanding; information and data about coastal processes at specific sites are often inadequate; coastal ecosystems are complex and often not well understood. Hence economic, community and political pressures could encourage unprofessional behaviour which ignores the adverse impacts of a project upon the coastal environment. These actions have the potential to impose unnecessary environmental and economic burdens upon society when it has to correct the consequent environmental damage.

Engineers Australia (EA) is the national forum for the advancement of engineering and the professional development of its members. With more than 90,000 members embracing all disciplines of the engineering team, Engineers Australia is the largest and most diverse professional body for engineers in Australia. Professional engineers who are members of EA must comply with the Code of Ethics (EA, 2010, reproduced in Appendix 1) and Engineers Australia has the power to discipline members for breaches of this Code as set out in Disciplinary Regulations (EA 2007). The four basic tenets of the Code of Ethics are to demonstrate integrity, practise competently, exercise leadership and promote sustainability. Guidelines produced to aid the application of the Code of Ethics in practice exhort engineers to promote sustainability by engaging responsibly with the community and other stakeholders, practise engineering to foster the health, safety and well being of the community and the environment and balance the needs of the present with the needs of future generations. The Code of Ethics and Guidelines on Professional Conduct are included in Appendix 1.

Engineers practising in the coastal zone need to be thoroughly familiar with their Code of Ethics as well as their Policies on Sustainability and Climate Change, and be aware of their legal responsibilities with regard to duty of care and environmental and planning legislation, seeking expert legal advice when needed.

More specific guidance on sustainability is given by Engineers Australia's Sustainability Policy (SENG 2014a) which has as its guiding purpose:

> *Engineers Australia and its members are committed to creating and delivering outcomes that will ensure the long-term survival of life on earth in a fair and equitable manner.*
>
> *For our members, sustainability means that future generations will enjoy environmental, social and economic conditions that are equal to or better than those enjoyed by the present generation.*

In addition to the Sustainability Policy, EA have also released a policy on climate change (SENG 2014b) which acknowledges the science and points out engineers' roles and responsibility in the reduction of greenhouse gases, putting in place mitigation measures and contribute to relevant policy initiatives.

As both of these policies are relevant to engineering in the coastal zone they are reproduced in Appendix 1 where details can be found.

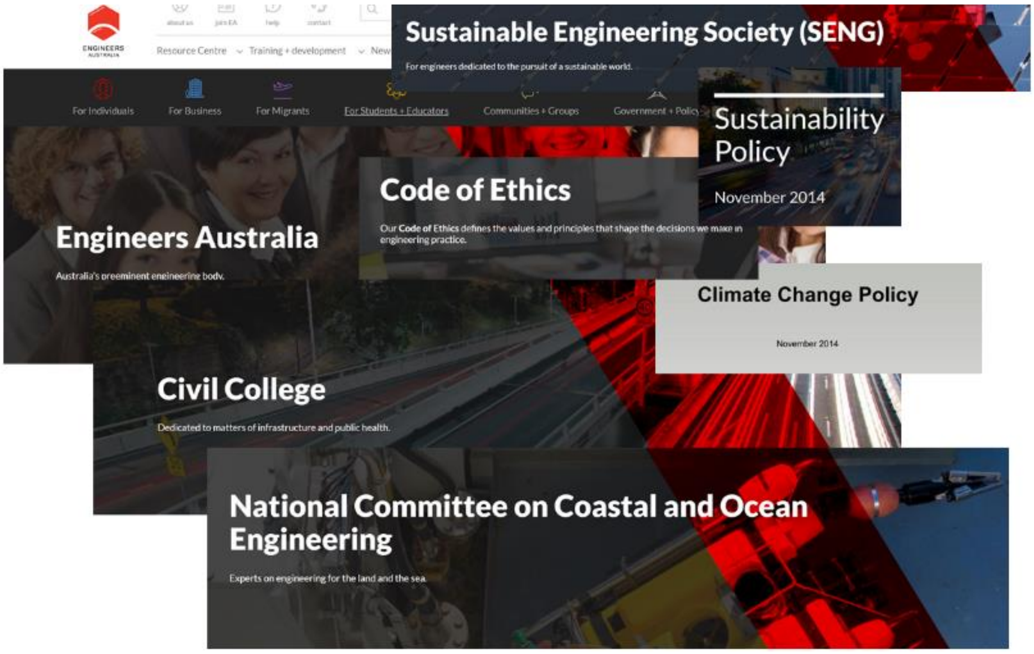
As well as responsibilities under EA's codes and policies there will be obligations under legislation at all government levels. Overarching legislation at national level is provided by the Environment Protection and Biodiversity Conservation Act (EPBC), 1999. States/Territories have enacted legislation for control of pollution, conservation of flora and fauna, protection of cultural and natural heritage, control of hazardous substance, climate change, exploitation of resources, land use planning and environmental impact assessment. Local Government also has a major role to play, often in administering the legislation, but also directly, e.g. land zoning. There are also statutory authorities that span state or local government jurisdictions, such as Natural Resource Management Regions, and Catchment Management Authorities, and in some states, Coastal Authorities.

Coastal engineers and others managing the coastal zone are also subject to the law of negligence, which embodies the principle of a "duty of care". In general terms an engineer is expected to practise "professionally" and exercise their professional judgement in a way that would be expected of an engineer with particular experience and training in any given circumstance. This means in practice that an engineer, like any other professional, will be liable for the foreseeable consequence of careless and unskilful conduct.

In addition, engineers will be subject to the terms of contracts they may have entered into for the provision of their services. Careful attention should be paid to the terms of those contracts: what they are required to do, by when and any particular conditions are all important considerations. Contracts may also limit the liability of either the engineer or the person/body engaging their services and the engineer should be aware of this and seek legal advice if those terms are unclear.

Engineers practising in the coastal zone need to be thoroughly familiar with the Code of Ethics, the Sustainability

Charter, and their legal responsibilities in negligence and contract and under environmental (and other) legislation, seeking expert legal advice when needed.



A range of publications and groups provide guidance on the obligation of engineers to adhere to sustainability principles in all their work.

3 COASTAL ZONE POLICY

Effective coastal zone policy needs to be based on a sound understanding of coastal processes and the coastal environment; it should recognise its administrative and other impacts; and it must be supported by adequate resources for its implementation. Additionally, if coastal planning is to receive community and political support, and is to be defensible in law if challenged, it must be based on a detailed quantified understanding of the coastal environment using the most complete information available at the time.

National and State coastal zone policy provides the framework for planning that strikes a balance between development and environment.

Commonwealth, State and Local Governments all have responsibilities in the coastal zone and have developed policies to be applied specifically in that zone. These policies seek to strike a balance between development and environment where activities associated with these two are in conflict, and to seek management options such that they are not in conflict. Human use of coastal zone environments poses threats to their ecological systems. The concept of Ecologically Sustainable Development (ESD) provides guidance to governments, communities and professional practitioners devising and implementing policy for future developments in the coastal zone and elsewhere. The goal of ESD has been defined in the *National Strategy for Ecologically Sustainable Development 1992* (DEH 1992) as:

> *"…development that improves the total quality of life, both now and in the future, in a way that maintains the ecological processes on which life depends."*

Its core objectives are:

- to enhance individual and community well-being by following a path of economic development that safeguards the welfare of future generations
- to provide for equity within and between generations
- to protect biological diversity and maintain essential ecological processes and life-support systems.

These principles are being adopted increasingly by all levels of government in the development of their coastal zone policies.

One of the challenges for Governments to achieve ESD is the establishment of an integrated coastal zone management (ICZM) process (see Supplement F), which would overcome the fragmentation of single-sector based governance. ICZM aims to better integrate the management of uses of coastal, estuarine and marine resources. The *National Cooperative Approach to Integrated Coastal Zone Management*, adopted by Commonwealth, States and Northern Territory, reflects the attempt to establish such a process. The Commonwealth Government seeks to provide overarching policy in the coastal and ocean areas through such a cooperative approach as well as more directly through *Australia's Ocean Policy* (1998).

The Commonwealth department with responsibility for environment in the coastal zone is Department of the Environment and Energy (DEE), The DEE web pages provide information on Australian Government initiatives to adapting to coastal climate change. Current focus is on initiatives to preserve the Great Barrier Reef. Other actions taken by the government include funding research through the Australian Climate Change Science Program, Marine and Climate Super Science Initiative and National Climate Change Adaptation Research Facility (NCCARF).

Each State and the Northern Territory has developed policies and programs of relevance to engineering in the coastal zone, some with more focus than others. These are often concerned with land use within the coastal zone and seek to encourage the preservation, conservation and development of the coast in an ecologically sustainable manner.

Local Government is the area where most detailed land use planning occurs, but that level of Government does not have the power to enact law. The practice generally adopted is for State or Territory Governments to make law regarding the coastal zone and, either explicitly or implicitly, delegate to Local Government the execution of that law. State Governments retain for themselves the right to over-ride Local Government decisions by the use of ministerial powers. There are also specially convened courts wherein the decisions of Local Government with respect to the coastal zone can be appealed.

A more detailed summary of the laws, procedures, and policy publications regarding coastal zone management in Australia can be found in Appendix 2 – Policies, Programs and Associated Publications.

National policies and frameworks form the basis for many policies and programs implemented at State and Local Government level.

4 COASTAL ENVIRONMENT

4.1 Coastal Zone

The coastal zone is the interface between the land and the sea. Its extent depends upon how far terrestrial and marine processes interact. It may extend seaward as far as the edge of the continental shelf, but not as far as the 200 nautical mile Exclusive Economic Zone (EEZ). The most physically dynamic portion of the coastal zone is the littoral zone, extending from the seaward limit of wave breaking to the swale behind the foredune. The dynamic sand movements within the littoral zone result in the continuing reshaping of coastal morphology. The landward boundary of the coastal zone will include all land potentially floodable by the sea and all wetlands, salt-marshes, estuaries and marine lakes. For administrative convenience the landward boundary is sometimes set at one kilometre landward from the littoral zone, although significantly different rules can apply under different jurisdictions.

Whenever activity is contemplated in a given coastal area, it is essential to define the extent of the overall coastal system affected by and affecting the proposed activity.

Australia's coastal zone is one of the largest and most varied of any nation. Extending from hot tropical to cool temperate latitudes, the environment within this coastal zone is the result of interaction between many factors including varied geology, large-scale oceanic currents, climatic variability and diverse ecosystems. As the balance between these factors changes from place to place and from time to time, so does the character of the various local coastal systems within the overall coastal zone.

Australia's coastal zone is one of the largest and most varied of any nation, extending from hot tropical to cool temperate latitudes.

The following sections provide brief summaries of the physical and ecological characteristics of the Australian coastal environment. These provide the basis for an overall understanding of the nature of the coastal systems in which coastal engineering is undertaken. Practitioners will need to consult other sources for more detailed information concerning the various processes and their interactions at specific sites. An excellent recent comprehensive study is provided by Short and Woodroffe, 2009. See also DEE's web pages on 'Australia's coast and climate change'.

4.2 Physical Environment

4.2.1 Geology and Geomorphology

The nature and location of the coast are determined by the geology of the land and seabed, and the elevation of the sea at the present time. All other processes determining the physical and ecological environment of the coast are constrained by these two parameters. Australia lies within one of the earth's more stable tectonic plates and hence, in contrast to coasts on active plate margins such as those of New Zealand and Western America, is in a region of generally low tectonic activity and small isostatic uplift. The surface of Australia is flatter than any other continent and its rivers generally contribute relatively small quantities of sediment to its coasts. In few places is the sediment supply sufficient to be causing significant accretion of the shoreline.

Aerial view of the Murray Mouth and Coorong, South Australia
© Murray Darling Basin Authority, Photo: Michael Bell

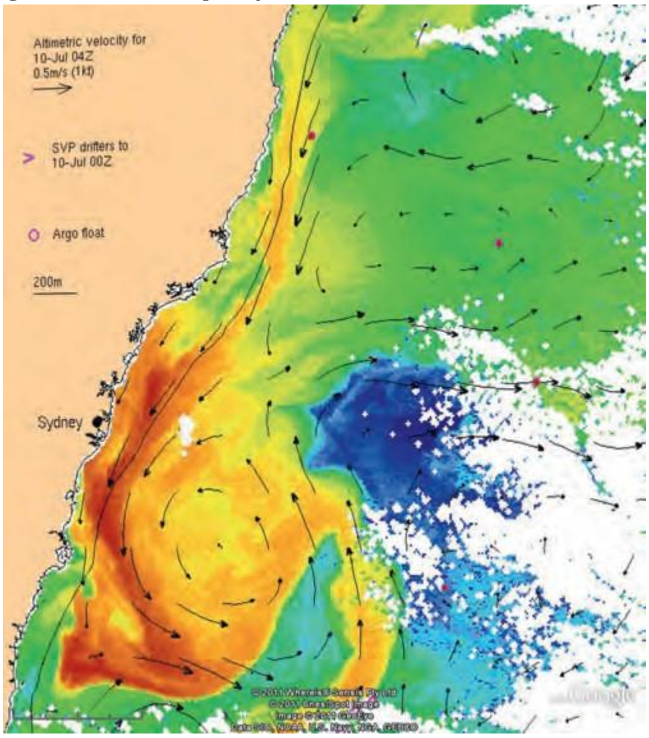
The most significant factor determining the present geomorphology of the world's coastlines has been a sea level rise of more than 100 m since the last ice age, 18 000 years ago. Existing coasts have developed during the last 6 000 years during which sea level has been relatively stable. The alignment and form of a coast is controlled by the presence of rocky areas and the interaction of transporting agencies, such as winds, waves, tides, etc., with coastal sediments. Natural coasts range between the extremes of "hard" or rocky coasts, which generally do not change significantly on a human time frame, to "soft" or sandy coasts, which visibly change under the influence of the transporting agencies. Catastrophic events such as tropical cyclones, earthquakes and tsunami have potential for significant shoreline change in very short time frames.

Coastal sediments may be of either terrigenous (land) origin or biogenic (living) origin. In the former case, they often are formed predominantly of silica sand. In the latter case they are predominantly calcium carbonate derived from marine organisms either directly from detrital skeletal material and shells or indirectly from limestone rocks. Coastal landforms and sediments vary around the Australian coast depending upon variations in the physical and biological processes and the local geology.

4.2.2 Meteorology and Oceanography

Coastal environments are determined by the interaction of meteorological and oceanographical processes with the local topography. Large scale oceanic circulation manifests as currents which move along the margins of the continental shelf, advecting and mixing water properties such as temperature, dissolved chemicals/salinity, nutrients, micro-organisms, particles and sediments. At the shelf margins, upwelling of nutrient rich, deeper ocean waters may occur at specific locations. Currents on the continental shelf, while affected by offshelf circulation, are increasingly determined by local meteorological and topographical conditions.

The East Australian Current (EAC) carries warm low salinity Coral Sea water southward into the cooler more saline Tasman Sea. The northern limit of the EAC is usually defined as latitude 18 °S whilst its southern boundary, usually at latitude 32 °S, is quite variable and can extend as far south as 42 °S. The EAC is present at all times of the year but is generally strongest between December and April. Its surface speed is usually between 0.5 and 1.0 m/s and its effect can be felt at depth. Seaward of the continental shelf the current speed at a depth of 250 m is approximately half that at the surface. Its maximum width is about 150 km. The landward edge of the current frequently encroaches onto the shelf with an effect on coastal processes such as the movement of seabed sediment. The southerly flow often separates from the coast between 29 °S and 32 °S, heading east across the Tasman Sea. At the point of separation the current repeatedly forms loops that break off as large eddies that can sometimes interact with coastal waters similarly to the EAC itself.



Sea surface temperature and current velocity image of the Tasman Sea off NSW, showing the warm East Australian Current flowing into a warm-core eddy. A cold-core eddy is evident farther offshore.
Source: David Griffin, CSIRO Marine and Atmospheric Research, visualised using Google Earth

The Leeuwin Current is a relatively narrow, southward flowing body of warm low salinity water flowing down the Western Australian coast. Its properties and strength vary seasonally, with the result that in about March/April the surface salinity off Perth decreases significantly. In winter when it achieves its most southerly extent it can pass around Cape Leeuwin (the south-western tip of Western Australia) at speeds of up to 1.5 m/s.

South of the Australian continent the Antarctic circumpolar current links the earth's major oceans as it encircles the Antarctic continent. It also responds to the general eastward atmospheric circulation and movement of weather systems around the Southern Ocean and across southern Australia. Strong westerly winds, generally associated with mid-latitude low-pressure systems, generate both the storm waves and the swells which impact the south-western, southern and south-eastern coasts of the continent, especially during winter months.

Within tropical and subtropical regions the southeast trade winds in the Coral and Tasman Seas are a surface component of the atmospheric circulation system driven by the uneven heating of the earth's surface between the equatorial and polar regions, modified by Coriolis (earth rotational) effects. The distribution of land masses and ocean temperatures in equatorial regions results also in a general east-west surface circulation over the Pacific Ocean. Quasi-biennial fluctuations in surface temperatures and air pressures may cause a reversal of this circulation over the western Pacific, which is associated with the El Niño – Southern Oscillation (ENSO) phenomenon. During the summer months between November and April warmer sea surface temperatures in the tropical seas adjacent to northern Australia, south of about latitude 10 °S, provide conditions favourable for the generation of tropical cyclones. Together with the north-west monsoon which brings moisture laden air to the northern part of the continent, tropical cyclones significantly affect summer coastal climates in northern Australia. Characteristically the summer is the wet season and the winter is the dry season. Tropical cyclones generate strong winds, rain, large storm waves and storm surges, a combination with potentially enormous disastrous impact for low lying islands and coastal regions.

Inshore on the continental shelf, current speeds and directions as well as local sea levels are influenced by both wind stress and barometric pressure fluctuations. Meteorological disturbances on the Western Australian continental shelf can generate long period (~ 10 day) continental shelf waves propagating from the west around the southern shelf and up the eastern coast. These continental shelf waves generate currents that can dominate other processes.

Close to the coast the astronomical tides, generated by periodic variations in the gravitational attraction exerted by the moon and sun upon oceanic and coastal waters, are in some regions an important factor determining both sea levels and currents. Particularly in estuaries and large bays, tidal currents dominate.

Whatever the generating mechanism, topographical features such as headlands or islands significantly modify the currents. The projection of a headland will cause the current to accelerate locally. In the lee of headlands and islands there will often be a wake consisting of eddies and gyres. Such local variations can have a major influence on sediment and pollutant transport.

4.2.3 Climatic Variability and Climate Change

The climate of a given region cannot be regarded as constant as it is changing continually within a variety of time frames. Climatic variability represents variation of climate about a mean condition whereas climatic change represents a change or trend in that mean condition (and also possibly the variation). Climatic change can only be reliably detected if the time frame of observations is sufficiently long. If the time frame for which information is available is short, e.g. 10s of years or less, it is often impossible to detect the relatively small long-term change because of the large “noise” from shorter-term variability effects. The authoritative synthesis of the science of climate change are the reports by Intergovernmental Panel on Climate Change, the most recent (AR5, released in 2014) concludes that global atmospheric warming is unequivocal and gives varying levels of confidence to a wide range of impacts. On the basis of this evidence and coupled atmospheric-oceanographic modelling they give consensus projections on the likely climate change effects over time frames of importance to coastal engineers and planners.

4.2.3.1 Climatic Variability

The time frames within which climate varies range from:

- the annual or seasonal variation consequent on the earth’s motion around the sun
- variations of a few years as a consequence, for example, of the ENSO (El Niño-Southern Oscillation) and Indian Ocean Dipole phenomena
- variations of a few decades or several centuries which may be related to fluctuations in the amount of solar radiation reaching the earth’s surface
- variations of the order of 100 000 years associated with the freezing and thawing cycles of the various ice ages.

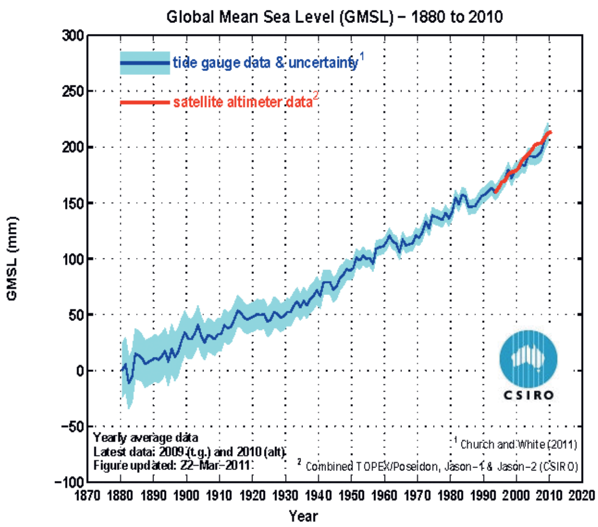
If the Pleistocene geological time frame (last two million years) is considered, then the ice ages and their intervening warm periods, which have occurred at 100 000 to 120 000 year intervals, are examples of long term climatic variability. On the other hand, during the Holocene time frame (last 10 000 years) the earth has been warming, and the ice caps melting. The sea level initially rose at a rate of the order of 10 mm per year until it stabilised about 6 000 years ago at approximately its present level. Hence, on a Holocene time frame, the postglacial warming has produced significant climatic change, which has drastically altered the form and location of the world’s coasts.

Within the time frame of meteorological records in Australia (50 to 120 years), the ENSO cycle is the most well known cause of climatic variability and has been linked to the strength of the monsoon, the occurrence of droughts and the frequency and distribution of tropical cyclones.

4.2.3.2 Climate Change

Over the past four decades there has been growing awareness of the potential impacts that human-induced global climate change might have on the coastal environment. A companion volume to these guidelines, Guidelines for Responding to the Effects of Climate Change in Coastal and Ocean Engineering, (Climate Change Guidelines), sets out the background to climate change issues, describes the current status of scientific evidence, provides latest global scenario projections, offers guidelines for response and adaptation measures, includes an extensive bibliography and outlines a risk-based methodology with example assessments. While a brief summary is given here, the reader is advised to refer to the full Climate Change Guidelines for details.

There is sufficient evidence in climate data supported by climate models for the IPCC to conclude that warming of the climate system is unequivocal, that many natural systems are being affected by regional climate changes, particularly temperature increases. Additionally there is medium confidence that other effects of regional climate change on natural and human environments are emerging, although many are difficult to discern due to adaptation and non-climatic drivers. As to likely causes the IPCC concludes that most of the observed increase in global average temperatures since the mid-20th century is due to the observed increase in anthropogenic greenhouse gas concentrations. The Climate Change Guidelines shows a Bureau of Meteorology map indicating measured average sea level rise rates relative to the land of up to 8 mm/yr for Australian ports over the years 1993 to 2015.



Global sea levels since 1880. CSIRO Marine and Atmospheric Research, http://www.cmar.csiro.au/sealevel/

Global projected changes by the year the end of the 21st century based on a range of Representative Concentration Pathways (RCPs) applied to atmosphere-ocean models include:

- Land surface temperature will increase by 0.3 °C to 4.8 °C.
- Global average sea level will rise by between 0.26 and 0.98 m with increased confidence regarding processes such as climate-carbon feedback and ice sheet flow. compared to AR4
- There is medium confidence in the prediction that overall precipitation associated with the Asian-Australian monsoon will increase but projected changes for Australia specifically are small.
- There is no firm conclusion regarding historical changes to tropical cyclone patterns however model predictions point to increasing intensity and reduced frequency of tropical cyclones.
- As with tropical cyclones, the detection of long-term changes in extratropical storms is hampered by incomplete and changing observing systems. Nevertheless the most consistent model results show, for a future warmer climate, a poleward shift of storm tracks with greater storm activity in higher latitudes. For many regions an increase in extreme wave height is predicted. Changes in wave direction would also have consequences for sediment transport.

With regard to impacts, adaption and vulnerability to climate change, the IPCC focusses on a three tiered approach, viz., how sensitive a particular system might be to climate change, how adaptable that system appears to be, and how vulnerable the system ultimately is to climate change. Because of the concentration of population along Australia's coastline, impacts from sea level rise and other climate change effects could be severely felt (with significant regional variations) to infrastructure, residential and commercial assets. Sea level rise potential impacts on natural systems include inundation and displacement of wetlands and lowlands, increased shoreline erosion, increased coastal flooding, salinity intrusion of estuaries and aquifers, altered tidal ranges, patterns and circulation in estuaries, changed sedimentation patterns, and decreased light penetration. Deltaic coasts are particularly vulnerable as are coastal wetlands and coral reefs and reef islands. Adaptation options include retreat, accommodate or protect, or a combination of these at various times and scales. The third volume in the NCCOE guideline series, Climate Change Adaptation in Coastal Management and Planning, provides practical interpretation of these options at local government level.

The first volume of this series of guidelines (Climate Change Guidelines), provides a summary of Australian research, impact studies, and specific state government policies. It gives a methodology for engineering impact assessment for climate change which includes a procedure flow chart with detailed tables relating to elements within the flow chart. It covers a comprehensive range of climate variables and their relationship with the coastal environments encountered on the Australian coast. It takes a risk-based approach giving clear strategies for selection of encounter probability to average recurrence intervals. Detailed examples clarify how the methodology is applied.

Although climate change has received a great deal of attention it is important to keep the risk in perspective. Natural climate variability on a regional basis remains as the single greatest source of uncertainty affecting engineering assessments of risk. It is important for engineering design and management in the coastal zone that in giving appropriate attention to climate change we do not lose focus on the extreme climate events and other coastal hazards as discussed below in Section 5.4. Our overall response to enhanced greenhouse should therefore be seen as an expansion of our current methodologies, which are integral to sustainable development. The extent to which the non- stationary changes associated with climate change need to be explicitly accounted for depends, in part, on the design life of the particular project or asset.

4.2.3.3 Coastal and Estuarine Processes

Coastal and estuarine environments are a consequence of interaction between physical processes, sediments and marine biota. These physical processes include winds and waves, tides and currents, rainfall and runoff.

Under conditions of stable mean sea level, water levels in the coastal zone vary with the astronomical tides with twice daily, daily, fortnightly and longer period variations. These levels are modified by meteorological effects, such as wind set-up caused by wind blowing over the water surface and barometric pressure variations – an extreme example being cyclonic storm surges. The combined extreme effects produce storm tide levels which may inundate low lying coastal land areas and which also allow waves to erode coastal dunes.

Storm waves are generated by wind and, once generated, continue to propagate as swell in the absence of wind. Both the wave-induced orbital motion of the water and the turbulence associated with wave-breaking stir up sediments which can then be transported by whatever currents are present. Offshore of the surf zone these currents are generally a consequence of meteorological (wind) effects or oceanic currents. Within the surf zone and further inshore wave-generated currents usually predominate, whereas near and within the mouths of estuaries or tidal lagoons, periodically changing tidal currents are significant. When waves break directly on cliffs or structures or currents flow around or over reefs or structures, forces of considerable magnitude, often cyclic in nature, may be exerted on these immersed objects.

Sandy coastlines are generally formed by waves moving sand both from offshore onto the beach and from alongshore. Sand accreting on the beach under constructive wave action often is blown landward by onshore winds where it is trapped by vegetation and builds up into coastal sand dunes. During stormy periods, particularly during extreme storm tides, erosion of these dunes provides sand to build up a protective offshore bar at the seaward edge of the surf zone. In many places sand dune barriers enclose large bays, shallow estuarine areas or tidal lakes. Mangrove forests and salt marshes occupy many such areas.

Noosa River Entrance, Qld Source: Owen Wilson

The lower reaches of rivers discharging into the sea are generally tidal and the mixing of upland freshwater with saline sea water as the tide flows in and out of the estuary controls the nature of the estuarine environment. Large runoff from the upland drainage basin (catchment) of rivers discharging into estuaries may flood adjoining low lying estuarine flood plains. Where the runoff is large in comparison with tidal flows, it also reduces temporarily the salinity of estuarine waters, flushes estuarine organisms out to sea and discharges significant amounts of sediment laden water, often accompanied by various nutrients and pollutants, into the coastal waters in the vicinity of the estuary. Fine sediments may e trapped within estuaries by a combination of saltwater density currents, flocculation and deposition in slack water areas associated with mangroves or sea grasses, or created by dredging.

The impacts of extreme events, such as tropical cyclones, tsunami, and other storms and floods, may change the previously established balance between various physical, chemical and biological processes in a given coastal area and hence create new local coastal environments. The latter are then developed and maintained by prevailing climatic conditions until disrupted by a subsequent extreme event. Extreme weather events may become more intense and more frequent in certain regions as a result of climate change (see section 4.2.3.2).

While the basic coastal and estuarine processes are similar along all parts of the coastal zone, their relative magnitudes and effects vary around the Australian coast. Tides around the coast vary both in tidal range and from semidiurnal to diurnal. For example, on the eastern coast of Queensland, tides vary from less than 2 m up to 9 m in range and may be either semidiurnal or mixed (combination of diurnal and semidiurnal). In the southern Gulf of Carpentaria tides are diurnal. In Western Australia micro tides (1 m) tending to diurnal predominate in the south while in the north-west semidiurnal macro tides (10 m) occur.

The different climatic conditions in the tropics and temperate zones result in different wave climates. In northern Australia the largest waves are generally associated with the occurrence of tropical cyclones, whereas in southern Australia they are usually caused by winter storms. The southern parts of the continent are exposed almost continually to swells, whereas, for example, the tropical Queensland coast is protected from most swell action by the Great Barrier Reef. Such differences in wave climate result in different coastal sediment movement patterns and very different ecosystems.

4.3 Ecological Environment

Australia's coastal zone contains various ecosystems associated with the transitions from terrestrial to marine conditions and from tropical to temperate climates. The terrestrial environments include coastal sand dunes, cliff faces and headlands, coastal rain forests, etc. In some cases terrestrial environments included by administrative definition in the coastal zone may not be significantly affected by marine conditions. In other cases, such as coastal sand dunes which are formed by and subjected to continuing coastal processes, ecosystems exist in continuing threat of disturbance or destruction by the sea. Hence dune plants generally are salt tolerant and adaptable to exposed windy conditions.

An assessment of the condition of Australia's marine environment prepared for the Commonwealth in 1995 still has relevance. This State of the Marine Environment Report (SOMER – Zann 1995) identifies the principal marine ecosystems within Australia's coastal zone as estuaries, coastlines and shore communities, coastal salt-marshes, mangrove forests, seagrass beds, temperate reefs, coral reefs and the sea floor communities of the continental shelf. The following is drawn largely from Zann (1995), updated where relevant by information from recent Australian State of the Environment Reports (SoE, 2006, Ward and Butler 2006, SoE, 2011).

Estuaries are the portions of rivers and coastal lagoons where fresh and salt water meet and mix under the influence of both variable upland runoff and alternating tidal flow. These highly variable physical conditions result in a relatively low diversity of plants and animals, although their abundance and adaptability are high. Extensive intertidal mangrove forests provide a major source of organic nutrients which sustain aquatic life, often making the estuarine ecology a very productive one. Estuaries play a very important role in the reproductive cycle of many marine species and are important fish habitats. Australia has almost 800 major estuaries, over half in tropical regions and a quarter in temperate regions, with the remainder in subtropical regions.

Apart from direct physical destruction caused by reclamation or similar developmental activity and dredging, estuarine ecologies can be altered by increased sediment concentrations in upland runoff changing light penetration which affects rates of photosynthesis. Settlement of suspended sediments can also smother seabed organisms. Significant increases in nutrients in estuarine waters may cause eutrophication, that is the excessive growth of algae, which can smother other organisms and deplete oxygen levels. This process is particularly likely to occur in those estuaries and coastal lagoons which are not well flushed by tidal flows.

The **intertidal shore**s of the coastline are the interface between land and sea. They are continually subject to wetting and drying and are also subject to extremes of salinity. The shores of Australia's coast include open coasts with rocky headlands, cliffs and sandy beaches; and sheltered coasts, bays and estuaries with muddy and sandy intertidal flats. Such geomorphological diversity accompanied by climatic variation is reflected in a high diversity of specialised animals, birds and plants and some environments have high biological productivity. Often the marine biota are not obvious; for example, on sandy beaches most organisms live below the surface of the sand. On intertidal rocky shores, where habitat areas are often limited, marine communities are vulnerable to over-harvesting and damage from human visitors, oil and other pollutants.

Coastal salt-marshes are intertidal plant communities dominated by herbs and low shrubs and are often associated with estuaries. They are highly productive, key habitats which support many other organisms. They are an essential habitat for many migratory species of birds. As well as being vulnerable to land reclamation for various purposes, salt-marshes are potentially endangered by sea level rise, particularly in populated areas where urban and other developments prevent their landward migration.

Seagrasses grow in sheltered coastal and estuarine waters. **Seagrass beds** are highly productive ecosystems and are important as fisheries habitats and, in tropical regions, as the habitats for dugongs and turtles. Like terrestrial grasses they have the ability to trap and stabilise sediments. Australia has large areas of both tropical and temperate seagrass beds. Overall they are the most biodiverse in the world. There has been very significant dieback of temperate seagrasses in many parts of southern and south-eastern Australia during recent decades with losses continuing due to mining activities and coastal discharges.

Seagrass at Warnbro Sound, Western Australia

Mangroves are tree and shrub species which live in the periodically inundated and salty conditions of the intertidal zone. **Mangrove forests** are very productive ecosystems, providing habitats and nurseries for fish and habitats for many birds and other wildlife. Mangroves encourage accretion of estuarine sediments, reduce the impact of storm waves upon coastlines and are natural nutrient filters. Australia's mangrove forests vary in diversity from over 30 species in some parts of the north- eastern wet tropics to only two or three species in temperate southern regions. In southern Australia most mangroves belong to a single species. Destruction of mangroves has occurred in areas close to towns and cities but growth and expansion of mangrove forests has also been observed in some areas during the last 50 years. More recently there has been significant success in replanting and regeneration of previously damaged mangrove areas.

Rocky reefs off Australia's temperate southern coastline have very high species diversity and a high proportion (80 to 90%) of endemic flora and fauna species. They are the sites of important commercial and recreational fisheries.

Coral reefs are unique among Australia's ecosystems in that their underlying structure and sediments are essentially of biologic origin. Ecologically, they are among the most productive, diverse and complex systems in the world. Australia has the largest area of coral reefs of any nation and the largest reef complex, the Great Barrier Reef. Significant reef systems also exist along central and northern Western Australia, in Torres Strait, and offshore in the Coral Sea. While Australia's coral reefs are generally well protected and relatively unaffected by human activities, elevated nutrients and sediments from upland soil erosion pose threats in some places. In other parts of the Indo-Pacific region coral reefs are significantly degraded. Water quality in the Great Barrier Reef is under considerable pressure from the intensive agriculture from the one quarter of Queensland that drains into the World Heritage Area. This is exacerbated by urban development and aquaculture.

Pelsaert Island – Abrolhos Island group, Western Australia
Image: Graeme Gibbons.

While the majority of ecosystems and their various, diverse biota have existed for many thousands or millions of years, it is important to recognise that the actual marine ecosystems presently existing along the world's coasts have only existed in their present locations for about 6 000 years since sea level reached its present level. The reefs and cays of the Great Barrier Reef, mangroves and seagrasses of Moreton Bay, Botany Bay, Port Phillip Bay and all the diverse estuaries around Australia's coast are all less than 10 000 years old and did not exist in their present locations during the last ice age.

While many marine ecosystems have proven to be very adaptable to natural climatic variability, some coastal ecosystems are particularly at risk from climate change particularly where natural systems are bound by the built environment and hence "squeezed" over time. At risk systems include saltwater marshes, mangrove ecosystems, coastal wetlands, sandy beaches, coral reefs, coral cays and river deltas. The IPCC AR4 Working Group II report on impacts on coral reefs point to the threat from ocean warming and acidification on the biology of corals leading to increased bleaching, reduced calcification, weakening coral skeletons and erosion of reef frameworks.

Key points identified by SoE, 2006 include the issue that Australia still does not have a comprehensive, nationally consistent coastal ecosystem monitoring system; planning for climate change adaptation should be a priority; and there remains a need to resolve existing problems to stem the slow decline of environmental quality. The most recent update (SoE, 2011) found that nearshore marine areas adjacent to intensive settlement have suffered the most from human activities although open ocean conditions are generally good. However, the pressures on all these areas are increasing, and the early warning signs of degradation are becoming commonplace in a number of ecosystems and habitats. As in 2006 it pointed to the urgency of an integrated national system of multilevel governance for conservation and management. In the coastal region it pointed to the continued pressures from urban expansion and the cumulative effects of small developments.

Some trends, such as expansion of conservation and Indigenous areas and improvements in land management practices, are acting to reduce some pressures. Climate change will have a major impact on our coasts, particularly through sea level rise. The implementation of recommendations from *Managing our coastal zone in a changing climate: the time to act is now* would support a more strategic approach to managing coastal resources.

4.4 Coastal Systems

Whenever activity is contemplated in a given coastal area, regardless of whether this is for conservation, management or development, it is essential to define the extent of the overall coastal system affected by and affecting the proposed activity. In most cases the relevant system will be, to a greater or lesser extent, open-ended rather than closed. For example, even if a particular bay is a closed system for sediment transport, there will be interchange of bay water with offshore waters and the system will be, at least to some extent, open from an ecological perspective. Storage reservoirs and agricultural activities in the catchment of a river discharging into the bay, as well as deepening for ship movements and construction of port structures in the river estuary, are all likely to modify the hydrology and/ or quality of upland runoff discharged into the bay and hence may have impacts upon its ecology. A proposed marina within the bay may not interfere with alongshore sediment transport but may be a potential source of contaminants which can be dispersed by waves and currents into adjoining coastal waters.

Having defined the extent of the coastal system relevant to the contemplated activity, it is important to consider wider socio-cultural issues as well as the physical, chemical and biological processes. For example, there may be parts of the system that have significant natural heritage value or have particular cultural significance.

All activities within a given region of the coastal zone require a general understanding of many issues including:

- the regional geomorphological and sedimentological processes which have occurred and are continuing within the Holocene time frame
- the hydrology and water quality of its inflowing streams and the oceanography of the adjoining sea
- the ecosystems within the region's coastal zone and its waters
- the natural heritage values of the region
- the impacts from other previous or continuing human activities.

This overall regional understanding provides the frame of reference for the development of conceptual models of the physical, chemical and biological processes at specific sites within the region where activities are being undertaken.

Such conceptual models provide a basis for planning data acquisition programmes and developing the numerical or physical models required to obtain a more complete understanding of the processes affecting and affected by engineering or other projects. Once this understanding has been gained then it becomes possible to develop predictions or scenarios of the likely impacts of the proposed activities.

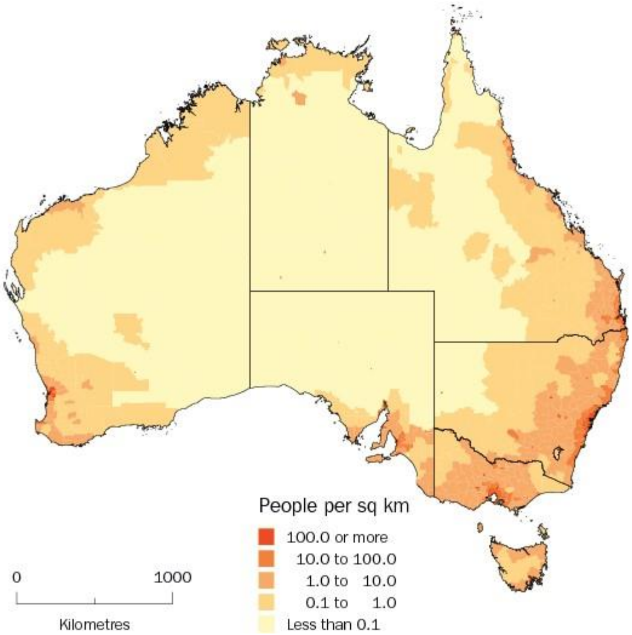
Checklist – Coastal Systems and Environment

- Is there a sufficient range of expertise available to evaluate the characteristics of the system and the impact of the proposed activities upon its coastal environment?
- Has the extent of the coastal system likely to be affected by the proposed activities been defined?
- Have the time frames of climatic variability and climatic change relevant for this system and the proposed activities been identified?
- Have the important physical and ecological factors likely to be influenced by or to influence the proposed activities been identified?
- Have the significant natural heritage values of the system been identified?
- Are human activities already influencing the system and/or are other developments within it also being proposed?

5 COASTAL DEVELOPMENT

5.1 Use of the Coastal Zone

While early human urban civilisations developed in fertile river valleys where water was available for irrigation, subsequently new population centres developed on the coast, generally at the mouths of rivers, as a consequence of the development of maritime trade. Initially the needs and impacts of these activities imposed only small disturbances upon the coastal environment. However, the advent of modern transportation technology, first the railway and then the steamship – later the car and the aeroplane, has allowed communities to use and develop the coastal zone much more extensively and intensively than previously. Indeed, this trend for increasing use of the coastal zone is strong within Australia.



Australian population density distribution in 2010
Source: Australian Bureau of Statistics

"*The coastal zone has a special place in the lives of Australians. Most Australians want to live or take their holidays there. It is a priceless national asset.*" (DEST 1995).

With two thirds of the Australian continent lying in an arid zone it is not surprising that 86% of Australia's population live within its relatively well watered coastal zone. According to the 2006 State of Environment Report (SoE, 2006) "*Of continuing concern for Australia's immediate future is continued population growth along the coastline. The formation of mega-metropolitan centres with increasing population density on Australia's coasts has the potential to displace much valuable biodiversity and 'high-value' agricultural land.*" Between 1980 and 2004 the length of urbanised coast (as measured at 1:100000 scale) increased Australia-wide by 30%. About half of the total population growth during this period has occurred in regions away from the older population centres based on the state capital cities. The most rapidly developing coastal areas are the south-east and far north of Queensland, the south-west of Western Australia and the central and north coasts of New South Wales. However as a state, Tasmania has recorded the largest coastal expansion at 80% over 25 years. In such a situation coastal engineering has had, and should be continuing to have, a significant role in meeting the needs of the community while at the same time ensuring sustainability.

Coastal Engineering is frequently required if there is or has been actual human use of the coastal zone or adjoining areas which affect the coastal zone. In many cases adequate planning for good coastal management in the past would have eliminated the need for coastal protection works. However, ever since communities have lived and worked in the coastal zone, they have sought to provide facilities for their maritime and other activities and to protect themselves, their homes and their resources against the impacts of the marine environment in all its varied moods. Even with the best planning, the need for some coastal engineering works would rarely be eliminated. Indeed in some situations positive management of the environment using coastal engineering works will enable natural conditions to be restored, replicated or improved.

5.2 Ecologically Sustainable Development

The success of new coastal engineering works and activities in achieving their purposes requires the practical application of the principles of Ecologically Sustainable Development in their conception, design and implementation.

It is also important to recognise and assess the cumulative impacts of continuing environmental degradation upon the viability of ecosystems, biodiversity, etc. Habitat loss, decline in habitat quality, changes in ecological processes, direct removal of species for human use or from other causes, etc. are becoming increasingly significant in threatening the sustainability of the coastal environment.

Engineers Australia's Sustainability Policy (Appendix 1) has amongst its principles and guidance that members of Engineers Australia should:

- Seek outcomes that deliver fairness and equity within the present generation as well as between present and future generations.
- In circumstances where scientific information is incomplete, the precautionary principle and risk management

practices should be used to ensure irreversible negative consequences are avoided and not passed on to future generations.

- The rate of release of any substances to the environment should do no net harm, and be limited to the capacity of the environment to absorb or assimilate the substances, and maintain continuity of ecosystem services. In all instances, such releases should be lifecycle-costed and attributed.
- Be proactive in addressing risks to the environment, society and the economy.
- Ecologically Sustainable Development principles are therefore applicable to all of the common coastal engineering activities required by the community as described briefly in the following Section 5.3.

5.3 Coastal Engineering Activities

Coastal engineering activities occupy a continuum from deep offshore to wherever the inshore limit is defined. A list of such facilities (necessarily incomplete) starting from deepwater would include: offshore resource extraction structures, offshore loading/unloading facilities, pipelines, offshore coastal protection works, ocean outfalls, desalination intakes/outlets, alternate energy structures (some yet to be trialled in Australia, others under research), harbours, ports, marinas, onshore coastal structures, river entrance works, canal estates. Some of these are discussed below.

5.3.1 Ports, Harbours and Offshore Facilities

Facilities for the loading and unloading, operation and servicing of shipping involved in maritime trade are an essential need for an island nation such as Australia, the economy of which is also highly dependent upon the export of bulk commodities. The port and harbour water land interface facilitates the commercial fishing, harvesting and associated maritime service industries.

Carnegie CETO wave power generator installation off Garden Island WA
Courtesy Carnegie Clean Energy Ltd

Coastal engineering works associated with these activities include breakwater-protected artificial harbours on open coasts, river entrance and other training walls for estuarine ports, dredged channels, wharf structures including offshore facilities for loading bulk commodities or for petroleum production, pipelines and navigation aids, as well as port waste treatment and disposal. New types of structures continue to appear on the Australian coastal scene. The desalination marine structures appearing in the last decade are discussed below. Wave power generators are being trialled at several sites and offshore wind farms have been suggested. All such structures have the potential to disrupt coastal processes such as wave transmission, coastal currents and sediment transport and hence considerable effort needs to go into design, construction and operation to mitigate any adverse impacts.

5.3.2 Coastal Protection and Management

Subdivisions to or near the high water mark have led to the construction of houses and other facilities on coastal sand dunes and other unstable or vulnerable parts of the coast. In some places such developments have been further endangered by natural shoreline erosion or by the disturbance of shoreline processes caused by port and harbour works.

Coastal engineering activities may include seawalls, revetments, groynes, offshore breakwaters, beach replenishment, sand bypassing, dune stabilisation and various combinations of the above. Beach replenishment is frequently adopted to create or enhance beaches for recreational or tourist use or for aesthetic or heritage purposes but can also have environmental benefits through the restoration of natural systems. Further discussion is presented in Supplement A on Beach Replenishment.

Australian coastal engineers' experience in coping with mistakes of the past led to the establishment of public authorities such as Queensland's Beach Protection Authority and South Australia's Coast Protection Board some of which have since been subsumed into other government bodies. Besides encouraging good coastal management practices, these and similar organisations, or their successors, in most other states provide data collection programmes for the understanding of coastal processes, for the design of coastal engineering works and for the modelling of the impacts of both engineering works and management practices upon the coastal environment under various developmental and climatic scenarios.

5.3.3 Reclamation and Canal Developments

In the early years of canal style development not all processes and environments were well enough understood and some notable failures resulted. With improved knowledge such developments in appropriate environments may be possible, but caution is required. Strict regulations are usually applied and some jurisdictions (e.g. Tasmania and Victoria) have or are considering an outright prohibition.

Problems of acid sulphate leaching from soils into coastal waters can occur naturally, but excavations and exposure of such soils through development can grossly exacerbate the problems. Significant stretches of coastline affected by acid-sulphate soils exist in every state and Northern Territory (ASRIS, 2011) and serious consideration must be given to its management for any development in such areas. Concrete and steel foundations of buildings or other structures constructed on low lying geologically recent coastal and estuarine sediments may deteriorate rapidly because of the presence of acid sulphate soils.

5.3.4 Marinas and Small Craft Facilities

The increasing use of the coastal zone by both Australians and overseas tourists is creating the demand for facilities for various water-based activities using small craft of all kinds. Most coastal resort towns will establish at least one marina. Both resorts and urban communities located around large bays or estuaries are making increasing use of fast passenger ferries. Facilities for these vessels are also required on offshore islands and various reefs within the Great Barrier Reef and other coastal waters. In certain situations vessel wakes may have adverse impacts. Further discussion is presented in Supplement B on Marinas.

5.3.5 Excavation, Dredging and Disposal of Sediments

Developments within the coastal zone inevitably disturb the environment. Clearing of vegetation and earth moving activities initiate soil erosion and, if not controlled, unwanted and possibly contaminated sediments may be discharged into wetlands or estuaries. Harbour and other works, including dredging and reclamation activities, not only in estuaries but on some sandy shorelines underlain by fine sediments and on coral reefs, also are potential sources of fine suspended sediments. Control of turbidity from disturbed fine sediments and the disposal of dredged material, particularly if it is contaminated, often are significant problems requiring careful operational planning and sediment settling systems.

5.3.6 Waste Disposal and Water Quality

Disposal of sewage, industrial waste and stormwater in the coastal zone (open ocean, estuaries, rivers, wetlands and dunes) is common practice world-wide. As the quantities of wastes have increased over time the impacts on coastal water quality within Australia have become increasingly detrimental and locally unacceptable to many communities. With improved knowledge of the environmental and ecological impacts of waste disposal, waste management options and practices are rapidly being modified and improved. Urban stormwater can bring with it oils and greases from pavements, sewage leakage and overflows, and both degradable and non-degradable detritus. Trade waste management, source control, innovations in treatment technology, re-use where practicable, stormwater control and high energy deepwater ocean outfalls have resulted in significant improvements in coastal water quality in some regions. Ongoing serious degradation of many coastal areas remains.

More diffuse discharge of nutrients and pesticides from upland agricultural activities can also affect estuarine and coastal water quality causing eutrophication and hence the need not only to control such discharges but also to improve tidal flushing of tidal lakes and bays. The disturbance of acid sulphate soils adjoining rivers and estuaries may make estuarine waters and coastal lakes toxic to fish. Appropriate coastal or other engineering works may provide solutions to such problems in some situations. Further discussion is presented in Supplement C – Outfalls.

5.3.7 Desalination Marine Structures

Desalination facilities to supplement water supplies in coastal cities are a recent major addition to our coastal landscape. These facilities incorporate an intake and an outlet structure, both of which potentially impact on the coastal environment. There are some issues in common with the wastewater outfalls discussed above (point discharge, interruption to sediment transport, focus for marine growth) but there are also some differences. The intake has the potential to entrain marine biota, the discharge is dense and hence impacts the seabed, and the potential constituents are specific to the desalination process. Appropriate coastal/marine engineering expertise is needed (combined with marine biology and chemistry studies) to ensure minimisation of environmental impact. Further discussion is presented in Supplement E – Desalination Marine Structures.

5.4 Coastal Hazards

While the coastal zone is generally a pleasant environment in which to live, there are also various potential hazards that threaten human life and developments from time to time. These hazards include tropical cyclones, storms, floods, storm surges, extreme waves and tsunamis.

Tropical cyclones and severe storms generate strong winds which may destroy buildings, blow down trees, move sand dunes on coastal land, as well as generate large waves in coastal waters. These waves may damage coastal structures, cause cliff collapses, interfere with maritime activities and erode beaches. Floods from upland runoff may inundate coastal towns located on estuarine flood plains and infill dredged navigation channels with sediments. Storm surges may inundate low-lying coastal towns and resorts with sea water and also facilitate the erosion of the foreshore by waves. For example, 300

Damage to luxury yachts and marina at Port Hinchinbrook, Cardwell, Qld, from Tropical Cyclone Yasi, Feb. 2011
Source: Newspix, Photo Marc McCormack, Cairns Post

persons drowned in 1899 when a tropical cyclone and storm surge destroyed a pearling fleet anchored near the remote north Queensland coast. In 1918 a combination of cyclonic winds, storm surge from the sea and subsequent upland runoff devastated the Queensland city of Mackay, killing 30 people. The damage caused by tropical cyclone Yasi with its 5 m storm surge on the coast of northern Queensland in February 2011 is a recent reminder of the destructive power of such systems although thankfully there were no deaths in this case.

Tsunamis are also a potential cause of inundation and damage from the sea. The major earthquake (8.6 on the Richter scale) of 1960 in Chile generated tsunami waves in Sydney Harbour which persisted for several days. Damage to moored boats was significant but limited because the peak 0.8m tsunami wave arrived at low tide. The north-west coast is perhaps more vulnerable to tsunami impact. The 1994 Java and 1977 Sumbawa earthquakes resulted in water level increases of four to six metres on the sparsely populated northern West Australian coast. The 2004 Boxing Day Aceh and the February 2011 Sendai events were terrible reminders of the destructive potential of tsunami.

Waves breaking on coastal rock shelves or shallow coastal bars are a significant hazard for anglers and users of small boats. All vessel operators need to be wary of the confluence of strong tidal currents and waves at river and estuary entrances with often rapid changing conditions. Port operators need to be wary of minimum under-keel clearance requirements for the safe passage of ships at times of low tide and strong offshore winds. Unstable or undercut coastal cliffs pose threats both to human lives and to buildings and other facilities.

Climate change presents the potential increased occurrence or severity of some of these hazards and the threat of sea level rise exposes more development to such hazards as well as increasing the hazard of inundation. While human use of the coastal zone poses threats to the coastal environment, it is important to recognise that the coast can be a harsh and dynamic environment in which to establish settlements and infrastructure. Planning and design of coastal developments and structures to withstand or minimise exposure to the risks of these hazards require coastal engineering expertise. The following checklist highlights many issues that would indicate a need for specialist coastal or engineering consultation.

Checklist – Is engineering expertise needed for a proposed development or activity in the coastal zone?

- Does the project involve port and harbour facilities?
- Are buildings or other facilities constructed near the shoreline being, or likely to be, threatened by erosion?
- Are coastal structures such as breakwaters, groynes, training walls, jetties, seawalls, etc. to be constructed?
- Are low-impact engineering alternatives being considered?
- Are any dredging activities being considered?
- Is turbidity and its control an issue?
- Will there be any interference with coastal or estuarine sediment transport systems?
- Are flood prevention/mitigation works required?
- Is a knowledge of wind, wave or current forces on a structure or object required?
- Is data on waves, tides or currents required?
- Is physical or numerical modelling of environmental impacts on a structure or development required?
- Is physical or numerical modelling of the impacts of a structure or development on the environment required?
- Is a planning decision requiring quantification of coastal processes involved?
- Are land reclamation and/or canal works being considered?
- Are engineering works required to restore or replicate a natural coastal or marine environment?
- Will the operation of facilities or equipment be dependent on environmental parameters?
- Is the marine environment causing unacceptable deterioration of buildings or facilities?
- Does a culturally significant structure or precinct need to be restored, reconstructed or relocated?
- Is storm water runoff to be discharged into a wetland area?
- Are acid soils likely to be disturbed by the project?
- Does the project involve a marina or other small craft facilities?
- Is waste disposal infrastructure including possible outfalls and water re-use under consideration?
- Is a structure to be built on a reef or offshore?
- Does tidal flushing of a coastal lake or bay need to be improved?
- Is the proposed development or activity likely to be vulnerable to coastal hazards such as tropical cyclones, storms, floods, storm surges, extreme waves or tsunamis?
- Are such extreme events likely to change with time due to climate change?
- Is the proposed development resilient in allowing for sea level rise and other projected climate change effects?
- **Is there a hazard to human life?**

If the answer to any of the above or similar questions is YES, then coastal engineering and/or other expertise is needed for the proposed development or activity in the coastal zone. In many situations, the engineer will need to obtain relevant specialist advice from marine scientists and other allied professionals.

6 COASTAL ENGINEERING METHODOLOGY

6.1 Design Philosophy

A design philosophy should underpin all coastal engineering projects. The design process should be based upon the appropriate level of professional engineering competence, a sufficiently broad scientific understanding of the coastal environment relevant to the project, the concepts of ecological sustainability, and an understanding of social and community values and aspirations. Designs should fit within the framework of Integrated Coastal Zone Management (ICZM) where it has been developed for a region or state. This concept is a structured co-ordination of activities within the coastal zone aimed at ensuring appropriate balance between the triple bottom line targets for economic, social and environmental goals. (See Supplement F.)

It is important for the coastal engineer to seek appropriate professional advice concerning other aspects of a project so that the decision-making process is based upon accurate, clear and complete information

The design process itself will involve the consideration of different options for achieving the project goals. The practitioner's technical and economic competence will be applied to assess the relative merits of these options. This will involve a consideration of the level of risk of failure and the consequences of that failure, such as structural collapse with or without loss of human life, inability to function as required, environmental damage, excessive cost, non-acceptance by the community, etc. While some aspects of risk assessment will be based upon statistical and economic analyses, others will depend upon subjective factors such as community attitudes concerning the value of human life and of the coastal environment. Not only the risks involved in a project need to be identified but also the party which will be responsible for managing and bearing the consequences of each risk.

While communities are becoming increasingly aware of environmental matters, the level of education, concern and interest on any particular aspect is likely to be varied within any group. This variation needs to be acknowledged and incorporated into the choice of public consultation methods and approaches used for a project. Within the constraints of the resources made available to them, coastal engineers are responsible for providing clear and accurate information about proposed projects to assist clients, communities and approving authorities in decision making.

Specialist consultants and public agencies may have resources to provide or assist in obtaining a broader and deeper environmental knowledge, especially in value assessment and comparison. However, it should be recognised that the increasing operation of community power structures, different perceptions of relevant issues, varied and changing community expectations, all mean that the consultation process will be increasingly an open-ended one in which the option adopted at a specific site at a given time will not necessarily be a predictable one.

Aerial view of Heron Island and reef. SOURCE: OCEANWIDE IMAGES

Nevertheless, any coastal engineering project should have a coastal engineer as one of the project leaders and he or she must take responsibility for identifying environmental considerations, ensuring that the project is undertaken with due regard to ecological as well as economic sustainability.

The coastal engineering methodology explained in the following sections has been compiled to provide overall guidelines for all coastal engineering projects. In all cases the necessary amount of consultation, investigation and design should be determined considering both the likely capital cost of the project and its potential to cause continuing undesirable environmental or other impacts. It should be recognised that not all projects will require or can afford wide-ranging consultation, extensive investigations or detailed consideration of many design options. For small projects an experienced coastal engineer can often make informed judgements about the likely upper limits of various physical processes and other aspects of the project, hence avoiding the need for extensive investigations and unnecessarily high extra project costs. Nevertheless, it is important for the coastal engineer to seek appropriate professional advice concerning other aspects of a project so that the decision-making process is based upon accurate, clear and complete information.

Not all coastal engineering projects fit easily into conventional engineering practice. For example, a boat access channel and small harbour previously dredged through the coral reef surrounding Heron Island in the southern Great Barrier Reef had caused environmental degradation of the adjoining reef-flat and loss of sediment from the island. Any solution to these problems had to be implemented with minimal environmental disturbance. Both the project and its budget were small but the physical and ecological systems are both complex and extensive. There were no surveys of reef-top topography to the required accuracy and detail, and no systematic data was available concerning prevailing waves and currents. The site is remote and in a world heritage area under continuing use and observation by tourists, scientists and marine park rangers, all of whom rely on the existing facilities for access. When confronted with such a complex situation and with limited resources for investigation, design and construction, it is inevitable that some compromises must be made in the development of an appropriate solution.

6.2 Conceptual Design

Conceptual design begins with the formulation of the overall purpose and the significant requirements of a particular project. It then proceeds to document in specific but unquantified terms the strategies and assets to be used to satisfy the objectives of the undertaking, be it a management program, a new development, or a structure. The types of outputs from a conceptual design would be flow charts of processes and procedures, development plans, schematic diagrams of the project, environmental assessment analyses and processes, the degree of community involvement, measures for environmental impact amelioration, definition of dredging areas and disposal sites, the location of source areas for materials, maintenance and repair needs, etc. At this stage there still may be several options under consideration.

It is during the conceptual design phase that ecological sustainability is incorporated in the process instead of as an add-on or a test at the completion of the project.

Checklist – Conceptual Design

- Has the need for the project been clearly stated and tested?
- Are there any aspects of the project superfluous to that need?
- Is this a suitable approach to the problem?
- Is this an appropriate use for the site?
- Has the environmental robustness of the site been considered in locating the project?
- What are the likely environmental impacts/benefits and which of these are of most concern/consequence?
- Does the proposed design incorporate Ecologically Sustainable Development principles appropriate for the coast?
- What are the likely visual and social impacts?
- Have relevant external factors, including other projects, affecting the project been considered?
- Have relevant options been considered?
- Are the proposals sufficiently flexible to allow meaningful public consultation and what form will this consultation take?

6.3 Public Consultation

Public consultation is an important opportunity for all groups with a perceived interest in any aspect or impact of the project to become involved. These may include individuals likely to be directly affected by the project, the local community, special interest groups, indigenous people, local government and state government agencies charged with specific responsibilities such as coastal management, coastal industries, water quality, cultural and heritage values, natural and living resources.

Public consultation is best initiated early in the process. In some cases this will be before a specific concept has been developed so that site specific issues and environmental constraints and objectives can be defined first. For other cases, where the nature of the project has been determined by other factors, the best time would be immediately after the formulation of the concept of the project (works or program). At this time enough information has been formulated to serve as a kernel upon which to engage the interest of the stakeholders. Importantly though, the proponent will not yet have an overly large commitment to a particular concept, nor will the other stakeholders feel that they are being presented with a fait accompli. In situations where formal public consultation processes are specified (e.g. in regard to environmental impact statements), those requirements may be the prime factor determining the public consultation process.

Some of the questions raised during early public consultation may not be able to be answered definitively and some of the counter-proposals may need to be dealt with on the basis of experience and judgement. Nevertheless, it is likely that suggestions or strategies arising during public consultation can be incorporated to the overall benefit of the project.

Early engagement and consultation with indigenous parties, local and state government is beneficial in identifying approval requirements, local considerations and which can then be incorporated into project scope and planning.

Checklist – Public Consultation (a) Project Matters

- Have any flaws been uncovered in the basic reasoning behind the concept?
- Has the relative ranking of the environmental attributes been changed?
- Are there any sites of significance to indigenous people?
- Does the project affect any sites of particular natural heritage value or cultural significance?
- Are there any previously unidentified concerns?
- Are there any non-tradeable attributes?
- Does the community have a strong positive or negative response to any particular option?

Checklist – Public Consultation (b) Process Matters

- Is the proposed consultation process appropriate for the project?
- Have genuine stakeholders been identified and consulted?
- Has consultation with stakeholders been effective and acceptable to them?
- Have indigenous people been consulted in a culturally sensitive way?
- Is there provision for continuing consultation as the project develops?
- Have the important concerns been addressed?
- Is there a need for mediation to deal with unresolved differences?

6.4 Investigations

6.4.1 Scope

Coastal engineering requires an understanding of the dynamic interactions of the water, land, sediments, suspended matter, soluble particulates, and flora and fauna in the coastal zone. While some of these fields are beyond the expertise of the practising coastal engineer and will require input from biologists, geologists, botanists, planners, and other professionals, the coastal engineer is nonetheless required to have an appreciation and general understanding of their importance to sustainable management of the coastal zone. In many cases the coastal engineer may be responsible for project management and sourcing or commissioning studies from specialists in other disciplines. Following identification of the task (Conceptual Design) and a general public acceptance of the direction of the project, including the community's input into that direction, investigations into the project are ready to commence. These should involve:

- collection and collation of data
- identification of all the physical, chemical and biological aspects of coastal dynamics relevant to the project
- setting design criteria
- scenario modelling and assessment of design options
- environmental impact assessment
- early consideration of licences and approvals required
- costs of options.

These investigations are not independent and results of "later" stages of investigation may raise aspects not identified earlier. For example, when setting design criteria it may be found that additional data is needed before modelling studies and assessment of design options against the criteria can be carried out.

Investigations always should be carried out with an awareness of likely changes of conditions over the life of the project. Examples of such possible changes include:

- full range of natural fluctuations in environmental conditions
- environmental changes including land use, catchment runoff
- climate change effects such as sea level rise and variation in wave climate
- planning and/or management changes
- increased production, trade or use of larger vessels, etc., requiring expansion of facilities
- structural changes such as deterioration in materials – concrete spalling, steel corrosion or geotextile abrasion
- increasing contamination of marinas and harbours
- social and cultural changes such as new or changing community needs and developing cultural significance of the project or parts of it.

All investigations provide information to be used by the coastal engineer in a manner appropriate for the particular project, for the environment in which it is located and the community which will use it. No amount of investigation, modelling or simulation can provide absolute certainty of outcomes and the coastal engineer will always need to make informed judgements based on his or her personal experience and knowledge of good engineering practice.

6.4.2 Data

An understanding of the coastal zone dynamics in the region of interest requires the collection and collation of data, both historical and present day. This data must be meaningfully interpreted and then used to consider alternative scenarios and design options. The listing below summarises the physical, chemical and biological data which could be required for coastal engineering projects. It will be necessary also to determine if the project will affect areas or artefacts of natural heritage value, cultural significance or engineering heritage value.

The specific data required for a given project will depend upon the nature of both the project and the local coastal environment. This data needs to be identified together with both the area and the duration over which it is required.

Data will be available in various formats, some of which are more convenient to use than others. Formats include:

- books, reports and other published and unpublished papers
- historical records in archives
- maps, charts, plans, drawings
- instrumental recordings and analyses of such recordings
- sedimentological or biological samples
- aerial photographs, satellite imagery, LIDAR surveys
- geographical information systems (GIS) or other data bases
- personal knowledge of people familiar with the area.

Such data may have to be assembled from many sources. In some cases it will be available online (or ordered online) from such sources as BoM, Geoscience Australia, IMOS, AODN, CSIRO, AODJCF, Manly Hydraulics Laboratory etc. In other cases it may have to be extracted painstakingly from old documents, microfilm or microfiche. In many cases its reliability may be questionable or the data source, such as a map, chart or GIS, may be a composite of data obtained from different sources at different times with different accuracies. In all such cases, an assessment must be made as to the suitability of the available data. If it is found to be unsuitable, the possibility and cost of replacing or expanding it with more reliable or more extensive information needs to be considered.

The temporal relevance of the data must also be assessed. The longest wave data set available in Australia is of the order of 40 years, which is barely adequate for the design of significant coastal structures. Many data sets are considerably shorter in length and some may be inconsistent in quality. Hence hindcasting techniques will be required to extend these records, assuming that meteorological (wind speed, direction, duration and fetch length) data is available for longer periods – 50 years or more are available at some sites. Other data such as rainfall may be available for as long as 100 years or more. However, some hydrological or meteorological data sets may not extend to the present (nor to the future) because of cost cutting by data collection agencies in recent times. Biological data is seldom available over any extended period. Indeed, while the SOMER 1995 report provides baseline data for future comparison, there is little reliable data available at most sites to assess the natural variability of marine ecosystems let alone their tolerance to disturbance by human activities.

Checklist – Data Relevant to Coastal Engineering Projects

Physical Data

- water level – tides, floods, storm surge, wave set-up and sea level change
- waves – short period, long period, seiche, coastally trapped and tsunami
- wind – over water and over land
- beach erosion – short term fluctuations and long term shoreline movements including onshore, offshore and alongshore transport
- cliff erosion rates (e.g. from aerial photographs/historical surveys)
- rainfall/runoff – in estuaries, rivers and the ocean
- currents – local wind and wave-generated, flood and tidal, continental shelf and oceanic
- beach and surf zone morphology, seabed bathymetry
- sediments – grain size, mineralogy, carbonate and organic content
- geotechnical properties of subsurface strata
- water quality – sources, dilution and advection of pollutants, effluent outfall performance, stormwater.

Chemical Data – sources, distribution and concentrations of:

- natural materials, including acid sulphate soils
- industrial chemicals and waste (e.g. heavy metals, PCBs, etc.)
- agricultural chemicals (e.g. pesticides, fertilisers, etc.)
- human effluent and waste pollutants
- contaminants on beaches, in bathing areas and on the shoreline generally (e.g. litter, toxic organisms, oil, etc.)
- sediment chemistry
- salinity and temperature in estuarine and nearshore waters.

Biological Data

- flora (e.g. mangroves, wetland plants, algae, seagrasses, etc.)
  – species diversity, population numbers, distribution and condition
- fauna (e.g. marine and land animals and birds, benthic organisms, etc.)
  – species diversity, population numbers, distribution and condition
- presence of rare, endangered or threatened species
- evidence of biological influence on coastal sediment movement
- identification of biological indicators for water quality.

However, long term physical data such as rainfall, runoff, wind velocity, sea temperature, salinity or biological data from coral head growth may be used as indicators of climatic variations or trends over a longer period of time and hence may allow some extrapolation of the length of other shorter term data time series. Deficiencies in the spatial extent of data usually can be remedied by project specific data collection programs covering all relevant quantities over an appropriate short-term time frame.

Coastal engineering involves working at the land-sea interface and usually includes both land-based and marine activities. Maps and plans for land-based activities generally have elevations referred to Australian Height Datum (AHD), whereas those for marine activities generally require the depth of water available for navigation and hence have elevations referred to a low water datum such as Lowest Astronomical Tide (LAT). Older maps, plans and charts may use other datums. A consistent elevation datum is essential for each project and particular care should be taken when comparing historical elevation data from various maps and charts.

Allowance for different definitions for the meridian, e.g. true, magnetic or grid north and use of consistent map projections and grid coordinate origins is also important. The previous Australian Geodetic Datum (AGD) (based upon a mathematical surface of the earth designed to fit the Australian region) has recently been replaced by the Geocentric Datum of Australia (GDA); a geocentric datum that is directly compatible with satellite based navigation systems. GDA and AGD co-ordinates vary by about 200 m. However the change from AGD to GDA, does not affect levels defined by Australian Height Datum (AHD).

Waverider Buoy at Byron Bay, NSW ocean wave data collection undertaken by NSW Public Works' Manly Hydraulics Laboratory for the Office of Environment and Heritage Photo: MHL

The quality of data is an important aspect for the design of engineering projects undertaken in the coastal zone. Data is necessary for both risk assessment and evaluation of the consequences of accepting a risk level. Investment in quality data and long-term data programs is an investment in reducing the uncertainty of risk, resulting in more appropriate design criteria and parameter selection. The outcome of this investment should be a reduction in the capital costs of projects and elimination of expensive failures. Where project requirements demand the acquisition of new original data, the coastal engineer should also be conscious of the long-term value of that data for future uses, whether public or private, and seek to ensure that scientific method is applied and adequate quality control and archival procedures are put in place. There have been various attempts to create overarching data servers, the latest of which is Australian Ocean Data Network which aims to include coastal data. These will only succeed if agencies and others responsible for data collection are willing to contribute.

6.4.3 Coastal Dynamics

As outlined in Section 4.4, it is essential to define the extent of the overall coastal system affected by and affecting the proposed project. The extent of the system involved will depend, among other things, upon the size and nature of the project. The latter will also determine the quantity of data and the extent of data analysis required to identify the significant aspects of the system's coastal dynamics.

When the coastal system and its characteristics have been identified (see Section 4.4), the coastal dynamics and environmental qualities in the vicinity of the local site(s) should be identified from an engineering and scientific assessment of the available data. In most cases it will be found that there is insufficient data or that, while data on one aspect, for example tides, is adequate, there is virtually nothing known about other aspects, for example, the local ecosystems or the extent of interchange between inshore and offshore waters.

Hence it often will be necessary to undertake further investigations and specific data acquisition programs to obtain sufficient understanding of the coastal dynamics of the local area, both affected by and affecting the project. Information obtained from such studies could include:

- magnitude and frequency of winds, waves, water levels, currents
- coastal processes and shoreline changes over appropriate time frames

- rainfall, runoff, flushing of semi-enclosed waters
- water quality and factors affecting it
- marine, coastal and estuarine ecosystems
- environmental and other aspects of special value.

Data acquisition programs should, wherever possible, be planned to take account of the full range of natural fluctuations, as well as potential changes in intensity and frequency of events resulting from climate change.

6.4.4 Design Criteria

"Design" is the traditional name given to the process by which an engineering solution is investigated and developed in response to a stated objective, so as to provide a required amenity or to solve or prevent a particular problem. Coastal engineering design outcomes need not lead to construction or physical intervention but might commonly result in planning or other decisions which satisfy the stated objectives. The criteria for such a design will vary enormously depending upon the problem but will always involve performance requirements or criteria of some type, which may be multi- faceted. The design process is therefore targeted towards ensuring that the solution does not "fail" within the context of those requirements.

The criteria for design of a coastal project should be based principally on the adopted planning horizon, the perceived acceptable risk of "failure", the consequences of that failure and relevant social, environmental and economic considerations.

Richmond River Entrance (Ballina, NSW). SOURCE: GoogleEarth

The planning horizon, or the period of time for which the outcome is required, may differ significantly depending upon the type of problem or project being considered. A consideration of the effects of chronic coastal erosion on a beach might adopt a very long planning horizon if the intent is to "permanently" protect a particular amenity, i.e. a zero risk of failure. However, when faced with sea level rise or a naturally receding shoreline, permanence may not be feasible without significant cost or even be possible at all. The cost of meeting the desirable planning horizon might be expressed in terms of capital expenditure that would be needed to construct a defensive or other interventionist system. Equally, the cost might be in terms of the resuming or setting aside of extensive tracts of land which have high desirability and amenity for the present generation. Alternatively, the cost might relate to the value in preserving the local ecosystem. Any design will inevitably be a compromise based on a philosophy of acceptable risk to the perceived benefit. Design decisions made by the responsible authorities must therefore be agreed and appropriately communicated, across generations if necessary, to ensure that all stakeholders are continually aware of the assumptions of the decisions, the data upon which they are based and the possible consequences. By ensuring provisions are made also for obtaining more and better data, greater knowledge and enhanced predictive capability of coastal processes, subsequently updated decisions will accord with the principles of ecologically sustainable development.

As a separate example, the functional life of a particular coastal structure or facility might reasonably be limited to a specific period of time, say 20 years. This may be justified on the basis of a known limited resource or need, or a firm expectation of redevelopment. Alternatively, predicted rising maintenance costs or new technology could dictate replacement or removal after this approximate period of time. If the consequence of "failure" of such a facility during the 20-year period is deemed relatively costly in terms of human life, infrastructure or the environment it would be necessary to target a solution yielding a relatively low probability of failure. On the other hand, if failure of the facility is deemed to result in minimal inconvenience, then the risk of failure could be set significantly higher. Again, the stakeholders must be fully involved in any such philosophical decisions.

Risk analysis must therefore play an integral part in the planning of coastal activities and the design of coastal structures. The acceptable risk of failure within the assumed planning horizon, or "design life", combined with the estimated probability of a threat to the performance of the facility, will have a significant bearing on the capital and/or operating cost (social, environmental or economic) of the project.

The principal threats to stability of coastal features, both natural and built, take the form of short-term environmental loadings, such as winds, currents or waves. Because of the seasonal tendency for such events, the concept of the "return period", typically in years, has been favoured as a practical expression of the risk of their occurrence. The return period is simply the average time between equalling or exceeding a given magnitude of an event but is often misunderstood. By considering that the inverse of the return period is the average annual probability of exceedance, this reveals the important issue for design against any type of threat – the adopted level of risk. For clarity, the return period herein is termed the average recurrence interval to better convey its true meaning, e.g. a 100 year average recurrence interval event has a 1/100 chance of being exceeded in any one year.

Threats to *sustainability* – such as sea level rise – might be seen to be much longer term but return period is still a relevant concept. However, because of the relatively short databases upon which return periods have been estimated, (traditionally 50-100 years at best), a common misconception is that adopting design return periods which are significantly longer than these values is not only unnecessary but inaccurate and inappropriate. Setting aside for the moment the difficulty and accuracy of establishing such estimates, particularly within the context of possible climate change, the important concept here is the actual level of risk.

Conveniently, the above considerations can be conceptually combined in a statistical description which greatly assists the decision making process. Originally termed "encounter probability" (Borgman, 1963), the following principal parameters of:

Threat:	Average Recurrence Interval,	T (yr)
Exposure:	Planning Horizon or Design Lifetime,	N (yr)
Acceptability:	Risk of Encounter within that Lifetime,	R (%)

can be related by:

$$T = \frac{-N}{ln(1 - R/100)}$$

This equation provides the appropriate average recurrence interval of the threat, T, to be considered in the design if, within the planning horizon of N years, the acceptable risk of encounter (or possible failure at that level of threat) is chosen to be R. It is readily apparent from the summary of values presented below in Table 1 that relatively high values of the average recurrence interval T will be required to limit the potential for failure of typical projects below a level of 10% over their lifetime. For example, if a structure is to have a 5% risk of encountering an event magnitude which is equalled or exceeded at least once during the next 50 years, then the design extreme event is one with a 975-year (say 1000-year) average recurrence interval. In fact, there is approximately a 64% chance of equalling or exceeding the magnitude of the 50-year average recurrence interval event in any consecutive period of 50 years. Expressed in another way, in the next 50 years there is a 5% chance that the 1000 year average recurrence interval event or greater will occur, but a 64% chance that the 50 year event or *greater* will occur.

Table 1 – Design Average Recurrence Interval *T* in Years.

% Risk of Encounter (*R*)	Planning Horizon in Years (*N*)					
	1	10	20	50	100	500
99	0.2	2.2	4.3	11	22	109
90	0.4	4.3	8.7	22	43	217
64	1.0	10	20	49	98	489
50	1.4	14	29	72	144	721
20	4.5	45	90	224	448	2241
10	9.5	95	190	475	949	4746
5	19	195	390	975	1950	9748
1	99	995	1990	4975	9950	49750

A design need not completely fail when it encounters the design event. For example, rubble-mound breakwaters are commonly designed to accept up to 5% damage of their armour layer during the design storm. This is a long way from complete failure and this type of structure is likely to withstand a storm of much greater average recurrence interval before total failure occurs. Indeed where failure depends upon the simultaneous occurrence of two or more extreme conditions, such as large waves and high water levels, the probability of total failure may be very small. However, it is important to consider whether or not the proposed solution will fulfil all its performance requirements. The breakwater's strength may withstand the design wave conditions, yet it may still not provide the required protection to shipping sheltering behind it owing to overtopping by waves or unfavourable wave refraction. The breakwater configuration might also redirect wave energy under severe storm conditions and cause increased erosion on adjacent beaches.

The estimation of average recurrence intervals of design threats (e.g. winds, waves, currents, storm surge, sediment transport rates) is a highly specialised activity normally involving the use of sophisticated numerical models and is reliant on local data to demonstrate accuracy in prediction. When the database for determining design threats is limited in extent and/or duration, design should be based on one of two conditions. Either a conservative view of threats (e.g. loadings, strengths, transport rates) should be taken by erring on the safe side of uncertainty, or the design explicitly should allow for possible later modifications in response to updated estimates of risk. Depending on the consequences of failure, so-called soft options could be used. These would include devices that can be modified or removed if unsuccessful or reinforced to be more durable if proven to be the right solution. This might avoid the high capital cost of potentially conservative over-design, but procedures must be put in place to monitor and document the design performance. The stakeholders also must be agreeable to the design philosophy, accepting that ongoing change and maintenance costs are likely.

Other criteria which need to be considered in the investigation of engineering options include mandatory design constraints (structure height, width, town planning regulations, etc.) environmental impacts, socio-economic consequences, visual impacts and community acceptance. Most of these issues are addressed in Environmental Impact Statements (EIS) (see Section 6.4.6).

6.4.5 Modelling

Scenario modelling to investigate a number of engineering options is usually undertaken to determine the effectiveness of each alternative. This process may include numerical and physical modelling and both qualitative and quantitative output with a preliminary assessment of impacts. Implementation, social and maintenance costs of each option are then determined and a short list of favoured options put forward.

Laboratory model of Barrow Island harbour
SOURCE: Water Research Laboratory, UNSW

Whenever any modelling is undertaken, it is essential that the limitations of the model results be clearly understood by the model user and also clearly communicated to clients and all interested parties. A model, either numerical or physical, of a particular process must reproduce the relevant aspects of that process reliably. This implies that the model must be soundly based upon relevant theory and have been properly calibrated using data which is derived from either the system being studied or a similar one. Moreover, the calibrated model should be verified by testing it using different sets of appropriate data.

Choice of appropriate models and modelling strategies to investigate specific matters is essential. This requires informed professional judgement since virtually all coastal systems and their processes are too complex to be modelled in their entirety, regardless of the resources available

The increasing availability of "user-friendly" software with attractive dynamic graphical outputs is allowing nontechnical persons to gain a better understanding of model outputs. However, it needs to be emphasised that these outputs are very much dependent upon the inherent assumptions made in formulating the model and in the reliability and suitability of the input data used to calibrate, verify and operate the model. Numerical modelling techniques, correctly used, are an essential tool for assessing the performance of various engineering options for most projects. However, if applied by inexperienced or untrained operators, they have the potential to produce either misleading or possibly completely wrong results. An appropriately qualified experienced engineer should overview and interpret model outputs.

Despite the increased utility and use of software models there is still a role for physical scale models. Examples include wave impact and flow around structures of complex shape, plume interaction from multi-port outfalls, and wave actions in shallow water. Modelling facilities exist in Australia at Manly Hydraulic Laboratory and Water Research Laboratory in

Sydney, SMEC in Cooma and several university departments have capability in specific areas.

It is important to keep in mind the role of modelling as only part of an investigation process, to be used in conjunction with data collection and analysis as well as other studies to aid in the design.

6.4.6 Environmental Impact Assessment

Environmental Impact Assessment (EIA) is a process for the orderly and systematic evaluation of a proposed project including its alternatives and objectives, and its effect on the environment, including the mitigation and management of that effect. At the Commonwealth level EIA is of an advisory nature unless the project affects Commonwealth waters or land. For most States and Territories, EIA (or its equivalent), is an integral part of the planning approval process. Each State or Territory has its own specific requirements.

The environmental impact assessment concept has been adopted by the Commonwealth and all State and Territorial government authorities. The document in which this assessment is made most commonly is referred to as an Environmental Impact Statement (EIS) although other equivalent terms are also used. The principal aim of the EIS is to identify environmental issues to be taken into account in decision making by all interested parties associated with the project. Under all EIA procedures, the responsibility for preparation of the document rests with the proponent of the proposed project.

The EIS should include a number of options. The “do-nothing” option is generally included, in part to serve as a benchmark. The document is then subject to another set of consultations with the stakeholders. Following the completion of the EIS the client, consultant, approval authorities and the general community will have additional information to assist in making a decision as to the worth of the project and, if it proceeds, which options are the most suitable. Monitoring, amelioration measures and other environmental management needs associated with these options also will have been identified.

An EIS is normally only produced for major projects. However, in many situations, there are administrative or legal requirements for statements of environmental effects for smaller projects or those not having significant impacts. Good engineering practice requires a suitably scaled version of the EIS process for smaller projects, irrespective of the designated procedures required for development approvals.

6.4.7 Licences and Approvals

The licensing and approval procedures and requirements of all spheres of Government, as well as other public regulatory authorities, should be considered at all stages of a project, but especially prior to detailed design. Approvals required will range from overall planning approval to specific approvals under Local Authority building regulations. Environmental licences will include noise, dredging, marine discharges, sea dumping, etc. Appropriate contractual provisions, including requirements that contractors comply with all relevant licence conditions, should be included in project documentation. Licences required and approval procedures, etc. vary in different States and Local Authorities and from time to time. Practitioners need to ensure that they are fully informed concerning the current requirements of all regulatory authorities with jurisdiction over their project’s life.

6.4.8 Costs

Project budgets should include adequate provision for environmental investigation and analyses, consultation, design, documentation and environmental monitoring and reporting. The achievement of desired outcomes in an efficient manner should be considered throughout all processes, in order to achieve optimal use of generally limited resources.

The costs of undertaking appropriate investigation for coastal engineering projects are often a small proportion of the total project costs. In some cases environmental complexity or uncertainty may require relatively more costly investigations than is normally the case. However, pressure to reduce the effort and cost of investigations can lead to false economy whereby, owing to inadequate knowledge of the coastal processes, sub-optimal designs may result in increased capital or maintenance costs and may adversely affect the environment in ways not fully understood at the time of the decision to proceed with the project. Equally, inadequate knowledge resulting in sub-optimal designs may inhibit approval with financial costs associated with delays and may even result in proposals with high community value being rejected.

Checklist – Investigations

- Have Handbooks/Manuals/Reviews treating the relevant processes been consulted and understood?
- Is the available data sufficient to define adequately the relevant environmental parameters and impacts?
- If the data is not sufficient, can the additional data required be obtained with available resources within a reasonable time frame?
- Is the proposed program of investigation appropriate for the project, i.e. does it cover all relevant matters, and is its cost consistent with the expected overall project cost?
- If additional data cannot be obtained, does the increased risk and/or cost associated with this lack of data make the project nonviable?
- Are there specific natural heritage values or culturally significant precincts or artefacts, particularly any relevant to indigenous people or of engineering heritage value, which impose constraints on the project?
- Has the overall coastal system been clearly defined?
- Are the coastal dynamics within that system clearly and well understood?
- Have acceptable design criteria been defined for the important aspects of the project including its integrity, function, impacts, acceptability?
- Has the effectiveness of various options been determined?
- Has the reliability of modelling activities been tested?
- Have areas of scientific uncertainty been appropriately addressed?
- Has the environmental impact of the project been assessed and costed in an appropriate manner?
- Has the EIS identified environmentally sensitive issues not previously considered?
- Have licenses and approvals required before the project can be implemented been identified?
- Have intergenerational equity issues been addressed?
- Have viable and acceptable options been properly costed?
- Can a preferred option be identified?

6.5 Detailed Design

Traditional practice has been to undertake the tasks of design and construction separately. Following acceptance of the preferred engineering solution, detailed design commences to develop and refine all aspects of the project. This is followed by the preparation of contract documents and the calling of tenders for construction of the project. During this process, explicit construction methods and materials will be identified, together with expected maintenance and performance monitoring requirements. This approach is outlined in the following sections.

There is an increasing use by public authorities of integrated private sector delivery of projects, otherwise known as infrastructure partnership or build-own-operate-transfer (BOOT) approaches. Under this arrangement, developers, their contractors and consultants are invited to provide an integrated design, construction, operation and maintenance service. In the implementation of this approach the responsibilities for various parts of the design, documentation and construction phases, as well as their sequence and details, may vary from those described herein.

Detailed design generally includes:

- development of a Functional Specification for the facility, specifying design and performance criteria
- detailed analysis of all site conditions and design concepts, alternatives and optimisation
- data collection
- numerical and/or physical modelling
- selection of construction materials

- consideration of construction techniques
- environmental assessment
- cost estimation of the project
- detailed documentation and plans
- development of a maintenance program
- a removal or reinstatement plan if applicable.

As an example, a breakwater is to be designed for the development of a port facility. Preliminary design is usually based on numerical modelling and accepted relationships for armour stability, wave run-up, overtopping volumes, head, trunk and toe design, etc. These relationships are not exact and, depending on the project site, may over-estimate or under-estimate the designed components. Physical modelling can then be used to refine the design and optimise costs (e.g. reduce armour size and crest level) and provide design details for which limited research data has been published (e.g. wave overtopping). All these actions more precisely define the operational or failure mode and hence reduce the associated risk.

Detailed project cost estimating may need to consider cost/benefit or net present value analyses, which could include capital, maintenance, operating and possible removal/modification costs. Where costs are still highly uncertain, sensitivity analyses based on scenario testing or probabilistic budgeting and scheduling should be used to determine the upper and lower bounds and the possible median outcome to allow setting of contingency allowances. It is important that the project financier understands the basis upon which the project cost estimate has been made, has been appraised of the degree of uncertainty and therefore agrees to the adopted philosophy.

Construction materials and techniques require careful consideration in the detailed design and will affect the overall cost of the project. For the breakwater example, material considerations include source of armour rock (i.e. quarry location) and available quantity and quality of this rock. Availability of construction equipment and the constructability of the design should be assessed. In addition, placement techniques and placement tolerances need to be considered in some detail. Such issues are fundamental to the detailed design and can cover a broad range of issues depending on the type and scope of the project. Construction techniques and construction materials are considered in Section 6.7.

Detailed plans showing all dimensions and aspects of the project need to be prepared. Drawings need to be of appropriate quality to communicate all physical aspects of the design to the client, approving authorities, potential contractors and the community in general. Depending on the scope of the design, the drawings also may include setting out details for construction. To avoid confusion, all references to elevations should be to the same datum and examples given of conversions from one datum to another (e.g. AHD to Chart Datum).

Maintenance requirements, following development of the project, need to be included in the detailed design. Too often maintenance requirements are not communicated well enough between the developer, consultant and the Principal or final owner. This is particularly the case where a development may change ownership or an authority may have a turnover in personnel without due advice on their duties to maintain the facilities. Maintenance may also include ongoing monitoring programs which may be stipulated as part of the EIS (e.g. long term changes in water quality) or simply be a requirement to assess the performance of the engineering design (e.g. beach erosion control). Maintenance requirements in the coastal zone are discussed in Section 6.8. Particular attention needs to be given to increased maintenance or even adaptation for climate change impacts.

A design report which describes the project requirements, the design concept, data used, assumptions made, procedures and outcomes is a worthwhile effort at this stage in the project. It serves the discipline of ensuring that what the designer thought was being done was actually being done. It can also be the method by which an engineering peer review is undertaken. Review of specific aspects of the design by other professionals and general review of its acceptability by various stakeholders also should be obtained where appropriate.

Checklist – Detailed Design

- Have Handbooks/Manuals/Reviews treating the relevant design processes been consulted and understood?
- Is the design clear and concise; does it address all issues relevant to the project?
- Does the design reflect the needs of the Functional Specification?
- Are the selected construction materials and techniques appropriate for the marine environment at the site?
- Does the cost estimate for the final design include all factors required to construct/ implement the project?
- Has all necessary design documentation been prepared?
- Has an appropriate maintenance program been developed and costed?
- Does the design complement regional coastal management policy including the ecological sustainability of the coast?
- Is the design adaptable for future needs including coping with climate change impacts such as sea level rise?
- Has the design been peer-reviewed?
- Is the final design acceptable to the community?

6.6 Contract Documentation

Following the detailed design of a project and receipt of planning approvals from the relevant authorities, the project and tasks are documented to facilitate tendering and construction.

Contracts are generally structured so that the delivery of the completed project at a specified time and cost is the responsibility of the contractor. As such, the contractor accepts the legal, financial and managerial obligations of the project. It is essential that the contractor not only has a good understanding of construction contracts to ensure the sound management and operation of a project but also is experienced in working in a marine environment. Similarly, it is equally important that the engineers who assist in the formulation of the contract document have a good understanding of both the marine environment and construction contracts to ensure the document is not deficient in some technical or legal aspect, or prove to be burdensome to the contractor and ultimately the project.

Most government and large engineering consulting firms have standard contract documentation which may be used on almost all projects with the inclusion of a section on Technical Specifications prepared exclusively for each project. Contracts are generally structured so that payments to the contractor are based on one of the following three methods (or a combination):

- Lump Sum – pay an agreed fixed sum of money for the completion of a project conforming to the plans and specifications.
- Unit Price – pay an agreed sum of money for each unit of work completed on a project (e.g. dredging charged at cost per cubic metre rate).
- Cost Plus Fee – reimbursement of all costs plus additional management fee. This is used where the scope of the work cannot be well defined. It is more difficult to control the contractor and is less popular than Lump Sum and Unit Price Contracts.

Guidelines for the development of general contract documentation can be found in numerous coursework study programs and textbooks. However, careful consideration needs to be given to some unique factors which affect work in the coastal zone. Downtime and delays in construction project schedules can occur due to numerous environmental influences such as:

- unfavourable wave conditions
- strong or unfavourable currents
- strong winds
- elevated water levels and/or flooding
- rainfall

- unacceptable environmental disturbance
- continuing coastal processes may infill dredged excavations or remove deposited sediments (beach replenishment) during the contract period.

In the maritime environment other special conditions may also apply, such as navigation or vessel passage allowances, which can cause significant delays in project schedules.

Contract documentation needs to provide for agreements as to how risks will be shared. Criteria for and methods of assessing high likelihood downtime and delay conditions need to be addressed. Examples of such high likelihood conditions might include:

- extremes in operating conditions, e.g. waves, winds
- latent conditions, e.g. rock, soft sediments, debris, discovery of unexpected sites or artefacts of cultural significance
- changed conditions, e.g. results of storms – sediment scouring and deposition, damage to partially constructed works, or to equipment.

The risks of working in the coastal zone are significantly greater than those for similar land based projects. The Principal needs to consciously identify each of the risks which may reflect on a particular project and then decide the level of risk sharing to be borne by both the Principal and the Contractor. However, the Principal may decide, for example, that all risks should be borne by the Contractor, in which case the tendered prices are likely to be higher to reflect the greater proportion of risk to which the Contractor is exposed.

Checklist – Pre-Construction

- Is the form of the contract suitable for the project?
- Does it conform with the relevant Australian or FIDIC standard form of contract?
- Does the contract contain any unnecessary or irrelevant clauses?
- Is the contract written and compiled so as to minimise the possibility of subsequent legal conflicts?
- Does the contract take account of the special conditions which affect work in the coastal zone?
- Does the contract define clearly how risks will be shared?
- Have possible construction methods been evaluated for environmental impact?
- Does the contract include penalties for environmental damage during construction?
- Does the selected contractor have a good occupational health and safety and environmental record?
- Is the contract fair and reasonable to all concerned parties?
- Is the level and type of insurance appropriate?

6.7 Construction (Techniques & Materials)

6.7.1 Techniques

The techniques employed in coastal zone projects range from the very low to the very high capital intensive systems. Typical of the low capital intensive projects are those initiated and executed by local community groups with some aid from government. These use very little capital but have quite a large input of volunteer labour. For projects such as dune restoration which may extend over several years, this method is the most appropriate. On the other hand, projects which depend for their viability upon an early cash flow generally tend to employ large quantities of capital borrowed for short term or else raised as equity. Such projects often will use highly specialised construction techniques and equipment which may have limited availability and long lead times.

6.7.2 Materials

Selection of materials for use in the coastal zone is dependent on an extensive number of criteria of which the most important are listed in the following broad categories:

- type and purpose of structure
- structural integrity of material
- material costs and availability
- maintenance and serviceability
- construction and installation techniques
- aesthetic and environmental suitability.

Checklist – Post Construction

- Has the contractor complied with all environmental requirements?
- Was the design easily built?
- Could improvements have been made to the construction method?
- Could improvements have been made to the contract?
- Was the project completed to the satisfaction of the principal?

These matters are discussed in the Supplement D on Construction Materials for the Marine Environment.

Coffs Harbour seawall repair with Hanbar units. SOURCE: NSW Manly Hydraulics Laboratory, Office of Environment and Heritage

6.8 Maintenance and Performance Monitoring

6.8.1 Maintenance

Maintenance of projects is driven by economics (e.g. cost to replace/repair versus cost to maintain), design life of the project, consequences of failure and aesthetics. Conditions in the coastal zone are abrasive, corrosive, subject to extremes of natural conditions and forces, as well as attack by marine and terrestrial organisms. Neglecting maintenance in the coastal zone will lead to deterioration of the facility and ultimately its failure to perform its designated tasks.

Maintenance of coastal zone projects and facilities can generally be classified into three categories:

- built-in maintenance
- routine maintenance
- event-driven maintenance.

In some circumstances there may be no requirement for specific maintenance allowances. This may be the case where the project design life is of short duration (e.g. temporary groyne) or the cost to rehabilitate or replace is more economical than maintenance measures.

Built-in maintenance – is a preventative maintenance method adopted during the construction phase of a project. Material selection and protective techniques are important criteria reflecting on both the initial capital outlay and maintenance of a project.

Built-in maintenance methods are generally employed on projects where the design life of the project is of significant duration and the costs can be justified. These systems usually require some form of ongoing monitoring and routine maintenance. However, the routine maintenance is considerably less than that of a similar project without built-in maintenance.

This type of maintenance can be effective in extending the life of a facility, where the design life is controlled by material or structure durability in the coastal zone.

Several examples of built-in maintenance on engineering projects in the coastal zone are:

- cathodic protection of steel piles
- impressed current protection of concrete reinforcement
- selection of larger than required grain size for beach replenishment
- installation of litter removal systems in storm water drains.

Allowing for future modifications in the event of climate changes also comes under this heading, e.g. ensuring foundations and design of a seawall can accommodate height increase.

Routine maintenance – involves regular monitoring of the completed project and being pro-active in the prevention of deterioration by providing maintenance on a routine basis. Routine maintenance also includes projects such as maintenance dredging, mechanical beach cleaning and storm water trash rack cleaning.

Routine monitoring or inspection includes periodic measurements of the performance of cathodic protection systems, inspection of paint systems, beach surveys for sand replenishment projects, dune stabilisation projects, breakwater inspections and hydrosurveys for dredging programs, etc. Maintenance is undertaken or implemented when the monitoring identifies the requirement for maintenance.

Event-driven maintenance – involves maintenance or repair following storm events. For example, replacement of dislodged rocks from a breakwater following a storm or, in some instances, repeat replenishment of a beach after a major storm has passed. This action is undertaken in addition to routine maintenance to ensure that repair of any damage or necessary maintenance is carried out immediately, rather than to address the maintenance or repair at the next programmed routine inspection.

Unforeseen maintenance may occur where inappropriate planning, design or construction methods have been employed or when unforeseen events occur. For example a concrete mix may be incorrectly specified during the design process or the curing process may be inadequately controlled resulting in cracking and exposure of reinforcement to chloride attack. Unforeseen maintenance can be avoided when due care is exercised.

6.8.2 Performance Monitoring

Monitoring of the performance of a project is important from both a client, consultant and contractor perspective. The client pays for a project to be undertaken based on a clear set of outcomes and levels of quality assurance. Usually the contract documentation will provide performance clauses relating to the design and construction phases of a project including a 6 to 12 month monitoring period for which the responsibility of the project performance is held by the design engineer and the contractor. During this period, any inadequacies in the project are rectified by the engineer and/or contractor.

Performance monitoring is a tool used in quality assurance (Section 7) and can be a useful mechanism for improving design and construction methods.

Performance monitoring may include:

- biological monitoring for a project’s impact on water quality
- beach and dune surveys for effectiveness of erosion control
- breakwater surveys for subsidence or rock displacement
- general workmanship.

In many cases project approval will include the requirement that an appropriate environmental monitoring program be developed and implemented commencing before the project begins, continuing during its implementation and for a specified duration after its completion. Publication of interesting/unusual projects is encouraged as a means of improving the knowledge base and benefiting the coastal engineering profession.

Checklist – Performance and Maintenance

- Is the project performing satisfactorily and meeting design guidelines?
- Is the maintenance scheme effective in preserving the functionality of the project?
- Are the chosen construction materials proving suitable for the marine environment?
- Is the community satisfied with the outcomes of the project?
- Are there any unforeseen environmental impacts?
- Has consideration been given to publicising interesting or unusual features of the project?

6.9 Removal and Life Cycle Planning

Life cycle planning or, as it is sometimes known, life cycle costing, is a means of incorporating all the costs of a project in one accounting. These costs will include capital, operating, maintenance, levies and charges, and the residual value of any assets involved. The item most frequently overlooked is the one of residual value. While this may not be critical for projects where there is a positive residual value, there are circumstances where the asset at the end of its useful life may have a high negative residual value. In other words, while the asset may no longer be serviceable, it may be expensive to remove.

The failure to account for this negative residual value in planning can impose unexpected financial burdens upon organisations such as Local Government or Public Utilities. Where life cycle planning is undertaken and where this includes the programmed removal of the asset, a cash flow can be calculated which distributes the cost of the project equitably over its lifetime.

Checklist – Removal and Life Cycle Planning

- Have all operating, maintenance and removal costs been determined?
- Have possible removal and disposal methods been identified?
- Will the environmental impacts of removal be acceptable?

Additional questions for existing structures before removal:

- Is the structure culturally significant?
- Does it have significant engineering heritage value?
- Should it be restored, reconstructed or removed?

The environmental impacts of the removal and disposal process also need to be carefully considered.

7 STANDARDS, CODES AND QUALITY ASSURANCE

In Australia, there are few specific Standards and/or Codes addressing investigations, design and/ or construction for coastal projects. Only two Australian Standards directly address our domain – AS 4997-2005, Guidelines for the design of maritime structures and AS 3962-2001, Guidelines for the design of marinas. The first of these addresses the design, preservation and practical applications of such structures as fixed moorings for the berthing of vessels, piles and other parts of a substructure, wharf and jetty decks, building substructures over waters, etc. The second provides designers, manufacturers and operators of marina and vessel berthing facilities with a set of guidelines for recreational marinas and small commercial vessels up to 50 m in length. Guidance is also given for on-shore facilities such as dry boat storage, boatlifts, boat ramps and associated parking facilities. Both are cast as guidelines only.

A more comprehensive set of standards are provided by British Standard suite BS 6349, Maritime Structures. This is a set of eight standards covering 1. General criteria; 2. Keywalls, jetties and dolphins; 3. Design of dry docks, locks, slipways and shipbuilding berths, shiplifts, etc.; 4. Fending and mooring systems; 5. Dredging and land reclamation; 6. Inshore moorings and floating structures;. Breakwaters; and 8. Ro-Ro ramps, linkspans and walkways.

In Australia, there are few specific Standards and/or Codes for coastal projects. International or country-specific Standards and Codes may provide guidance but should be used with caution.

A possible reason for the paucity of Australian standards is the complexity of coastal processes and the wide variability of the Australian coastal environment. Some general design and construction codes may be applicable for particular types of projects (NSW Maritime, 2005 lists several), but because if the frequently encountered unique conditions for each project coastal projects should often be treated as one-offs for which general codes may be of little use. Designers and constructors of coastal works need to be abreast of the technical literature and one publication that has long been seen as a de facto standard is US Army Corps of Engineers Coastal Hydraulics Laboratory's Coastal Engineering Manual (formerly Shore Protection Manual). Care needs to be taken that appropriate interpretation is made for Australian conditions.

For coastal water quality studies, a widely adopted guideline that often forms the basis for state authority standards or licence conditions is the ANZECC *Australian water quality guidelines for fresh and marine waters*.

The principle upon which Quality Assurance is based is one which gives a purchaser confidence in the quality of the product produced by the supplier. This is achieved by the supplier having a manual and a set of documented procedures against which each project is checked off through its several phases. The manual gives organisation-wide operational requirements, while the procedures deal with particular activities within the organisation. The Quality System is subject to regular audit and certification by organisations registered to undertake this function.

Quality assurance is managed at an organisational level. It cannot be applied to a project within an organisation which does not already have a quality assurance system.

The International Standards Organisation issued the ISO 9000 series of standards applying to quality assurance (ISO 9000 to ISO 9004) in 1987. Standards Australia has adopted the ISO system in its entirety as a set of Australian standards (ASNZS ISO 9000 to ASNZS 9004). A similar set of standards have been released for environmental management (ISO 14000 series).

The most important aspect of Quality Assurance is that all aspects of any project are implemented carefully at a sufficiently high standard of workmanship to ensure that the project fulfils all its planned uses and meets all required environmental standards. The maintenance of a quality assurance system is a means towards achieving this end result. It is not an end in itself.

Checklist – Standards, Codes and Quality Assurance

- Have any relevant Standards and/or Codes been consulted and applied if necessary?
- If international standards or guidelines are used, has the application been appropriately interpreted for the particular Australian circumstances?
- Are all aspects of the project being monitored by an appropriate quality assurance system?
- Is the quality assurance system achieving the standards of quality required for the project?

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APPENDIX 1
ENGINEERS AUSTRALIA CODE OF ETHICS, SUSTAINABILITY POLICY AND CLIMATE CHANGE POLICY

OUR CODE OF ETHICS

As engineering practitioners, we use our knowledge and skills for the benefit of the community to create engineering solutions for a sustainable future. In doing so, we strive to serve the community ahead of other personal or sectional interests.

Our *Code of Ethics* defines the values and principles that shape the decisions we make in engineering practice. The related Guidelines on Professional Conduct provide a framework for members of Engineers Australia to use when exercising their judgment in the practice of engineering.

As members of Engineers Australia, we commit to practise in accordance with the Code of Ethics and accept that we will be held accountable for our conduct under Engineers Australia's disciplinary regulations.

In the course of engineering practice we will:

1. DEMONSTRATE INTEGRITY
   - 1.1. Act on the basis of a well-informed conscience
   - 1.2. Be honest and trustworthy
   - 1.3. Respect the dignity of all persons.
2. PRACTISE COMPETENTLY
   - 2.1. Maintain and develop knowledge and skills
   - 2.2. Represent areas of competence objectively
   - 2.3. Act on the basis of adequate knowledge.
3. EXERCISE LEADERSHIP
   - 3.1. Uphold the reputation and trustworthiness of the practice of engineering
   - 3.2. Support and encourage diversity
   - 3.3. Communicate honestly and effectively, taking into account the reliance of others on engineering expertise.
4. PROMOTE SUSTAINABILITY
   - 4.1. Engage responsibly with the community and other stakeholders
   - 4.2. Practise engineering to foster the health, safety and wellbeing of the community and the environment
   - 4.3. Balance the needs of the present with the needs of future generations.

GUIDELINES ON PROFESSIONAL CONDUCT

The *Guidelines on Professional Conduct* provide a framework for members of Engineers Australia to use when exercising their judgement in the practice of engineering.

The Guidelines are not intended to be, nor should they be interpreted as, a full or exhaustive list of the situations and circumstances which may comprise compliance and non compliance with the *Code of Ethics*.

If called upon to do so, members are expected to justify any departure from both the provisions and spirit of the Code.

Ethical engineering practice requires judgment, interpretation and balanced decision-making in context.

Engineers Australia recognises that, while our ethical values and principles are enduring, standards of acceptable conduct are not permanently fixed. Community standards, and the requirements and aspirations of engineering practice, will develop and change over time. Within limits, what constitutes acceptable conduct may also depend on the nature of individual circumstances.

Allegations of non-compliance will be evaluated on a case-by-case basis and administered in accordance with the disciplinary regulations.

1. DEMONSTRATE INTEGRITY
   - 1.1. Act on the basis of a well-informed conscience
     - a) be discerning and do what you think is right
     - b) act impartially and objectively
     - c) act appropriately, and in a professional manner, when you perceive something to be wrong
     - d) give due weight to all legal, contractual and employment obligations.
   - 1.2. Be honest and trustworthy

a) accept, as well as give, honest and fair criticism
b) be prepared to explain your work and reasoning
c) give proper credit to those to whom proper credit is due
d) in managing perceived conflicts of interest, ensure that those conflicts are disclosed to relevant parties
e) respect confidentiality obligations, express or implied
f) do not engage in fraudulent, corrupt or criminal conduct.

1.3. Respect the dignity of all persons

a) treat others with courtesy and without discrimination or harassment
b) apply knowledge and skills without bias in respect of race, religion, gender, age, sexual orientation, marital or family status, national origin, or mental or physical handicaps.

2. PRACTISE COMPETENTLY

2.1. Maintain and develop knowledge and skills

a) continue to develop relevant knowledge and expertise
b) act in a careful and diligent manner
c) seek peer review
d) support the ongoing development of others.

2.2. Represent areas of competence objectively

a) practise within areas of competence
b) neither falsify nor misrepresent qualifications, grades of membership, experience or prior responsibilities.

2.3. Act on the basis of adequate knowledge

a) practise in accordance with legal and statutory requirements, and with the commonly accepted standards of the day
b) inform employers or clients if a task requires qualifications and experience outside your areas of competence.

3. EXERCISE LEADERSHIP

3.1. Uphold the reputation and trustworthiness of the practice of engineering

a) advocate and support the extension of ethical practice
b) engage responsibly in public debate and deliberation.

3.2. Support and encourage diversity

a) select, and provide opportunities for, all engineering practitioners on the basis of merit
b) promote diversity in engineering leadership.

3.3. Communicate honestly and effectively, taking into account the reliance of others on engineering expertise

a) provide clear and timely communications on issues such as engineering services, costs, outcomes and risks.

4. PROMOTE SUSTAINABILITY

4.1. Engage responsibly with the community and other stakeholders

a) be sensitive to public concerns
b) inform employers or clients of the likely consequences of proposed activities on the community and the environment
c) promote the involvement of all stakeholders and the community in decisions and processes that may impact upon them and the environment.

4.2. Practise engineering to foster the health, safety and wellbeing of the community and the environment

a) incorporate social, cultural, health, safety, environmental and economic considerations into the engineering task.

4.3. Balance the needs of the present with the needs of future generations

a) in identifying sustainable outcomes consider all options in terms of their economic, environmental and social consequences
b) aim to deliver outcomes that do not compromise the ability of future life to enjoy the same or better environment, health, wellbeing and safety as currently enjoyed.

ENGINEERS AUSTRALIA SUSTAINABILITY POLICY

PURPOSE

Engineers Australia and its members are committed to creating and delivering outcomes that will ensure the long-term survival of life on earth in a fair and equitable manner.

For our members, sustainability means that future generations will enjoy environmental, social and economic conditions that are equal to or better than those enjoyed by the present generation.

Our Code of Ethics requires us to develop engineering solutions that repair and regenerate both natural and social capital, while maintaining economic health.

CONTEXT

Engineers Australia acknowledges that to achieve sustainability outcomes requires transformative change in business practices, lifestyles, and in the way resource allocation decisions are made.

Fundamental to this change is the recognition that a healthy economy is underpinned by a healthy environment and respect for all life on earth.

Engineers Australia and its members commit to ensuring all relevant stakeholders are consulted, and that open and regular reporting of progress towards delivering sustainability outcomes forms a fundamental component of engineering practice.

PRINCIPLES

In implementing sustainability across any engineering activity, members of Engineers Australia should:

1. Objectively apply engineering knowledge, skill, and experience to achieve measurable outcomes that enhance both natural and social capital.
2. Maintain an up-to-date knowledge and understanding of sustainability principles, and practices relevant to their area of practice.
3. Seek outcomes that deliver fairness and equity within the present generation as well as between present and future generations.
4. Think holistically, and innovatively, and account for externalities and whole of life impacts, such that there is a net sustainability benefit.
5. Be proactive in addressing risks to the environment, society and the economy.
6. Build shared community value, robustness, and resilience.
7. Always practice within the Engineers Australia Code of Ethics.

GUIDANCE

Engineers Australia, as an organisation, considers that sustainability is a key consideration, informed by societal expectations, technical knowledge and expertise, and is to be applied in all areas of its endeavour and strongly promoted to all of its members.

This Sustainability Policy is supported by an Implementation Plan, which articulates specific changes to engineering practice that arise from adoption of this Policy.

Specific sustainability considerations to be applied to engineering practice (policy and projects) include (not in priority order):

1. The use of resources should not exceed the limits of regeneration.
2. The use of non-renewable resources should create enduring asset value (everlasting and/or fully recyclable), and be limited to applications where substitution with renewable resources is not practical.
3. Engineering design, including product design, should be whole system based, with consideration of all impacts from product inception to reuse/repurposing.
4. Product and project design should consider longevity, component re-use, repair and recyclability.
5. Eliminating waste should be a primary design consideration. Unavoidable waste from any one process should be

examined for recycling potential as input to another productive process.

6. The rate of release of any substances to the environment should do no net harm, and be limited to the capacity of the environment to absorb or assimilate the substances, and maintain continuity of ecosystem services. In all instances, such releases should be lifecycle-costed and attributed.
7. Proactive and integrated solutions are preferable to reactive, linear, "end of pipe" solutions, such that there is a net sustainability benefit.
8. In circumstances where scientific information is inconclusive, or incomplete, the precautionary principle and risk management practices should be applied to ensure irreversible negative consequences are avoided and not passed as a liability to future generations.

ENGINEERS AUSTRALIA CLIMATE CHANGE POLICY

PURPOSE

Engineers Australia accepts the comprehensive scientific basis regarding climate change, the influence of anthropogenic global warming, and that climate change can have very serious community consequences.

Engineers are uniquely placed to provide both mitigation and adaptation solutions for this serious global problem, as well as address future advances in climate change science.

This Climate Change Policy Statement has been developed to enable organisational governance on the problem, and provide support for members in the discipline and practice of the engineering profession.

CONTEXT

Building upon a long history of Engineers Australia policy development, and as the largest technically informed professional body in Australia, Engineers Australia advocates that Engineers must act proactively to address climate change as an ecological, social and economic risk.

The role of engineers is to lead innovation for, and apply contemporary knowledge towards solutions that add value to ecological, social, and economic wellness.

Engineers Australia is committed to natural resources policy reform to adopt full life-cycle analysis, including the pricing of resource use externalities, to ensure responsible resource allocation decisions.

Engineers Australia considers Australia is particularly vulnerable to climate change impacts arising from an average global temperature rise in excess of 2 degrees Celsius, relative to the average pre-industrial temperature. These impacts include:

- Increased loss and damage to natural and built environments resulting from greater a frequency and severity of weather events including: higher wind speeds and durations, lightning strikes, intensified precipitation, increased flood peaks and volumes, increased temperature variations and durations resulting in drought, heat wave, more intense wildfires, and cold snap;
- Increased loss and damage to natural and built environments in coastal and riparian environs from: sea-level rise, storm surge, wave action, inundation, ground water change, and saline intrusion;
- Increased health risks to people, flora and fauna, including from heat, humidity, physical damage and micro-biological change;
- Damage to terrestrial, aquatic and marine ecosystems, particularly coral reef and micro-biological systems;
- Loss of agricultural productivity from changes to rainfall volume and intensity, evaporation, temperature stress, salinity, acidification as well as spatial and temporal seasonal variability; and
- Increased global community instability arising from resource stress.

Engineers should work to eliminate the causal factors contributing to climate change from engineering endeavours, as well as consider contemporary science in adaptation and mitigation initiatives during planning, design, delivery, operation and decommissioning of engineering works and products.

POLICY

Engineers Australia policy position is that increasing atmospheric greenhouse gas concentrations, including from the combustion of fossil fuels, are contributing to anthropogenic global warming and adverse changes to Earth's climate systems.

Engineers Australia encourages national greenhouse gas emission reduction targets to be pursued to enable transition to renewable and sustainable energy, water, transport, industry and agriculture systems.

Engineers Australia will work to facilitate statutory, regulatory and policy reform such as progressive Renewable Energy Targets, incentives to promote renewable and sustainable energy technologies, energy efficiency standards, transport emission limits, and incentives/disincentives to reduce dependence on fossil fuel sources. It is recognised this is part of a transitional process.

Engineers Australia reinforces that Engineers are critical to the implementation of long-term strategic policies addressing the inextricable link between energy generation and use, resource consumption, and climate impacts.

Engineers Australia's members acknowledge:

- Engineers have an ethical responsibility for, and play a key role in, limiting atmospheric greenhouse gas concentrations, through transformative change and innovation in engineering education, and practice.
- Engineers are well placed to understand and assess the viability of climate change mitigation and adaptation strategies needed to make the difference and have the practical know-how to implement these strategies.
- Engineers proactively participate together to address the causes and impacts of climate change as a significant ecological, social and economic risk.
- Reduction of the emission of greenhouse gases to the atmosphere associated with engineering activities should be accorded urgent priority in engineering endeavours.
- Engineers should include risk analysis and advice of the likely impacts of climate change in their work.

Engineers should maintain an awareness of contemporary climate change science and advances thereof, and contribute to the refinement of knowledge and approach, to encourage the best possible engineering outcomes.

APPENDIX 2
POLICIES, PROGRAMS
AND ASSOCIATED PUBLICATIONS

Current September 2017

A1 POLICIES AND PROGRAMS

In Australia, the States and Territories (and through them, local governments) have responsibility for land management and regional planning and, hence, for most matters affecting coastal planning and management. They have a number of strategies and policies to guide and influence coastal management. Much of the detail flowing from these strategies and policies has been fixed in State and Local Government law. The Australian Government also has considerable responsibility, either directly through powers granted under the Constitution such as trade, external affairs and defence, or indirectly through funding arrangements, support for research, provision of information or establishment of national plans and policies.

The summaries presented in this appendix reflect the situation as at early 2017 and, as there are a great many policy areas that impinge on the coastal domain, are inevitably incomplete. In addition, as policies and programs may be revised or replaced, readers are advised to consult the relevant government department web sites or portals for updates. The following web addresses include both national and state sources. Other leads are given with references for the individual state sections:

- Australian Environment Portal http://www.environment.gov.au/,
- Environmental Defenders Office, http://edo.org.au/

Useful summary publications include a compilation of papers on marine resource management edited by Gullett, Schofield and Vince (2010), and a comprehensive overview of coastal planning for rising sea levels provided by Antarctic Climate & Ecosystems CRC (Good, 2011).

A1.1 National Policies and Programs

The two most directly relevant policies for coastal engineering are Framework for a National Cooperative Approach to Integrated Coastal Zone Management released first in 2003, reissued in 2006 along with the Implementation Plan and Australia's Ocean Policy (1998). These policies, frameworks and programs are discussed in turn.

Framework for a National Cooperative Approach to Integrated Coastal Zone Management is an intergovernmental policy released under the auspices of the Natural Resource Management Ministerial Council. The prime focus of the Framework is to conserve biodiversity, improve coastal water quality and protect the economic base of coastal areas. This is to be achieved through a two level approach – (1) managing national scale issues by coordination of across-government jurisdictions and (2) managing regional issues by complementing State and Territory initiatives.

One of the key themes identified is the catchment-coast-ocean continuum in which the aim is to draw together existing policies and programs such as Natural Heritage Trust, National Action Plan for Salinity and Water Quality and Australia's Oceans Policy. It also recognises international agreements such as World Heritage Convention, agreements on migratory birds, International Maritime Organisation agreements, Law of the Sea and the Global Program of Action for Protecting the Marine Environment from Land-based Sources of Pollution.

The second key theme is the identification of coastal issues for national collaboration including sources of pollution, managing climate change, introduced pests, allocation and use of coastal resources and capacity building.

The Implementation Plan identifies actions, timeframes and responsibilities for research priorities, freshwater flows, communication, national networks, state of the environment reporting, coastal and estuary water quality, acid sulphate soils, marine debris, ship waste, dredging, climate change management and adaptation, marine pests, population pressures, capacity building, monitoring and evaluation.

Australia's Ocean Policy – provides a framework for the integrated and ecosystem-based planning and management for Australia's marine jurisdictions, extending from the coast to the limit of the Australian Economic Exclusion Zone. Its implementation is based on Regional Marine Plans, the first of which was South-East covering Victoria, Tasmania and parts of South Australia and NSW. The implementation document for the South-East Regional Marine Plan was released in 2004 and following a review in 2006 resulted in Regional Marine Plans being replaced by a Marine Bioregional Planning Program. Such plans have now been released for five regions – South-west, North-west, North, Temperate-east and South-east. A review by University of Tasmania (Vince et al., 2015) examines the successes and shortcomings of this ambitious policy.

The Department of Environment and Energy coastal web pages provide information on Australian Government initiatives to adapting to coastal climate change. The government is committed to developing a national coastal adaptation agenda involving a coordinated national approach, with clear allocation of responsibilities, with the intention to reduce uncertainty in responding to climate change risks, and reduce the confusion and potential costs and inefficiencies associated with inconsistencies in a national market. Other actions taken by the government include funding research through the Australian Climate Change Science Program, Marine and Climate Super Science Initiative and National Climate Change Adaptation Research Facility (NCCARF).

Other policies and programs can be found via the web links given above. Publications relevant to these policies and programs are listed in Section A2.1.

A1.2 New South Wales Coastal Management Framework

The current NSW coastal management framework is summarised below, and should be read in conjunction with the coastal reforms that are underway. The reforms will deliver a new legislative and regulatory framework for coastal management.

The key elements of the reform are new legislation - the Coastal Management Act 2016, a new State Environmental Planning Policy (Coastal Management), and a new coastal management manual to guide the preparation of coastal management programs.

Until the new Act is commenced, the legislative framework for coastal management in NSW is provided by:

- Coastal Protection Act 1979, amended by the Coastal Protection and Other Legislation Amendment Act 2010 and supported by the Coastal Protection Regulation 2011.
- Environmental Planning and Assessment Act 1979, supported by the Environmental Planning and Assessment Regulation, (2000), aims to ensure the proper management, development and conservation of land, and specifies amongst other things, matters for consideration for coastal development, including the NSW Coastal Policy and coastal zone management plans.
- Local Government Act 1993, which provides the legal framework and sets out roles and responsibilities for local government. It also provides an indemnity for councils that act in "good faith" when considering coastal issues.
- Marine Estate Management Act 2014 provides for strategic and integrated management of the whole marine estate including marine waters, coasts and estuaries.

Coastal management reforms

The new Coastal Management Act 2016 (not commenced as of September 2017) divides the coastal zone into four coastal management areas. The four areas are the:

- coastal wetlands and littoral rainforests area
- coastal vulnerability area
- coastal environment area
- coastal use area.

The four areas are defined in the new Act as part of the new State Environmental Planning Policy (Coastal Management) (SEPP). This legislation will establish clear, outcome-orientated management objectives for each area to ensure councils apply appropriate management tools and development controls.

The overriding object of the new Act is to manage the coastal environment of NSW in a manner consistent with the principles of ecologically sustainable development for the social, cultural and economic wellbeing of the community.

This overriding objective is underpinned by sub-objectives that include: protecting and enhancing natural coastal processes and coastal environmental values including natural character, scenic value, biological diversity and ecosystem integrity and resilience; supporting social and cultural values and maintaining public access and amenity; mitigating current and future risks from coastal hazards, taking into account the effects of climate change; recognising the local and regional scale of coastal processes and the inherent dynamic and ambulatory nature of the shoreline; and encouraging and promoting plans and strategies to improve the resilience of coastal assets to the impacts of an uncertain climate future, including impacts of extreme storm events.

The new Act places several obligations on local councils. Under s 13, a local council may (or, if directed by the Minister, must) prepare a coastal management program. The program sets out the long-term strategy for land management in the coastal zone. Under s 15, a coastal management program must identity coastal management issues in the region, the actions required to address these issues, and identify how and when those actions will be implemented. Local councils must also identify the costs of the actions, proposed cost-sharing arrangements and viable funding mechanisms to ensure delivery. Once prepared, a local council is to give effect to this program, and, in doing so, is to have regard to the objects of the Act under s 22(1).

The State Environmental Planning Policy (SEPP) (Coastal Management) will establish a new, strategic land use planning framework for coastal management. It will support implementation of the management objectives set out in the Coastal Management Act 2016.

The Coastal Management SEPP will consolidate and improve current coastal-related SEPPs. It will replace SEPP 14 (Coastal Wetlands), SEPP 26 (Littoral Rainforests) and SEPP 71 (Coastal Protection) and ensure that future coastal development is appropriate and sensitive to our coastal environment, and that we maintain public access to beaches and foreshore areas.

The SEPP (Coastal Management) will also better equip councils and coastal communities to plan for and effectively respond to coastal challenges such as major storms, coastal erosion and climate change impacts, through more strategic planning around coastal development and emergency management.

A1.3 Victoria Policies and Programs

Ninety-six per cent of the Victorian coast is Crown or public land. Around two-thirds of this coastal Crown land is managed by Parks Victoria including a number of national and coastal parks. The majority of the remainder is reserved for a variety of public purposes and is managed by Committees of Management or directly managed by the Department of Environment, Land, Water and Planning.

The Coastal Management Act 1995 provides for a coordinated strategic planning and management of the Victorian coast, an approvals process for use and development of the Victorian coast, and an approvals process for the use and development of coastal Crown land. It promotes long term planning to ensure protection for significant environmental coastal features, clear direction for future use of the coast, including the marine environment and sustainable use of natural resources. Strategic outcomes required by the Act are set out in the Victorian Coastal Strategy 2014. The strategy is reviewed every five years.

The strategy establishes principles to guide the long term planning of the coast, consistent with the concepts of ecologically sustainable development and integrated coastal zone planning and management. The following is the hierarchy of principles guiding the decision process:

1. Provide for the protection of significant environmental features – ensuring the conservation of biologically diverse, physical diversity and ecological integrity, and the preservation and maintenance of essential ecological processes and life support systems. Aboriginal and other sites of cultural, historic or scientific value will also be protected.
2. Ensure the sustainable use of natural coastal resources – addressing inter-generational equity.
3. Undertake integrated planning and provide direction for the future – providing integrated coastal zone planning and management regarding environmental, social and economic implications of the decisions and takes a long-term (rather than short term) view when making decisions.
4. When the above principles have been met, facilitate suitable development of the coast within existing modified and resilient environments when the demand for services is evident and requires management. It will generally be coastal dependent or related to coastal dependent uses.

The strategy addresses the issues of climate change by:

1. applying the policy of planning for sea level rise of not less than 0.8 metres by 2100
2. completing coastal vulnerability study and incorporating the findings into relevant policy, planning and management frameworks
3. establishing a climate change scientific research and data system and ensuring planning and management frameworks and actions respond quickly to the best available current and emerging science.

The Act also provides for the establishment of the Victorian Coastal Council and Regional Coastal Boards. Three Coastal Board Regions are defined; being the Western, Central and Gippsland Coastal Boards. These Boards are empowered to prepare Coastal Action Plans (CAP's), which take into consideration the strategic objectives and planning of the region or part of the region. The CAPs identify environmental values and risks in relation to the coastal regions, with a focus on foreshore activities.

The Planning and Environment Act 1987 (Vic) (PE ACT) regulates the development in the interests of orderly planning, through the mechanism of planning schemes, which are based on the generic Victoria planning provisions. The State Planning Policy Framework, which is common to all planning schemes, includes clauses directed generally at protection of the environment and specifically of the environment of the coast.

In 2017, the Coastal Management Act 1995 is currently being reformed as part of developing a new Marine and Coastal Act and changes are also proposed for management and planning structures in Victoria.

The Victorian Government is committed putting strong, effective legislation in place to strengthen the coastal management system ensuring that it protects both marine and coastal areas and meets long term challenges such as impacts from climate change, population growth and managing ageing coastal structures.

A consultation paper was prepared proposing a series of reforms to the coastal and marine management system. The proposed system will include a new Marine and Coastal Act and other reforms that will support Victorians to manage coastal and marine areas now and into the future.

Further information of the proposed marine and coastal reforms to improve the system can be found at:

https://www.coastsandmarine.vic.gov.au/marine-and-coastal-act.

A1.4 South Australia Policies and Programs

The Coast Protection Board was formed in 1972 following the proclamation of the *Coast Protection Act 1972*. Since then it has been the primary authority and prescribed body in South Australia managing coast protection issues and providing advice on coastal development.

The Board is subject to the control and direction of the Minister for Sustainability, Environment and Conservation. Its membership includes Government agency representatives and skills-based appointments (local government, coast protection and biological sciences and environmental protection).

The functions of the Coast Protection Board (as stated in the Act) are:

- to protect the coast from erosion, damage, deterioration, pollution and misuse
- to restore any part of the coast that has been subjected to erosion, damage, deterioration, pollution or misuse
- to develop any part of the coast for aesthetic improvement or for the purpose of rendering that part of the coast more appropriate for the use or enjoyment of those who may resort thereto
- to manage, maintain and, where appropriate, develop and improve coast facilities that are vested in, or under the care, control and management of, the Board
- to report to the Minister upon any matters that the Minister may refer to the Board for advice
- to carry out research, to cause research to be carried out, or to contribute towards research into matters relating to the protection, restoration or development of the coast
- to perform such other functions assigned to the Board by or under this or any other Act. Under the Act, the Board has the power to:
- carry out works
- remove sand
- acquire coastal land, with the approval of the Minister
- deal with its land, with the approval of the Minister
- enter land (any member of the Board or a person authorised)
- prohibit access to part of foreshore (with the Minister's agreement).

The Board has a range of policies, which have been formed over a period of time, for managing South Australia's coastline in conjunction with coastal councils. They were compiled into a single Coast Protection Board Policy Document in 2002 and address a number of key areas including:

- development
- coastal hazards – including flooding, erosion and acid sulphate soils
- protection works
- conservation of coast and marine habitats including coastal wetlands, rivers and estuaries,
- heritage and landscape
- access to the coast.

For flooding and erosion, the South Australian *Policy on Coast Protection and New Coastal Development* was prepared by the Coast Protection Board and endorsed by the South Australian Government in 1991. It includes provisions that require consideration of the effects of sea level rise as a result of climate change, both for flooding and in the estimation of necessary erosion buffers along the coast.

These policies were translated into the State's Development Plans by way of the *Regional Coastal Areas Policies Amendment* in 1994. Development Plans are the statutory planning instrument (*Development Act 1993*) against which development applications are assessed. The Development Act allows a Development Plan to relate to any geographical part of the state but no more than one plan may relate to a particular part of the State. There is a Development Plan for each of the 34 coastal local councils and 4 coastal Development Plans for specific areas of land and sea not within council areas. The Coastal Protection Branch of the Department of Environment, Water and Natural Resources provides input to the review and amendment of Development Plans undertaken by local councils or the planning Minister (who is supported by the Department of Planning and Local Government).

The Development Act (Section 37) and its Regulations (Regulation 24 and Schedule 8) require that, with some minor exceptions, applications for development on "coastal land" (which includes land in Development Plan coastal zones) are referred by the relevant planning authority (the council or the Development Assessment Commission) to the Coast Protection Board for advice or direction. Planning authorities are subject to the direction of the Board (the Board may direct refusal of the application or direct that specific conditions be attached to any approval) if development involves more than 9 cubic metres of excavating or filling of land, or the construction of coastal protection works within certain distances of high water mark.

Major Developments are subject to a separate statutory process of the Development Act. Input to the various stages of that process, including the environmental impact assessment documents, is provided by various state agencies. That includes advice from the Department of Environment and Natural Resources, which includes the consideration of coastal issues.

The Department of Environment, Water and Natural Resources provides technical and administrative support to the Board and coastal management advice to local councils on an ongoing basis. State Government funding through the Coast Protection Board is used to assist local government with public coast protection projects.

A1.5 Tasmania Policies and Programs

Tasmania's coastal zone is managed and protected in accordance with the *State Coastal Policy 1996* (SCP), which is empowered by the *State Policies and Projects Act 1993* (SPP Act) and part of the State's overarching Resource Management and Planning System.

Rather than a single coastal management authority, responsibility for coastal management in Tasmania falls to a range of State and local government agencies.

The purpose of the SCP is to provide a consistent, statewide approach to coastal management and protection, and it applies to all State waters, and to land within one kilometre inland of the high-water mark.

- The SCP comprises three overarching principles:
- the need to protect both natural and cultural values of the coast
- the need for sustainable use and development of the coast
- the need for shared responsibility in the management and protection of the coastal zone.

The SCP sets out a range of outcomes for each of these principles. These outcomes state that the "coastal zone will be managed to protect ecological, geomorphological and geological coastal features and aquatic environments of conservation value" (clause 1.1.2).

Under the SPP Act it is an offence to fail to comply with a provision of a State Policy. However, the SCP is a broad document primarily intended to provide a framework for coastal planning rather than a directly enforceable document.

Implementation of the SCP is generally achieved through planning schemes, which are administered and enforced by local governments under the *Land Use Planning and Approvals Act 1993*.

The SCP provides for a precautionary approach to be taken when assessing applications for use and development in the coastal zone, and requires coastal development to be located so as to minimise its environmental impact. The SCP requires planning schemes to identify; suitable urban and residential areas, areas of special value, important wetlands and coastal transport routes. The design and siting of development must also be subject to planning controls 'to ensure compatibility with natural landscapes'.

Tasmania's interim planning schemes were all required to be in accordance with the SCP, as were the State's three regional land use strategies: the *Southern Tasmania Regional Land Use Strategy* 2010-2035, *Regional Land Use Strategy of Northern Tasmania January 2016*, and *Living on the Coast: The Cradle Coast Regional Land Use Planning Framework October 2011*.

Similarly, in the Tasmanian Planning Scheme, the State Planning Provisions were drafted to be in accordance with the SCP, as will their application through the various Local Planning Provisions when these are developed.

The SCP also provides for areas subject to coastal hazards such as storm surge, erosion and sea level rise to be identified and managed (clause 1.4.1), and for policies to be developed to respond to the potential effects of climate change on use and development in the coastal zone (clause 1.4.3).

The Tasmanian Planning Scheme includes a Coastal Inundation Hazard Code and Coastal Erosion Hazard Code, which apply to those areas of Tasmania identified as vulnerable to these hazards, and for which State-wide mapping, incorporating the sea-level rise allowance, has been developed.

The codes apply additional acceptable solutions and performance standards to 'restrict' development proposed in the areas to which the codes apply. The level of restriction reflects the relative level of identified risk (low, medium or high).

Since its creation, the SCP has been subject to several reviews, and a Draft State Coastal Policy 2008 was prepared by the State Government and submitted to the Tasmanian Planning Commission for assessment. In April 2011, after the receipt of stakeholder comments and a process of review, the Commission decided to reject the proposed Draft Policy. The Tasmanian State Coastal Policy 1996 is therefore still in effect.

A1.6 Queensland Policies and Programs

The management of Coastal Queensland is governed by the *Coastal Protection and Management Act 1995*. Detailed provisions are set out in the Queensland Coastal Plan (management), the State Policy for Coastal Management (resources) and the Coastal Protection State Regulatory Planning Provision (developments).

The *Queensland Coastal Plan*, released in February 2012, replaces the S*tate Coastal Management Plan* (2001) and associated plans. The Queensland Coastal Plan has been prepared under the *Coastal Protection and Management Act 1995*. It includes a state planning policy under the *Sustainable Planning Act 2009*.

The Queensland Coastal Plan has two parts: *State Policy for Coastal Management* and the *State Planning Policy 3/11*: *Coastal Protection* (SPP) available at www.derm.qld.gov.au/coastalplan.

The *State Policy for Coastal Management* provides policy direction and guidance for natural resource management decision-makers about maintaining, rehabilitating, and protecting land on the coast, and managing activities undertaken on it, with particular emphasis on managing public coastal land.

The SPP provides policy direction and assessment criteria to direct land-use planning and development assessment decision making under the *Sustainable Planning Act 2009*. Policies for managing the major coastal issues are detailed under the following topic headings:

- Land-use planning
- Coastal hazards
- Nature conservation
- Scenic amenity
- Public access
- Coastal-dependent development
- Canals and artificial waterways.

The Queensland Coastal Plan, supporting guidelines, information sheets and mapping products are available at www.derm.qld.gov.au/coastalplan. Coastal hazards are specifically addressed in DERM (2012), "Queensland Coastal Plan , Coastal Hazards Guideline".

The Queensland Climate Change Centre of Excellence report *Queensland Coastal Processes and Climate Change* is also available at www.climatechange.qld.gov.au/qld-coastal-processes-and-climate-change.

The "*Operational Policy (Coastal Protection and Management Act 1995) Building and engineering standards for tidal works*" provides a framework for the consistent application and interpretation of the Sustainable Planning Act 2009 and for the management of non-legislative matters by the Queensland Government. This policy is not intended to apply inflexibly in all circumstances. This policy provides the minimum building and engineering criteria for tidal works approved under the *Sustainable Planning Act 2009*.

This policy lists the minimum standards or solutions for tidal works in the form of performance indicators and minimum acceptable standards:

- Design and safety
- Minimum design criteria

This policy does not apply to the assessment of "Prescribed Tidal Works" where Local Governments assess this component of development applications against the prescribed tidal works code in their roles as the assessment manager. "*Schedule 4A of the Integrated Development Assessment System (IDAS) code for development applications for prescribed tidal work*" is the applicable code for prescribed tidal works.

The purpose of this Schedule 4A is to ensure that prescribed tidal works:

- Compatible with the surrounding area
- Structurally sound
- Safe
- Adequately serviced (e.g. water and sewerage)
- Minimal use of tidal waters for non-maritime use
- Degrade public access to the foreshore
- Degrade / block navigation
- Degrade the environment
- Destabilise / degrade neighbouring structures

Schedule 4A lists codes and references and tabulates "Specific Outcomes" and corresponding "Probable Solutions"

Other legislation that might apply includes:

- *Environmental Protection Act 1994* (dredging)
- *Vegetation Management Act 1999* (clearing native vegetation)
- *Fisheries Act 1994* (fish habitat reserves / removal of marine plants)

- *Nature Conservation Act 1992* (reserves)
- *Marine Parks Act 2004* (parks)
- *Native Title Act 1993* (complements the Commonwealth Act)
- *South East Queensland Regional Plan 2009 – 2013*
- *State Planning Policy 2/20 Koala Conservation in South East Queensland.*

A1.7 Western Australia Policies and Programs

There is no specific coastal management legislation in Western Australia. A number of State government agencies operate under a variety of Acts and Policies to perform the task of planning and managing the States coastline in a manner that is sustainable and protects, conserves and enhances the coastal values.

In 2001, the Western Australian Government's policies for coastal management were outlined in the Coastal Zone Management Policy for Western Australia. This provided the framework for setting strategies and plans for the coast. Since then Coastal Zone Management is now encapsulated in the Western Australian Planning Commission (WAPC) 2013 *State Planning Policy No. 2.*6, *State Coastal Planning Policy* (SPP 2.6), which includes provisions to guide and direct planning for the sustainable use of the coast. The policy was first developed in 2003 and most recently revised in 2013. The Coastal Zone Management Policy (WAPC 2001) is presently under review by the Department of Planning.

Other documents that have been prepared to guide coastal management and planning in Western Australia are listed below:

- The WAPC 2013 *State Coastal Planning Guidelines* accompanying SPP2.6 provide detailed guidance for the application of the policy measures.
- The WAPC 2014 *Coastal hazard risk management and adaptation planning guideline*s (CHRMAP) to assist in the development and implementation of such plans.
- The WAPC 2003 *Coastal Planning and Management Manual: A Community Guide for Protecting and Conserving the Western Australian Coast*. This manual provides community groups, local government and other land managers with a practical guide to coastal planning and management for WA.
- The WAPC 2006 *State Planning Policy 3.4 for Natural Hazards and Disasters* (SPP 3.4), which provides a general framework for considering natural hazards for planning and development.
- *The Development Control Policy 1.8 Canal Estates and Other Artificial Waterway Developments*. This Policy sets out the requirements for the assessment and approval of canal developments.

SPP 2.6 applies to the coast throughout Western Australia but excludes estuaries that are predominantly riverine in character. Riverine environments are a focus of the Department of Parks and Wildlife and the Department of Water (under the Waterways Conservation Act 1976). Specific policies exist for the Swan and Canning River System in the Perth Metropolitan Area (*State Planning Policy No. 2.10 Swan-Canning River System and the Swan and Canning Rivers Management Act).*

The SPP 2.6 objectives are to:

- Ensure the location of coastal facilities and development takes into account coastal processes, landform stability, coastal hazards, climate change and biophysical criteria
- Ensure the identification of appropriate areas for the sustainable use of the coast for housing, tourism, recreation, ocean access, maritime industry, commercial and other activities
- Provide for public coastal foreshore reserves and access to them on the coast
- Protect, conserve and enhance coastal values, particularly in areas of landscape, nature conservation, indigenous and cultural significance.

Significant elements of the SPP 2.6 are the incorporation of risk management with particular regard to the impacts of coastal hazards on brownfield sites, infill development, and coastal protection works over a planning timeframe of 100 years. CHRMAP is intended to ensure appropriate risk assessment and management planning is incorporated into decision-making (WAPC 2014). It promotes the development of long term adaptive capacity for managing coastal hazard risk, and currently employs a sea level rise value of 0.9 m by 2110. With regard to public interest and safety, the policy encourages communities to be engaged and consulted throughout the process, provided with sufficient information, and understand the associated risks with coastal processes and hazards in a changing environment.

Certain areas have specific planning and development control requirements in addition to those of SPP 2.6. These include *State Planning Policy No. 6.1, Leeuwin-Naturaliste Ridge Policy* (SPP 6.1), *State Planning Policy No. 6.3* Ningaloo Coast (SPP 6.3)..

Many development proposals in tropical cyclone risk areas in Western Australia are on infill sites in towns with developed areas below the levels defined by the existing SPP 2.6 and should be in accordance with a CHRMAP. Most susceptible Western Australian town sites also manage tropical cyclone flood risk through the 2016 *State Hazard Plan for Cyclone*.

A1.8 Northern Territory Policies and Programs

The Northern Territory has no explicit policies or programs for coastal management although the NT EPA does offer

‘*Environmental Guidelines for Reclamation in Coastal* Areas’ designed to minimise impacts such as reduction in biodiversity, coastal erosion, and pollution of the marine environment, The document outlines the approval required according to Aboriginal land claim and native title, and the consent authorities for specific area or type of development. The *Northern Territory Planning Scheme* has as one of its General Performance Criteria a clause regarding Land Subject to Flooding and Storm Surge designed to ensure that planning reduces risk to people, damage to property and costs to the general community caused by flooding and storm surge.

The City of Darwin has a comprehensive *Climate Change Action Plan* in which a flexible approach is taken to address threats such as sea level rise. There is a commitment to provide tools for education, reduction in energy consumption and improved sustainability, and provide grants for relevant projects.

A1.9 A Note on Local Government Policies and Programs

As mentioned in the introduction, local coastal governments have a major role to play in setting or, at least, applying coastal policies and programs. The degree to which they do this varies widely even within any one State. Some examples are given in Good (2011) and readers are advised to consult the relevant local government web sites.

A2 ASSOCIATED PUBLICATIONS

Historical documents for all jurisdictions can be found in the previous edition of these Sustainability Guidelines.

A2.1 National and Australia-wide Policy and Program Publications

DAWR, Australian and New Zealand water quality guidelines for fresh and marine waters, Department of agriculture and Water Resources, http://www.agriculture.gov.au/water/quality/guidelines .

DCCEE, 2010, Adapting to climate change in Australia, An Australian Government Position Paper, http://www.climatechange.gov.au/government/adapt/adapting-to-climate-change-paper.aspx

http://www.environment.gov.au/climate-change/adaptation/publications/national-climate-resilience-and-adaptation-strategy

DCCEE, 2009, Climate Change Risks to Australia's Coasts, a first pass national assessment, Dept. Climate Change and Energy Efficiency, http://www.climatechange.gov.au/publications/coastline/ climate-change-risks-to-australias-coasts.aspx

DCCEE, 2010, Developing a national coastal adaptation agenda, http://www.climatechange.gov.au/ publications/adaptation/developing-national-coastal-adaptation-agenda.aspx

Environment Australia, 1998, Australia's Ocean Policy, http://www.environment.gov.au/coasts/oceans- policy/index.html

Environment Australia, 2006, National cooperative Approach to Integrated Coastal Zone Management

– Framework and Implementation Plan, http://www.environment.gov.au/coasts/publications/ framework/index.html

Good, M. 2011, Government coastal planning responses to rising sea levels, Australia and overseas, Antarctic Climate & Ecosystems CRC Technical Report, available from: http://www.sealevelrise. info/cms/Reports and Papers

Haward, M. & Vince, J. 2009, Australian Ocean Governance – Initiatives and Challenges, Coastal Management 37, pp. 1-16.

NRMMC, 2004, National Biodiversity and Climate Change Action Plan, Dept. Env. & Heritage for Natural Resource Management Ministerial Council, Canberra.

National Oceans Office, 2004, South-east Regional Marine Plan, NOA, Hobart.

NCCARF, National Climate Change Adaptation Research Facility, http://www.nccarf.edu.au/

NSW Agriculture, 2000, National Strategy for the Management of Coastal Acid Sulfate Soils, rep. for Agricultural and Resource Management Council of Australia and New Zealand, Australian and New Zealand Environment and Conservation Council, Ministerial Council Forestry, Fisheries and Aquaculture, http://www.mincos.gov.au/data/assets/pdf_file/0003/316065/natass.pdf

Lazarow, N., & Dovers, S. (2010), Ecologically sustainable development in marine areas: Environment, economics and people, in Gullett, W, C. Schofield & J. Vince (eds) Marine Resources Management, LexisNexis Butterworths.

Steffan, W. 2011, THE CRITICAL DECADE Climate science, risks and responses Climate Change 2011: Update of science, risks and responses, Climate Commission Rep., http://climatecommission. gov.au/topics/the-critical-decade/

Vince, J, A,D.M. Smith, K.J. Sainsbury, I.D. Cresswell, D.C. Smith, M. Haward., 2015, Australia's Oceans Policy: Past, present and future, Marine Policy, Elsevier, 57, Jul 2015, 1-8.

Ward, T. J. & Butler, A. 2006, Coasts and oceans, theme commentary prepared for the 2006 Australia State of the Environment Committee, Department of Environment and Heritage, Canberra, http://www.deh.gov.au/ soe/2006/commentaries/coasts/index.html

A2.2 New South Wales Policy and Program Publications

NSW Office of Environment & Heritage, 2016a, NSW Climate Change Policy Framework, http://www.environment.nsw.gov.au/topics/climate-change/policy-framework

NSW Office of Environment & Heritage, 2016b, Sea level and coasts, http://climatechange.environment.nsw.gov.au/Impacts-of-climate-change/Sea-level-and-coasts

NSW Office of Environment & Heritage, 2016c, Coastal Management Act 2016, http://www.environment.nsw.gov.au/coasts/coastreforms-act.htm

NSW Office of Environment & Heritage, 2016d, Draft coastal management manual, http://www.environment.nsw.gov.au/coasts/coastreforms-manual.htm

NSW Office of Environment & Heritage, 2016e, Coastal management manual – Toolkit, http://www.environment.nsw.gov.au/coasts/coastreforms-toolkit.htm

A2.3 Victoria Policy and Program Publications

Coastal Management Act, austlii legal database entry, http://www.austlii.edu.au/au/legis/vic/consol_act/cma1995168/

Department of Environment, Land, Water and Planning, Legislation and Regulations (incl. Planning and Environment Act, 1987), http://www.dpcd.vic.gov.au/planning/theplanningsystem/legislation-and-regulations

Department of Environment, Land, Water and Planning, Coasts and Marine Management pages, https://www.coastsandmarine.vic.gov.au

Victorian Coastal Council, 2014, Victorian Coastal Strategy, http://www.vcc.vic.gov.au/page/victorian-coastal-strategy-2014Victorian Coastal Council, 2011, Climate Change pages from Victorian Coastal Council, http://www.vcc.vic.gov.au/page/resources/guidance-materials

A2.4 South Australia Policy and Program Publications

South Australian Coast Protection Board, 2016, Coast Protection Board Policy Document. ISBN 978-0-646-43654-8, http://www.environment.sa.gov.au/about-us/boards-and-committees/Coast_Protection_Board/policies-strategic-plans

South Australian Coast Protection Board, 1992, Coastline: coastal erosion, flooding and sea level rise standards and protection policy, no.26, http://www.environment.sa.gov.au/our-places/coasts/Adelaides_Living_Beaches/Resources

Department of Environment and Heritage South Australia, 2005, Coastal Planning Information Package. http://www.environment.sa.gov.au/our-places/coasts/Adelaides_Living_Beaches/Resources

South Australia Coast Protection Act 1972, https://www.legislation.sa.gov.au/LZ/C/A/COAST%20PROTECTION%20ACT%201972.aspx

Department of Environment and Planning South Australia, 1991, Regional coastal areas policies: supplementary development plan by the Minister, Department of Environment and Planning, Adelaide.

Department for Environment and Heritage South Australia, 2005, Adelaide's Living Beaches: A strategy for 2005-2025, http://www.environment.sa.gov.au/our-places/coasts/Adelaides_Living_Beaches/Resources

South Australian Coast Protection Board 1984, Adelaide coast protection strategy review, http://www.environment.sa.gov.au/our-places/coasts/Adelaides_Living_Beaches/Resources

A2.5 Tasmania Policy and Program Publications

Tasmania Government web pages, http://www.environment.tas.gov.au/. http://www.epa.tas.gov.au/ (select 'Environment' and then click on 'EPA Division') EPA Division, Coastal Management web pages including:

- "What's New" (incl. links to "Managing Coastal Zone in a Changing Climate" and "Coastal Planning and Adaptation to Climate Change in Tasmania")
- "Tasmanian Coastal Works Manual"
- "Spatial Data & Indicators – Coastal Values Projects".

Tasmanian State Coastal Policy, 1996 (the Draft State Coastal Policy 2008 was rejected by the Tasmanian Planning Commission in 2011). This can be copied from: http://www.dpac.tas.gov. au/divisions/policy/state_policies/ (click on State Coastal Policy 1996). Information about the review can be found at http://www.environment.tas.gov.au/index.aspx?base=8380

A2.6 Queensland Policy and Program Publications

Queensland Government, 2012, The Queensland Coastal Plan, Department of Environment and Resource Management web site, www.derm.qld.gov.au/coastalplan

Queensland Climate Change Centre of Excellence, 2010, downloadable from Queensland Coastal Processes and Climate Change, http://www.climatechange.qld.gov.au/qld-coastal-processes- and-climate-change.html

A2.7 Western Australia Policy and Program Publications

Department for Planning and Infrastructure, 2006, Coastal Protection Policy for Western Australia: A Department for Planning and Infrastructure Operational Policy, http://www.transport.wa.gov.au/mediaFiles/MAR_P_CoastalProtect-ionPolicyWA.pdf

Department of Transport, 2010, Sea Level Change in Western Australia. Application to Coastal Planning. Discussion Paper, http://www.planning.wa.gov.au/dop_pub_pdf/sea_level_change_ in_wa_rev0_final.pdf

Fire and Emergency Services Australia, 2004, State Tropical Cyclone Emergency Management Plan, http://167.30.74.40/Westmap/Portals/0/Westplans/WESTPLAN_Cyclone_2004.pdf

Western Australian Planning Commission, 2001, Coastal Zone Management Policy for Western Australia, Draft for Public Comment, http://www.planning.wa.gov.au/publications/772.asp

Western Australian Planning Commission, 2003, Coastal Planning and Management Manual: A Community Guide for Protecting and Conserving the Western Australian Coast, Perth, http://www.planning.wa.gov.au/publications/768.asp

Western Australian Planning Commission, 2003 Statement of Planning Policy No. 6.1: Leeuwin- Naturaliste Ridge. Update from 1998, http://www.planning.wa.gov.au/publications/1183.asp

Western Australian Planning Commission, 2004 Statement of Planning Policy No. 6.3: Ningaloo Coast, http://www.planning.wa.gov.au/publications/981.asp

Western Australian Planning Commission, 2006, Statement of Planning Policy 2.6 State Coastal Planning, (June 2003, amended December 2006), http://ww w.planning .wa.gov.au/ publications/1168.asp

Western Australian Planning Commission, 2006 State Planning Policy No. 3.4: Natural Hazards and Disasters, Prepared under Section 26 of the Planning and Development Act 2005, http://www.planning.wa.gov.au/dop_pub_pdf/spp3_4.pdf

Western Australian Planning Commission, 2010, Position Statement – State Planning Policy No.2.6 State Coastal Planning Policy Schedule 1 Sea Level Rise, http://www.planning.wa.gov.au/dop_pub_pdf/Position_Statement_SPP2_6_Final_WAPC.pdf

Western Australian Planning Commission, 2011, Draft Development Control Policy-DC1.8 Canal Estates and Artificial Waterway Developments. Update of 1999 document, http://www.planning.wa.gov.au/publications/5936.asp

A2.8 Northern Territory Policy and Program Publications

Northern Territory Government, 2016, NT Planning Scheme, nt.gov.au/property/building-and-development/northern-territory-planning-scheme

NRETAS 2011, NT Marine and Coastal Biodiversity Management Strategy, http://www.nt.gov.au/nreta/wildlife/marine/planning.html#coastal

EPA, NT, 2006, Environmental Guidelines for Reclamation in Coastal Areas, nt.gov.au/__data/assets/pdf_file/0011/228989/environmental-guidelines.pdf

City of Darwin 2011, Climate Change Action Plan 2011-2020, http://www.darwin.nt.gov.au/climate-change/climate-change

APPENDIX 3 GLOSSARY OF COASTAL ENGINEERING TERMS

Adapted in part from Appendix A. Glossary of Terms in Shore Protection Manual Volume 2, US Department of the Army, Waterways Experiment Station/Coastal Engineering Research Center, Vicksburg, Miss., 1984 and adapted to Australian terminology.

ACCRETION: May be either NATURAL or ARTIFICIAL. Natural accretion is the buildup of land, solely by the action of the forces of nature, on a BEACH by deposition of water- or airborne material. Artificial accretion is a similar buildup of land caused by human action, such as the accretion formed by a groyne, breakwater, or beach fill deposited by mechanical means.

ADVECTION: The transport of material, e.g. water, sediment or pollutant, by mean flow.

ALONGSHORE: Parallel to and near the shoreline, usually referred to as LONGSHORE.

ARMOUR UNIT: A rock or concrete block designed to form the outer protective layer for a breakwater or seawall.

BAR: A submerged or emerged embankment of sand, gravel, or other unconsolidated material built on the sea floor in shallow water by waves and currents.

BARRIER BEACH: A bar essentially parallel to the shore, the crest of which is above normal high water level. Also called BARRIER ISLAND.

BARRIER LAGOON: A bay roughly parallel to the coast and separated from the open ocean by barrier islands. Also, the body of water encircled by coral islands and reefs, in which case it may be called an atoll lagoon.

BATHYMETRY: The measurement of depths of water in oceans, seas, and lakes; also information derived from such measurements.

BEACH BERM: A nearly horizontal part of the beach or backshore formed by the deposit of material by wave action. Some beaches have no berms, others have one or several.

BEACH REPLENISHMENT: The process of replenishing a beach with material (usually sand) obtained from another location. Also referred to as Artificial Nourishment.

BED FORMS: Any deviation from a flat bed that is readily detectable by eye and higher than the largest sediment size present in the parent bed material; generated on the bed of an alluvial channel by the flow; eg DUNES, RIPPLES.

BORE: A very rapid rise of the tide in which the advancing water presents an abrupt front of considerable height. In shallow estuaries where the range of tide is large, the high water is propagated inward faster than the low water because of the greater depth at high water. If the high water overtakes the low water, an abrupt front is presented, with the high-water crest finally falling forward as the tide continues to advance.

BREAKWATER: A structure protecting a shore area, harbour, anchorage or basin from waves. The most common breakwaters are in the form of a sloping wall protected by rocks or concrete armour units.

BYPASSING, SAND: Hydraulic or mechanical movement of sand from the accreting updrift side to the eroding downdrift side of an inlet or harbour entrance. The hydraulic movement may include natural movement as well as movement caused by human action.

CAUSTIC: In refraction of waves, the name given to the curve defined by the condition that adjacent wave orthogonals are tangents. The occurrence of a caustic always marks a region of converging orthogonals and high wave convergence.

CAY: A sedimentary island formed on a coral reef platform and composed of reef-derived sediments. Also referred to as Key (United States usage).

CELERITY: The speed of individual waves, same as phase velocity.

CHART DATUM (or PORT DATUM): The plane or level to which soundings (or elevations) or tide heights are referenced. For navigation safety, some level lower than MEAN SEA LEVEL is generally selected for hydrographic charts, such as MEAN LOWER LOW WATER or INDIAN SPRINGS LOW WATER or LOWEST ASTRONOMICAL TIDE.

CLAPOTIS: The French equivalent for a type of STANDING WAVE. It is usually associated with the standing wave phenomenon caused by the reflection of a nonbreaking wave train from a structure with a face that is vertical or nearly vertical. Full clapotis is one with 100 per cent reflection of the incident wave; partial clapotis is one with less than 100 per cent reflection.

COASTAL HAZARD/THREAT/RISK: A coastal hazard is any situation, activity or process whether or not of human origin that has the potential to cause harm to communities, infrastructure or the natural coastal environment. A coastal threat is the indication that harm will be done. Risk is a statistical term used to define the probability that harm will be done.

CONTINENTAL SHELF: The zone bordering a continent and extending from the low water line to the depth (usually about 180 metres) where there is a marked or rather steep descent toward a greater depth.

CONTROLLING DEPTH: The least depth in the navigable parts of a waterway, governing the maximum draft of vessels that can enter.

CORE: A vertical cylindrical sample of the bottom sediments from which the nature and stratification of the bottom may be determined.

CRENULATE BAY: Asymmetric equilibrium planform of a beach between two headlands or other fixed objects, indicating the direction of net littoral drift. Also called zeta bays.

CURRENT, COASTAL: One of the offshore currents flowing generally parallel to the shoreline in the deeper water beyond and near the surf zone; these may be related to tides, winds, continental shelf waves or ocean water properties.

CURRENT, EBB: The tidal current associated with the outgoing tide.

CURRENT, FLOOD: The tidal current Associated with the rising tide.

CURRENT, LITTORAL: Any current in the littoral zone caused primarily by wave action; eg, LONGSHORE CURRENT, RIP CURRENT.

CURRENT, LONGSHORE: The littoral current in the surf zone moving essentially parallel to the shore, usually generated by waves breaking at an angle to the shoreline.

CURRENT, TIDAL: The alternating horizontal movement of water associated with the rise and fall of the tide caused by the astronomical tide-producing forces.

CUSP: One of a series of low mounds of beach material separated by crescent-shaped troughs spaced at more or less regular intervals along the beach face.

DEEP WATER: Water sufficiently deep not to affect the propagation of surface waves. It is usual to consider water of depths greater than one-half of the surface wavelength as deep water.

DELTA: (1) An alluvial deposit, roughly triangular or digitate in shape, formed at a river mouth. (2) Tidal, flood tidal delta inside an inlet, ebb tidal delta outside an inlet.

DEPTH: Height of the mean water surface above the bed.

DEPTH OF CLOSURE: Depth beyond which sand level changes between annual surveys become unmeasurable or insignificant.

DIFFRACTION (of water waves). The phenomenon by which energy is transmitted laterally along a wave crest. When a part of a train of waves is interrupted by a barrier, such as a breakwater, the effect of diffraction is manifested by propagation of waves into the sheltered region within the barrier's geometric shadow.

DIURNAL TIDE: Tidal regime with only one high and one low tide per tidal day.

DOLPHIN: A cluster of PILES.

DOWNCROSSING ANALYSIS. Wave by wave analysis where waves are defined by surface level downcrossings (as opposed to upcrossings).

DUNES: (1) Ridges or mounds of loose, wind-blown material, usually sand. (2) BED FORMS smaller than bars but larger than ripples.

ECOLOGICAL SUSTAINABILITY: A capacity of ecosystems to maintain their essential functions and processes, and retain their biodiversity in full measure over the long-term.

EDGE WAVE: An ocean wave parallel to a coast, with crests normal to the shoreline. An edge wave may be STANDING or progressive. Its height diminishes rapidly seaward and is negligible at a distance of one wavelength offshore.

ESTUARY: (1) The part of a river that is affected by tides. (2) The region near a river mouth in which the fresh water of the river mixes with the salt water of the sea.

FATHOM: Unit measuring water depth used on older navigation charts. 1 Fathom = 6 feet = 1.829 metres

FETCH: The area in which SEAS are generated by a wind having a fairly constant direction and speed. Also GENERATING AREA.

FOREDUNE: The first dune behind a beach formed by deposition of sand blown from the beach by wind. Also known as frontal dune.

FORESHORE: The part of the shore, lying between the crest of the seaward berm (or upper limit of wave wash at high tide) and the ordinary low-water mark, that is ordinarily traversed by the uprush and backrush of waves as tides rise and fall.

FREEBOARD: The additional height of a structure above design high water level to prevent overflow. Also, at a given time, the vertical distance between the water level and the top of the structure.

FRINGING REEF: A coral reef attached directly to an island or continental shore.

FROUDE NUMBER: The dimensionless ratio of the inertial force to the force of gravity for a given fluid flow. It is given as, $F = V/\sqrt{gL}$ where V is fluid velocity, L is a length, usually the water depth, and g is gravitational acceleration.

GENERATING AREA: See FETCH.

GEOMETRIC SHADOW: In wave diffraction theory, the area outlined by drawing straight lines paralleling the direction of wave approach through the extremities of a protective structure. It differs from the actual protected area to the extent that the diffraction and refraction effects modify the wave pattern.

GEOMORPHOLOGY: That branch of both physiography and geology which deals with the form of the Earth, the general configuration of its surface, and the changes that take place in the evolution of landforms.

GRAVITY WAVE: A wave whose velocity of propagation is controlled primarily by gravity.

GROYNE: A shore protection structure built (usually perpendicular to the shoreline) to trap littoral drift or retard erosion of the shore.

GROUP VELOCITY: The velocity of a wave group – the speed with which wave energy is carried. In deep water, it is equal to one-half the velocity of the individual waves within the group;. in shallow water it equals the wave celerity.

HIGH WATER OF ORDINARY SPRING TIDES (HWOST): A tidal datum appearing in some British publications, based on high water of ordinary spring tides.

HIGHER HIGH WATER (HHW): The higher of the two high waters of any tidal day. The single high water occurring daily during periods when the tide is diurnal is considered to be a higher high water.

HIGHEST ASTRONOMICAL TIDE: Highest tide level which can occur due to purely astronomical forcing. Not necessarily the sum of the tidal coefficients as some tidal components are negatively correlated.

HINDCAST: To generate wave statistics from historical wind or air pressure data using computer wave models.

HM_0: Wave height which corresponds to the surface elevation variance or standard deviation, as opposed to a zero crossing height. For sine waves HM_0 equals $\sqrt{(8)}$ times the standard deviation.

HOOK: A spit or narrow cape of sand or gravel which turns landward at the outer end.

HYDRAULICALLY EQUIVALENT GRAINS: Sedimentary particles that settle at the same rate under the same conditions.

INDIAN SPRING LOW WATER (ISLW): The approximate level of the mean of lower low waters at spring tides, used principally in the Indian Ocean and along the east coast of Asia.

INTERMEDIATE DEPTHS: Water depths where neither deep-water or shallow water wave theory are adequate.

INTERNAL WAVES: Waves that occur within a fluid whose density changes with depth, either abruptly at a sharp surface of discontinuity (an interface), or gradually. Their amplitude is greatest at the density discontinuity or, in the case of a gradual density change, somewhere in the interior of the fluid and not at the free upper surface where the surface waves have their maximum amplitude.

ISOSTATIC UPLIFT: Raising of land due to removal of weight by erosion or glacial/ice sheet melt.

JETTY: (1) A wharf structure projecting from the shoreline. (2) A breakwater or training wall built to stabilise a river mouth or tidal inlet entrance (United States usage) See TRAINING WALL.

KNOT: The unit of speed used in navigation equal to one nautical mile per hour (1 knot = 0.515 m/s).

LENGTH OF WAVE: The horizontal distance between similar points on two successive waves measured perpendicularly to the crest.

LADS: "Laser Airborne Depth Sounder". Uses difference between infrared laser beam (which reflects from sea surface) and green laser beam (which penetrates clear water to reflect from seabed) to map shallow water.

LIDAR: "Light Detection and Ranging". General description for infrared distance measuring techniques of which LADS is an example specifically developed for bathymetry.

LITTORAL: Of or pertaining to a shore, especially of the sea.

LITTORAL DRIFT: The sedimentary material moved in the littoral zone under the influence of waves and currents.

LITTORAL ZONE: In beach terminology, an indefinite zone extending seaward from the shoreline to just beyond the breaker zone.

LONGSHORE: Parallel to and near the shoreline; also referred to as ALONGSHORE.

LONGSHORE TRANSPORT RATE: Rate of transport of sedimentary material parallel to the shore. Usually expressed in cubic metres per year. Commonly synonymous with LITTORAL TRANSPORT RATE.

LOWEST ASTRONOMICAL TIDE: The lowest tide level which can be predicted to occur under average meteorological conditions and any combination of astronomical conditions.

LOW WATER OF ORDINARY SPRING TIDES (LWOST): A tidal datum appearing in some British publications, based on low water of ordinary spring tides.

MANGROVE: A tropical tree with interlacing prop roots, confined to low-lying salt or brackish areas.

MARSH, SALT: A marsh periodically flooded by salt water.

MEAN HIGH WATER SPRINGS (MHWS): Long term average of the heights of two successive high waters during those periods of 24 hours (approximately once a fortnight) when the range of the tide is greatest, at full and new moon.

MEAN LOW WATER SPRINGS (MLWS): Long term average of the heights of two successive low waters over the same period as defined for MHWS.

MEAN HIGH WATER (MHW): The average height of the high waters over a 19-year period. For shorter periods of observations, corrections are applied to eliminate known variations and reduce the results to the equivalent of a mean 19-year value. All high water heights are included in the average where the type of tide is either semidiurnal or mixed. Only the higher high water heights are included in the average where the type of tide is diurnal. So determined, mean high water in the latter case is the same as mean higher high water.

MEAN HIGH WATER NEAPS (MHWN): Long term average of the heights of two successive high waters when the range of the tide is least, at the time of first and last quarter of the Moon.

MEAN HIGHER HIGH WATER (MHHW): The average height of the higher high waters over a 19-year period. For shorter periods of observation, corrections are applied to eliminate known variations and reduce the result to the equivalent of a mean 19-year value.

MEAN LOW WATER NEAPS (MLWN): Long term average of the heights of two successive low waters over the same period as defined for MHWN.

MEAN LOWER LOW WATER (MLLW): The average height of the lower low waters over a 19- year period. For shorter periods of observations, corrections are applied to eliminate known variations and reduce the results to the equivalent of a mean 19-year value.

MEAN SEA LEVEL: The average height of the surface of the sea for all stages of the tide over a 19-year period, usually determined from hourly height readings. Not necessarily equal to MEAN TIDE LEVEL.

MEAN TIDE LEVEL: A plane midway between MEAN HIGH WATER and mean low water. Not necessarily equal to MEAN SEA LEVEL: Also half-tide level.

MEAN WATER SURFACE: The surface which is obtained by averaging out individual wind waves. The MWS is not flat but may be below the still water level outside the surf zone due to wave setdown and above the SWL inside the surf zone.

MEDIAN DIAMETER: The diameter which marks the division of a given sand sample into two equal parts by weight, one part containing all grains larger than that diameter and the other part containing all grains smaller.

MIXED TIDE: A type of tide in which the presence of a diurnal wave is conspicuous by a large inequality in either the high or low water heights, with two high waters and two low waters usually occurring each tidal day. In strictness, all tides are mixed, but the name is usually applied without definite limits to the tide intermediate to those predominantly semidiurnal and those predominantly diurnal.

MONOCHROMATIC WAVES: A series of waves where each wave has the same length and period.

NEAP TIDE: A tide occurring near the time of quadrature of the moon with the sun. The neap tidal range is usually 10 to 30 per cent less than the mean tidal range.

NEARSHORE (zone): In beach terminology an indefinite zone extending seaward from the shoreline well beyond the breaker zone. It defines the area of nearshore currents.

OFFSHORE: In beach terminology, the comparatively flat zone of variable width, extending from the breaker zone to the seaward edge of the Continental Shelf.

OFFSHORE CURRENT: (1) Any current in the offshore zone. (2) Any current flowing away from shore.

OFFSHORE WIND: A wind blowing seaward from the land in the coastal area.

ONSHORE WIND: A wind blowing landward from the sea in the coastal area.

ORBITAL VEOLOCITY: The flow of water accompanying the orbital movement of the water particles in a wave. Not to be confused with wave-generated littoral currents.

ORTHOGONAL: On a wave-refraction diagram, a line drawn perpendicularly to the wave crests.

OUTFALL: A structure extending into a body of water for the purpose of discharging sewage (often treated), storm runoff, or cooling water.

OVERTOPPING: Passing of water over the top of a structure as a result of wave runup or surge action.

PARTICLE VELOCITY: The velocity induced by wave motion with which a specific water particle moves within a wave.

PERCHED BEACH: A beach or fillet of sand retained above the otherwise normal profile level by a submerged breakwater or reef.

PHASE VELOCITY: Speed with which individual waves propagate. (Same as celerity.).

PHI GRADE SCALE: A logarithmic transformation of the Wentworth grade scale for size classifications of sediment grains based on the negative logarithm to the base 2 of the particle diameter: i.e.: $\emptyset = -log_2 d$ where $d$is the particle diameter in mm.

PILE: A long, heavy timber or section of concrete or metal to be driven or jetted into the earth or seabed to serve as a support or protection.

PILE, SHEET: A pile with a generally slender flat cross section to be driven into the ground or seabed and meshed or interlocked with like members to form a diaphragm, wall, or bulkhead.

PLUNGE POINT: The final breaking point of the waves just before they rush up on the beach.

POCKET BEACH: A beach, usually small, in a bay or between two littoral barriers.

PORT DATUM: See CHART DATUM

PRECAUTIONARY PRINCIPLE: States that the lack of full scientific certainty should not be used as a reason for postponing a measure to prevent degradation of the environment where there are threats of serious or irreversible environmental damage.

PROTOTYPE: In laboratory usage, the full-scale structure, concept, or phenomenon used as a basis for constructing a scale model or copy.

RADIATION STRESS: Momentum flux associated with wave motion. Drives wave setdown, setup, surf-beat, longshore currents and rip currents

RADIUS TO MAXIMUM WINDS: Distance from the centre of the eye of a TROPICAL CYCLONE to the place where surface windspeeds are maximum.

REFLECTED WAVE: That part of an incident wave that is returned seaward when a wave impinges on a steep beach, barrier, or other reflecting surface.

REFRACTION (of water waves): (1) The process by which the direction of a wave moving in shallow water at an angle to the contours is changed: the part of the wave advancing in shallower water moves more slowly than that part still advancing in deeper water, causing the wave crest to bend toward alignment with the underwater contours. (2) The bending of wave crests by currents.

REFRACTION COEFFICIENT: The square root of the ratio of the distance between adjacent orthogonals in deep water to their distance apart in shallow water at a selected point. When multiplied by the shoaling factor and a factor for friction and percolation, this becomes the WAVE HEIGHT COEFFICIENT.

REFRACTION DIAGRAM: A drawing showing positions of wave crests and/or orthogonals in a given area for a specific deepwater wave period and direction.

REVETMENT: A facing of stone, concrete, etc., built to protect a scarp, embankment, or shore structure against erosion by wave action or currents.

RIPARIAN: Pertaining to the banks of a body of water.

RIP CURRENTS: Seaward directed surf-zone currents driven by waves. Serious drowning hazard.

RIPPLES (bed forms): Small bed forms with wavelengths less than one metre and heights less than 0.1 metre.

RMS WAVE HEIGHT (H_{rms}): Square root of the averaged squared wave height.

RUBBLE-MOUND STRUCTURE: A mound of random-shaped and random-placed stones protected with a cover layer of selected stones or specially shaped concrete armour units. (ARMOUR UNITS in a primary cover layer may be placed in an orderly manner or dumped at random.)

SALT MARSH: A marsh periodically flooded by salt water.

SEA STATE: Description of the sea surface as affected by wind-generated wave action. Also called state of sea.

SEAWALL: A structure separating land and water areas, primarily designed to prevent erosion and other damage due to wave action.

SEICHE: (1) A standing wave oscillation of an enclosed waterbody that continues, pendulum fashion, after the cessation of the originating force, which may have been either seismic or atmospheric .
(2) An oscillation of a fluid body in response to a disturbing force having the frequency close to the natural frequency of the fluid system. Tides are now considered to be seiches induced primarily by the periodic forces caused by the Sun and Moon.

SEMIDIURNAL TIDE: A tide with two high and two low waters in a tidal day with comparatively little diurnal inequality.

SHALLOW WATER: Water depths where shallow water- or long-wave theory is adequate.

SIGNIFICANT WAVE: A statistical term relating to the one-third highest waves of a given wave group and defined by the average of their heights and periods. The composition of the higher waves depends upon the extent to which the lower waves are considered. Experience indicates that a careful observer who attempts to establish the character of the higher waves will record values which approximately fit the definition of the significant wave.

SIGNIFICANT WAVE HEIGHT (H_s): The average height of the one-third highest waves of a given wave group. Approximately 1.41 times the RMS wave height in a Rayleigh wave height distribution.

SIGNIFICANT WAVE PERIOD: Average period of the highest 1/3 of the waves.

SOLITARY WAVE: A wave consisting of a single elevation (above the original water surface), whose height is not necessarily small compared to the depth, and neither followed nor preceded by another elevation or depression of the water surfaces.

STANDING WAVE: A type of wave in which the surface of the water oscillates vertically between fixed points, called nodes, without progression. The points of maximum vertical rise and fall are called antinodes or loops. At the nodes, the underlying water particles exhibit no vertical motion, but maximum horizontal motion. At the antinodes, the underlying water particles have no horizontal motion, but maximum vertical motion. A standing wave may be the result of two equal progressive wave trains travelling through each other in opposite directions. Sometimes called CLAPOTIS.

STILL-WATER LEVEL: The elevation that the surface of the water would assume if all wind and wave action were absent.

STORM SURGE: Rise in the SWL on the open coast due to abnormal atmospheric pressure and wind shear stress.

STORM TIDE: The coastal water level resulting from the combined effect of a storm surge and the astronomical tide.

SURF BEAT: Irregular oscillations of the nearshore water level with periods on the order of several minutes.

SURF ZONE: The area between the outermost breaker and the limit of wave uprush.

SUSPENDED LOAD: The material moving in suspension in a fluid, kept up by the upward components of the turbulent currents.

SWALE: The depression between two beach ridges.

SWASH: The rush of water up onto the beach face following bore collapse. Also called UPRUSH.

SWELL: Wind-generated waves that have travelled out of their generating area. Swell characteristically exhibits a more regular and longer period and has flatter troughs than waves within their fetch.

T_{02}: The wave period define as the square root of the ratio between the 0th and 2nd spectral moments

THALWEG: The along-channel line joining the deepest points of an inlet or stream channel.

TIDAL PERIOD: The interval of time between two consecutive, like phases of the tide.

TIDAL PLANES: Water level datums associated with various definitions of mean and extreme high and low tides.

TIDAL PRISM: The total amount of water that flows into a harbour or estuary or out again with movement of the tide, excluding any freshwater flow.

TIDAL RANGE: The difference between the height of high tide and the next succeeding or preceding low tide.

TOMBOLO: A bar or spit that connects or "ties" an island to the mainland or to another island.

TRAINING WALL: A wall or breakwater constructed to direct current flow in a river or estuary. See JETTY 2.

TROPICAL CYCLONE: An intense tropical storm in which winds move in near circular paths, spiralling inward towards a calm centre of low atmospheric pressure. Maximum surface wind velocities (10 minutes average) equal or exceed 33.5 m/s (65 knots). Known as Hurricanes in the Atlantic and as Typhoons in the northern Pacific.

TSUNAMI: A long-period wave caused by an underwater disturbance such as a volcanic eruption, earthquake or landslide. Commonly miscalled "tidal wave".

UPCROSSING WAVE HEIGHT: Wave height defined by successive surface level up-crossings (as opposed to down-crossings).

UPRUSH: The rush of water up onto the beach following bore collapse. Also called SWASH.

WAVE GROUP: A series of waves in which the wave direction, wavelength, and wave height vary only slightly. See also GROUP VELOCITY.

WAVE HEIGHT: The vertical distance between a crest and the preceding trough. See also SIGNIFICANT WAVE HEIGHT.

WAVE HEIGHT COEFFICIENT: The ratio of the wave height at a selected point to the deepwater wave height.

WAVE HEIGHT DISTRIBUTION: The probability distribution of wave heights in a given wave record.

WAVE PERIOD: The time for a wave crest to traverse a distance equal to one wavelength. The time for two successive wave crests to pass a fixed point. See also SIGNIFICANT WAVE.

WAVE SETUP: Superelevation of the mean water surface above the still water level. Increases towards the shore reaching approximately 0.4 times the rms offshore wave height at zero depth.

WAVE SPECTRUM: The distribution of wave energy in a given wave record as a function of frequency.

WIND WAVES: Any wave generated by wind.

ZERO CROSSING WAVE HEIGHT (Hz): Wave height defined on the basis of surface level zero crossings as opposed to surface elevation variance.

SUPPLEMENT A
BEACH REPLENISHMENT

Woorim, Bribie Island. PHOTO: QLD EPA

This Supplement has been prepared by the National Committee on Coastal and Ocean Engineering (NCCOE) of Engineers Australia, to assist professional engineers in the application and use of the Coastal Engineering guidelines for working with the Australia Coast in an ecologically sustainable way.

BEACH REPLENISHMENT

A.1 Purpose and Applications of Beach Replenishment

Beach replenishment, also known by the terms beach nourishment and beach fill, is the artificial addition of sand or gravel to the coast to improve beach condition, or to create a beach. Beach condition generally refers to recreational and amenity aspects of a beach and also to the capacity of a beach to act as a buffer against storm erosion, coastal recession or tidal inundation to protect the land behind.

In Australia, beach replenishment is used generally to provide both coast protection and amenity, particularly in situations where the recreational amenity of the coast is important, such as highly developed urban foreshores. In situations where coast protection is necessary, beach replenishment is weighed against other coast protection measures such as seawall, groyne and offshore breakwater construction as well as planned retreat. Replenishment may also be used in conjunction with these other measures with the aim of limiting project capital cost, minimising environmental impacts and extending the time before further replenishment is necessary.

Entirely artificial beaches may be created using beach replenishment methods, usually for amenity purposes. These often require construction works such as groynes at the ends of the beach to contain sand within the replenishment area to extend the life of the artificial beach.

While sand is the most commonly used material for beach replenishment, gravel, shingle and shellgrit may also be used, depending on material availability, native material at the site and the purpose of the project.

Coast protection purposes include increasing the beach buffer against episodic (storm) erosion, counteracting sediment losses which have resulted in cumulative erosion (recession), and raising the dune height to avoid inundation of low lying land behind the dunes. Any combination of these conditions may play a role for a given site and an assessment of these aspects is important. In the two erosion cases, but particularly where the coast is actively receding, "maintenance" replenishment is usually required following the initial work, and as an ongoing activity.

In future strategies for accommodating the probable sea level rise (and littoral system modifications) that will occur along many coasts as a result of climate change, active coastline maintenance involving beach replenishment is likely to continue to play a role.

A.2 Investigations

A.2.1 Scope

Investigations for beach replenishment projects will provide information useful in assessing the appropriate strategy, and hence the volume of replenishment material needed to provide the benefits sought, the stability or otherwise of the replenished beach and hence requirements for repeat replenishments as well as the suitability of replenishment for the site.

Investigations should also incorporate an appropriate level of environmental data collection, assessment, monitoring and reporting.

A.2.2 Understanding the Beach Processes

Central to the assessment of beach replenishment suitability for amenity or coast protection purposes, and for design and costing of a replenishment program, is a good understanding of beach and coastal processes. Of principal interest are considerations of morphology, native beach sediment, storm- induced variations and sediment budgets which relate to long-term stability. Aspects to be considered include morphology, sediment characteristics, storm-induced variations and the sediment budget.

Morphology

Understanding the local coastal morphology is essential for defining the nature and extent of the coastal system affected by the beach replenishment project:

- How was the coast formed?
- Is there a sediment supply, such as a river or sand moving onshore from nearshore deposits?
- Is the beach a pocket beach or part of a more extensive littoral system?
- Where are the boundaries of the relevant littoral system?
- Has the beach profile shape been monitored?
- Are there any sediment sampling/sieving analyses?

It is essential to determine active width and depth of the beach and nearshore zone, from beach profiles, bathymetric mapping and various analysis techniques (e.g. Hallermeier, 1981).

Sediment characteristics

Sediment characteristics of the existing native beach indicate the ambient conditions. The design and effectiveness of a beach replenishment project require appropriate sampling of the native beach sediment material:

- Composite sampling methods to represent material across the breadth of the active beach face.
- Sediment grading from sieve analysis to determine appropriate representative sizes (e.g. 84, 16 and 50 based on the logarithmic phi unit for the grain size parameters generally used in methods for assessing sediment characteristics).
- Sediment density (e.g. φ_{84}, φ_{16} and φ_{50} variation between silica and carbonate materials) is required for fall velocity calculations.
- Determination of fall velocity distribution, preferably directly using a settling column.

Storm-induced variations

Determine the episodic beach erosion likely to result from storm events. Methods available include:

- Assessment of beach profile records – where long-term and frequently monitored records exist this is the most reliable method.
- Analysis of aerial photographs, taken before and after erosion events, can provide estimates of erosion distances and volumes.
- Empirical methods such as Velinga (1983), Swart (1976), Edelman (1973).
- Numerical methods such as SBEACH (Larson & Kraus, 1989).
- For long-term application allow for climate change effects such as sea level rise and increased storminess.

Sediment budget

A serious attempt should be made to predict the movement of the deposited material. Techniques could include:

- Use aerial photographs, archival survey records, analysis of any long-term beach profile monitoring to identify and quantify any erosion/accretion trends.
- From an understanding of the beach morphology, develop an estimate of sediment sources, sinks and modes and rates of transport.
- Compare sediment sinks and sources to identify likely imbalances in the system.
- Determine probable causes for any erosion/accretion imbalances and consider possible increases or reductions to these. For example, a sediment-starved receding shore may recede more rapidly with an anticipated sea level rise; an eroding area downdrift of a structure may recover as sediment bypasses the structure either naturally or artificially.

Local benefits to beach condition are often provided by sand bypassing around harbour or river entrances. Bypassing may not strictly be considered a beach replenishment method as additional beach material is not added to the littoral system. However, where longshore sand budgets are unbalanced, bypassing will alleviate erosion downdrift of structures. Bypassing should be considered in any proposal to interrupt the longshore transport of sand in a littoral system.

The understanding of beach processes requires both investigations and long-term monitoring of both the behaviour of the beach and the driving environmental forces, particularly waves.

A.2.3 Source of Replenishment Material

Determining the borrow source for replenishment material requires assessment of both material characteristics and suitability, and the cost and feasibility of winning, transporting and placing the material as well as potential environmental impacts. Consideration needs to be given to sediment characteristics, methods of replenishment and possible impacts, as discussed below:

- Ideally, material for beach replenishment should have a similar grading and composition to that on the native beach, or be slightly coarser. If finer material is used, losses may be so rapid that the material should be excluded from consideration.
- A coarser material will generally provide better storm protection, and less volume may be required. However, if the replenishment material is much coarser than the native material, a steep and more reflective beach may form and this can result in less sand on the lower part of the beach. This may detract from the recreational amenity of the beach.
- Proportion of fines (commonly < 0.1 mm) should be low to minimise turbidity at the placement site. If dredging is used to win the material, fines content is also important in considering the turbidity produced at the source site. Environment protection licences may be required for high turbidity marine discharges. Turbidity control methods may need to be considered at source and deposit sites if fines content is high and better quality sand is not

available; possible methods at protected sites include bunding and silt curtains. Non-marine or onshore deposits used for beach replenishment may require washing which could be expensive.

A.2.4 Method of Replenishment

Various methods of winning, transporting and placing material are available. Those commonly used are:

- Dredging – generally using a trailer suction dredge with sand pumped ashore or barged to nearshore or, for shorter distances from protected locations, a cutter suction dredge, with or without booster stations. Dredge availability may be an important aspect for project timing since the cost of establishing equipment on site may often be a large proportion of the overall cost. Examples include trailer suction dredge replenishment for the southern Gold Coast beaches, Hampton Beach in Melbourne and Adelaide metropolitan beaches. A cutter suction dredge was used at the Gold Coast in 1974 to dredge sand for Surfers Paradise from the protected waters of the Broadwater.
- Trucking from onshore beach accumulation areas or relict deposits, for placement within and above the tidal beach; an example is replenishment of Adelaide metropolitan beaches in South Australia.
- Collecting from onshore accumulation by scraper or excavator; an example is the Mandurah Entrance and Dawesville Cut in Western Australia.
- Collecting from nearshore or harbour entrance deposits by jet pump or adapted systems and pumping to deposit site; examples are Nerang Entrance in Queensland and Portland Harbour in Victoria.
- Operating conditions and plant suitability will need to be considered in the selection of the plant, the placement methods and consequently location on the profile of the replenishment material. Operational issues for selection or assessment of suitable methods include:
- Wave and wind climate and potential dredge downtime.
- Depths of deposit for dredging and for discharge if using barges.
- The distance between source and discharge sites.
- Tides may limit beach width for along-beach trucking/pumping methods and soft sand can present difficulties for trucks.

A.2.5 Environmental Impacts

Potential physical impacts can arise from removal of material. Material for replenishment needs to be sourced from outside the active littoral system unless part of a bypassing or sand recycling program. In the latter case sand budgets and continuity of sediment source need to be closely assessed.

Consideration also needs to be given to potential detrimental impacts of removal of material which could include changes to bathymetry affecting wave climate at the shore. For example, removal of shoals which provide wave protection to leeward area, or excavation of deep dredge pits or scarps which may affect wave refraction, diffraction or reflection.

Potential impact on the ecological sustainability or heritage values of the source site requires the following considerations:

- An initial assessment of the vulnerability of site ecology to long-term damage from the method of material removal is prudent.
- Common precautions are that removal of material should not preclude re-establishment of the borrow area. For instance, although reshaped, sufficient depth of the original material should remain for recolonisation by marine/terrestrial vegetation and biota.
- Consideration of groundwater depth and stormwater runoff may be important for land sites.
- Seasons when marine organisms are most vulnerable to turbidity or bird or turtle nesting is most likely to be disturbed need to be considered in the context of other constraints and impacts.
- Consideration of whether heritage areas such as shipwrecks, marine parks or aboriginal sites exist at or near the site.

The impact of beach replenishment work on coastal residents is generally short-term and outweighed by the amenity advantages. It is prudent to plan to avoid times of high beach use and to minimise noise and other impacts on coastal residents. A public information program to explain the project and encourage public understanding, acceptance and confidence is recommended.

A.3 Design

Beach replenishment design needs to be more flexible to availability constraints and uncertainty in performance than many other aspects of coastal engineering. Although the design should include a determination of a minimum volume of material required for a project, this estimate, especially for a previously unreplenished beach, is based on techniques with a high degree of uncertainty. The designer should be aware that repeat replenishment may be required and that the initial fill volume will be a compromise between delaying the need for a repeat replenishment and the high initial cost and possible loss rates from a large initial project.

The design may need to include hard engineering works such as groynes, seawalls, offshore breakwaters, or artificial surfing reefs to improve the efficiency of the replenishment.

The establishment costs of equipment to undertake beach replenishment are generally high, and equipment is often limited both in time of availability and in performance capabilities, such as depth of working, and optimal volumes transported. Beach replenishment design and implementation need to be flexible to take advantage of opportunities as they arise.

Keeping in mind the flexibility required, the design analyses include:

- Consideration of whether replenishment is to provide a buffer against storm erosion events, to replenish the full beach width against coastal recession, to provide a dune to avoid inundation or to increase recreational beach width.
- Placement of material on specific portions of the active beach (dune, beach berm, intertidal, nearshore), depending upon the reasons for replenishment and the methods available. Understanding the effect of placement location and likely spreading or movement of the material will assist in assessing the performance of the beach replenishment.
- Determination of the volume necessary to fill the active width of the beach or the dune for a short-term erosion buffer. Consider measured/estimated erosion rates, storm cut estimates, longshore variability such as that produced on beaches with strong rips.
- Estimation of the "overfill ratio" (allowance for losses from the initially placed replenishment material). It is noted that "overfill ratio" provides an indication of the relative usefulness of potential borrow materials.
- Allowance for volume losses in designing the project. Storm take will generally be higher for a replenished beach than a natural one, especially if the replenished beach width is short compared with fill volume. An allowance may be useful to represent the more rapid realignment at ends of the beach fill length compared with the centre of the replenishment length.
- Appreciation of the likely variations in material compaction and in situ density between source site, transport volume in hoppers or trucks, initial placement and compaction as the material is reworked at the deposit site by the sea.
- Selection of the most appropriate time to implement the beach replenishment program taking account the local coastal processes and probable seasonal weather conditions.

It is essential that the need for repeat replenishments be recognised. Frequency of repeat replenishments can be estimated, although is best assessed from monitoring of previous replenishment projects at the site. The effect of extreme storms or a net loss of sand by transport out of the system on actual timing of repeat replenishments is one of the uncertainties of beach replenishment and is an important aspect which needs to be recognised in the project management.

The design should be mindful of the effects on particular types of beach usage such as swimming, surfing, fishing, etc.

A.4 Monitoring

Reliable replenishment design and therefore cost assessment relies on good monitoring of long-term beach behaviour. Assessment of past monitoring at source and deposit sites should be supplemented by continuing surveys as appropriate.

Measurements and studies previously undertaken may include:

- dune and beach profiles to wading depth
- full active beach profiling or surface modelling
- photogrammetric analysis of aerial photos
- aerial laser surveys (LIDAR and LADS)
- water quality (principally turbidity)
- wave climate
- sediment sampling and sieve analyses.

Monitoring during replenishment may include:

- Bathymetric and land survey to determine volume changes, either for contract management purposes or to supplement dredge/truck count volume estimates. (Note that hopper/trucked density is different from in situ deposit densities.)

- Water quality at source and deposit sites; licence provisions may apply.
- Monitoring of benthic/terrestrial environment, extent of disturbance.

Ongoing monitoring of replenishment performance will include beach volume and environmental aspects such as:

- profiles/bathymetric survey/aerial photos/LIDAR
- re-establishment of benthic/terrestrial organisms
- turbidity
- ongoing assessment of requirements for repeat replenishment
- monitoring sand volume changes across the active beach (dune, beach berm, intertidal and nearshore)
- buffer dune volume monitoring
- development and application of trigger criteria for repeat replenishment.

A.5 Management Issues

Management issues for beach replenishment projects include project evaluation and project implementation aspects. For beach replenishment projects at urban areas, consultation will be of particular importance. This will include conveying the advantages, disadvantages and uncertainties of replenishment clearly to decision makers and the community in general.

Management issues will vary from broad philosophical considerations, such as the inclusion of large associated works, to minor details for practical implementation. Crucial to these will be advance consideration of the relevance and importance of likely issues and allocation of resources for their appropriate resolution.

Management issues may include:

- The use of economic techniques to compare various coast protection methods. Need to identify and attempt to assess social/tourism/economic/environmental benefits of a beach as well as coast protection benefits and construction and maintenance costs.
- The availability of information on possible environmental impacts and on ecological vulnerability. Information on measures to minimise environmental impact.
- Consultation with the public, local and or State governments, beach user groups, residents groups, commercial groups.
- Support from key groups.
- Development approval requirements.
- Seasonal recreational beach use including school and public holidays, and major events.
- Possible disturbance to recreational or commercial fishing operations.
- The intensity and duration of a replenishment campaign.
- Management of potential sand drift with fencing and/or planting.
- The need to maintain stormwater outlets during replenishment to ensure outlets are not buried, water does not pond nor create backwater flow conditions.
- The possible need to close beaches during replenishment.
- Possible early adjustment of the profile. Movement of sand from a replenished beach to the nearshore zone can give the perception of project failure.
- Noise from machinery.
- Possible softness or unevenness of newly deposited uncompacted sand.
- Different sand texture and rock/shell content or colour of replenished beach compared with the “native” beach.

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SUPPLEMENT B
MARINAS

Mandura Harbour and Marina, Western Australia. SOURCE: AIRVIEWONLINE

This Supplement has been prepared by the National Committee on Coastal and Ocean Engineering (NCCOE) of Engineers Australia, to assist professional engineers in the application and use of the Coastal Engineering guidelines for working with the Australia Coast in an ecologically sustainable way.

MARINAS

B.1 Purpose and Principles of Marinas

For the purpose of this document a marina is defined as a complex at which recreational and commercial charter vessels are moored in a sheltered environment, from which land based (dry) access is provided to the vessel. It does not include ports (i.e. commercial vessel moorings) or other mooring structures (e.g. piles) from which dinghy access is required. However, it is acknowledged that marinas are often contained within ports, and also contain other ancillary recreational boating services which may include dinghy access moorings.

Sheltering of vessels from the natural elements (principally wind, waves and currents) may be provided by a number of engineering options and, to a significant extent, these (options/environmental influences) dictate the layout of the marina. Sheltering techniques include:

- naturally protected embayments
- mass armour breakwaters
- sea walls
- jetties (skirt)
- floating breakwaters
- wave screens.

Similarly, engineering design of mooring arrangements and access to vessels varies and is usually dependent on environmental considerations such as wave climate, tide range, water depth and cost of construction. In general, access to vessels is provided by the following, or a combination of the following:

- wharves, quaywall berths
- jetties
- floating pontoons.

Marinas are multi-functional facilities and, depending on their scale, provide a number of services to vessel owners which, in addition to sheltered storage and convenience of location, may include:

- services to marina berths including water, electricity, fuel and data
- security against accidental and deliberate damage
- security against theft slipway and boat ramp facilities
- vertical lifts
- dry storage
- repair workshops and personnel
- refuelling facilities
- waste discharge facilities
- chandlery, restaurants, showers and toilets
- a range of services providing competent advice on all aspects of vessel operation and safety requirements.

B.2 Investigation

Prior to the design of a marina, investigations are required to determine the physical nature of the proposed site together with developing an understanding of the coastal processes and their interaction with the coastal zone environment.

B.2.1 Data

To undertake these tasks, data needs to be sourced from historical records and/or a data collection program put in place to address data inadequacies.

In general, it is envisaged that the following data is required for the design of a marina:

- wind (magnitude, direction, seasonality and extremes)
- waves (amplitude, period, direction, seasonality and extremes)
- currents (magnitude, direction and periodicity)
- tides, floods, storm surges, and greenhouse induced sea level rise
- other climate changes such as increased storminess
- shoreline surveys, hydrographic surveys, and aerial photography
- geotechnical investigations (bed material, grain size, bearing capacity, depth to bedrock, stability etc.)

- coastal zone ecology and marine biology (including capacity of seagrass meadows to create seagrass wrack – see **B.6 Maintenance**) stormwater drainage to the site
- water quality
- current usage and values of the site
- previous reports and investigations in the region
- planning constraints
- location and availability of services
- design vessel sizes and numbers
- financial viability assessment.

B.3 Environmental Impacts

In assessing possible environmental impacts due consideration should be given to a wide range of effects including:

- water quality - waste, spillages
- aesthetics/visual impacts
- noise and artificial lights
- traffic, both land and sea
- construction
- reflected waves on adjoining properties
- changes to sediment processes
- siltation/turbidity
- flora and fauna, especially benthic communities.

Assessment may require application of computer or physical modelling to complement simpler analytical investigative techniques.

B.4 Design

B.4.1 Design Standards

Numerous state and international publications are available to provide guidelines to assist in the design of marinas. Designers should be familiar with the Australian Standards – AS 3962 2001 – Guidelines for Design of Marinas. A brief listing of a number of relevant publications is listed at the end of this supplement.

A considerable number of engineering issues need to be addressed regarding the design of water- based and waterfront facilities of marinas. A short summary of each of the major design criteria is discussed below.

B.4.2 Breakwater Configuration

With the exception of naturally protected embayments, sheltering of marinas is usually achieved by the construction of breakwaters. Breakwater types include:

- rock armour
- sheet pile walls and caissons
- jetties, skirts
- floating breakwaters.

The breakwater structure often forms a part of the marina mooring arrangement. For example, a floating breakwater will generally have mooring berths on its leeward side.

The selection of a breakwater type is strongly influenced by the site conditions and budgetary constraints. For example the choice between a floating and mass armour breakwater is dependent on the wave climate, water depth, currents, bed material (bearing capacity and mobility), availability of suitable rock armour, etc.

The engineering design of breakwaters is not addressed in this Supplement. Frequently, design requires use of physical modelling to optimise structural details, forces and performance.

Breakwater layout and configuration involves a trade-off/optimisation process between using either long breakwaters with no dredging or shorter breakwaters with a dredged basin to provide the required protected area and water depth.

B.4.3 Navigation

When designing a marina consideration needs to be given to navigation channels to facilitate vessel movements when entering/exiting the marina and berthing.

Marina Entrance Width – The navigable channel width of the marina entrance is dependent upon a number of major factors:

- marina sheltering: a wider entrance will allow higher wave energy to enter the sheltered zone
- directions and magnitudes of winds, waves and currents affect the manoeuvrability of vessels – narrow channels may also induce higher currents
- alignment of the marina entrance
- size and types of vessels using the marina entrance
- number of vessels using the marina entrance
- water quality: tidal flushing and water circulation may be important, particularly for impermeable breakwater structures.

Channel Width – The width of navigation channels inside the marina is more strongly influenced by the size, type and number of vessels than wind, waves and currents. In general, channel width is described as a function of vessel design length.

Channel Depth – Depth of navigation channels is referenced to Low Water Datum. The primary considerations for channel depth are vessel draft and required minimum keel clearance. In general, the draft of sail vessels is considerably greater than power boats. Other depth considerations include:

- wave/swell action: wave steepness and direction are influenced by water depth
- siltation and maintenance dredging
- infrastructure constraints: a deep channel close to the shoreline or a breakwater may require more costly foreshore work
- bed material: ease of dredging
- maintenance dredging requirements, i.e. desirability or otherwise of initial over-dredging of channels and basins.

It should be noted that dredging may alter the local wave climate (by changing wave penetration and reflections) and this should be taken into consideration during the design process.

B.4.4 Mooring/Berthing Arrangement

When designing a berthing arrangement the following criteria need to be considered:

- orientation of walkways and berths to provide protection from wind, waves and currents
- connections between floating elements
- fatigue of connections, service ducts, cables and pipework
- for floating marinas and pontoons, stability of floating units
- forces on structures (walkways and piles), including wind, waves, currents and boat impacts,
- tidal range and level: influence on design deck levels, mooring arrangements and whether to have fixed or floating access
- number of berths
- type and size of vessels: width and length and manoeuvrability of vessels
- vessel access
- provision of services
- construction materials: these affect the cost of construction, maintenance and aesthetics
- construction tolerances required for installation of prefabricated units
- the availability and suitability of proprietary berthing systems
- maintenance dredging requirements
- future expansion of facilities.

B.4.5 Marina Ancillary Facilities

As noted in Section B.1, marinas are multifunctional and usually will include slipways, boat ramps, waste discharge and refuelling facilities. Engineering design considerations for slipways and boat ramps will include the size of vessels, water depths and frequency of use.

Water quality issues and compliance with environmental regulations also need to be considered. Vessel waste discharge and refuelling spills need to be contained and contamination of the waterway during slipway repairs (antifouling paints etc.) must be avoided. Contaminated storm water should not be allowed to discharge into the marina or its vicinity as required by various state environment protection laws. There should be adequate flushing of the marina basin, which can generally be designed to optimise tidal exchange without affecting navigation.

Heavy foreshore traffic may lead to degradation and erosion of the shoreline and remedial or preventative measures such as revetments may be necessary.

The aesthetic value of the marina site needs to be maintained and due consideration given to neighbours and other local residents.

The financial viability of the proposed installations is also an important design issue. The consequences of the project failing to be fully completed should be considered in regard to the vulnerability of works partially constructed, interim public safety and the practicality of works restarting under new ownership after a period of time.

B.5 Construction

Marine and marina projects differ from land based construction in that they generally require quite specialised equipment and also need to contend with waves, exposed wind fetches, currents, fluctuating tide levels (resulting in periodic submergence and exposure of surfaces) and underwater operations. This generally leads to higher costs and downtime compared to conventional land-based construction activities.

Marinas encompass both land based and marine construction. Land based activities are generally referenced to Australian Height Datum (AHD) which approximates Mean Sea Level, whereas depth of navigation is usually referred to a Low Water datum such as Indian Springs Low Water (ISLW) or Chart Datum (CD) (see Appendix 3). Great care should be therefore be taken when “setting out” to ensure all marks are referenced to the same datum and that the correct offsets are applied to levels.

Piles are generally an integral part of a marina and are fabricated from either timber, steel or concrete. The choice of pile material is usually a function of cost, maintenance and aesthetics. Piles used in marina structures differ to those for ports in that forces and loads on marina piles are significantly smaller. As such, smaller piles with lower design capacities are driven into the bed using smaller operating plant than is commonly utilised in port construction.

Prefabrication, rather than on-site fabrication of marina components, and in particular concrete units, is recommended. Concrete units to be placed in the marine environment need to meet rigid manufacturing standards. These standards can be best achieved in a controlled environment such as a factory complex where environmental conditions may be controlled, rather than on a construction site. Furthermore, construction space at marinas is often at a premium and minimal disturbance of existing ground cover at the site is advisable to reduce sediment runoff and water quality deterioration.

Construction dredging and maintenance dredging are common practices at many marinas. During dredging operations, sediments are suspended through the water column. Precautions should be taken to reduce the impact area of sediment suspension by introducing appropriate measures such as silt or sediment skirts. Consideration also needs to be given to the disposal of dredged material and the likelihood that the sediments may contain contaminants. In some cases environmental and water quality monitoring may be required prior to, during and after dredging operations, particularly in cases where adverse impacts are a concern (e.g. adjacent oyster farms, etc.).

Dredging operations should be restricted to the smallest possible area and undertaken over the shortest possible time period to reduce the likelihood of impacts on the environment. Different types of dredges are also available (i.e. grab, suction, cutter suction) of which one may be more suitable for a particular application (e.g. reduce sediment suspension, shallow and deep water depths, high current and/or wave climate, confined space, high dredge volume, etc.).

Precautions should also be undertaken to ensure sediment runoff from land-based construction activities does not adversely impact on the marine environment. Disturbance of soils should be kept to a minimum and sediment traps installed to capture silt loads.

B.6 Maintenance

The most aggressive marina environment and region of severe corrosion potential is the inter-tidal zone between high and low water. Maintenance of marinas is an ongoing process which in terms of engineering considerations could include:

- periodic dredging of navigation channels and mooring basins of sediments and wrack (in some locations)
- repair of breakwaters due to storm damage and other environmental influences
- pile survey inspections including repair/replacement
- inspection of mooring systems
- cathodic protection
- antifouling and removal of growth from structures

- repair of structures due to vessel impact
- prevention of corrosion above the water line
- water quality monitoring.

The frequency of maintenance dredging of sediments is essentially a function of the infilling rate, dredged channel width and depth, and required channel width and depth for navigation. Careful consideration should be given to the disposal of dredged material to minimise environmental and aesthetic impacts and to ensure spoil does not re-enter the dredged areas.

Along many coastlines in southern Australia, maintenance dredging to keep channels, launching areas, adjacent beaches and moorings clear of seagrass wrack is often necessary. Seagrass wrack is the naturally shed leaves of some seagrass species (e.g. Posidionia spp.) which form mats and drift in response to waves, tides and wind. The ingress of wrack into channels and accumulation elsewhere is less predictable than movement of littoral sediments. Once wrack has entered a channel, it will often not clear without mechanical intervention, such as dredging. In addition, dredging of wrack to clear the channels can be far less efficient than the dredging of sand, silt or mud. It is not uncommon for the cost of channel maintenance to be underestimated because of insufficient consideration of the need for wrack clearance.

Timing of pile inspections is dependent on the type of material used and the local marine environment. For steel piles, cathodic protection is sometimes employed for protection below the water line. Regular monitoring (6 monthly) of the cathodic system and replacement of the sacrificial anodes is generally sufficient preventative maintenance. Timber piles may be attacked by marine borers and fungi and should be inspected on a regular basis (2 to 5 years). Timber piles should be turpentine or other species proven to be durable in a marine environment or (in practice) from species capable of accepting protective treatments. Timber piles may be repaired by encapsulation methods, but for most marinas it may be more economical to replace the pile. Concrete piles should be inspected on a regular basis (2 to 5 years) for evidence of cracks, vessel damage, rust stains and concrete scaling. Repairs to damaged piles (by specialist concrete consultants) should be undertaken immediately to prevent the onset of corroding reinforcement or concrete cancer.

Mooring systems for floating marinas may consist of pile (addressed above) or chain anchorage systems. Chain anchorage systems are generally cathodically protected and should be inspected for corrosion at regular six monthly intervals and inspected for wear due to abrasion at least annually.

Removal of growth from structures should be undertaken on an as needs basis for aesthetic purposes and to reduce drag forces from waves and currents. This may be done by means of hand rakes or underwater divers.

Prevention of corrosion above the water line is achieved by choice of material and/or protective covers. Materials such as aluminium, stainless steel, PVC, rubber, plastics and fibre-reinforced plastics may be suitable for particular applications. Similarly paints, anodising and hot dip galvanising may provide suitable protective cover. A more complete description of the suitability of materials is provided in the supplement on the use of materials in the marine environment.

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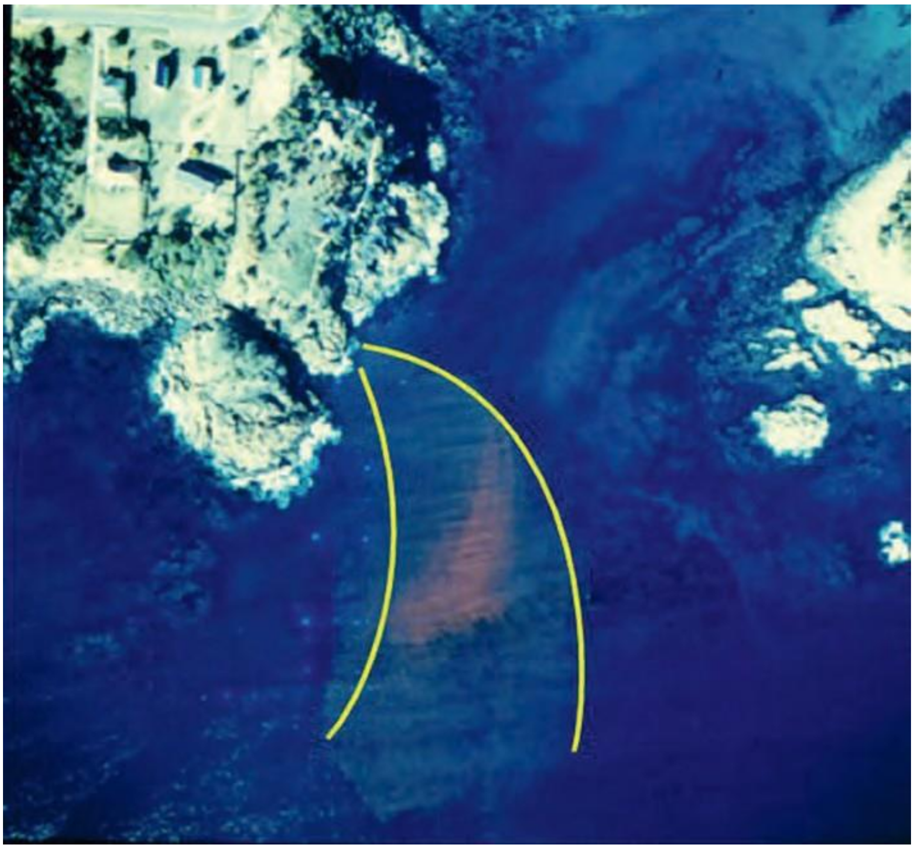
SUPPLEMENT C
OUTFALLS



Plume studies for Ocean Outfall NSW Coast. PHOTO: NSW – PWD

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OUTFALLS

C.1 Purpose of Outfalls

It is a common practice to use coastal waters (ocean or estuary) as a means of returning the byproducts of onshore activities to the environment. Any water is returned to the hydrological cycle and nutrients to the food chain. However, certain substances in certain circumstances can have an adverse impact on the environment unless good practice is followed. The structures through which these byproducts are conveyed to the receiving waters are termed outfalls. They generally consist of a single or multiple pipe system, and the materials so discharged can be stormwater, industrial waste, heated processed water typically from power stations, sewage or sewage effluent from treatment plants. There are more than 50 outfalls discharging sewage from Australian cities and other coastal communities to the ocean. Many coastal river basins have more than one ocean outfall. The outfalls range from small (less than 5 ML/day Average Dry Weather Flow) to very large (more than 50 ML/ day ADWF). They discharge at different locations: shore-based outfalls discharging usually below low tide level; nearshore outfalls discharging in water depths less than 10 metres; and offshore outfalls discharging significant distances offshore in depths from 10 to 80 metres.

Outfalls, where utilised, form an integral component of a broader sewage/waste byproduct management system. A wide range of options for different outfall types coupled to different levels of treatment are available. All options should be considered in selection of appropriate waste management and disposal systems if the objectives of prevention of public health risks, achievement of ecologically sustainable development and optimisation of economic costs and benefits are to be achieved.

Understanding of the overall environmental impact and effectiveness of different sewage/waste management strategies (e.g. ocean outfalls, high treatment levels, irrigation of effluent, potable re- use) is limited. Public confidence in outfalls significantly suffered in the 1980s with the Australia- wide reporting of excessive pollution of Sydney's beaches due to primary treated effluent being discharged in large volumes at shoreline outfalls. Since improvements in treatment, industrial trade waste management implementation and replacement of shore-based outfalls by offshore deepwater outfalls, the Sydney performance has improved to the extent that pollution levels and environmental impacts meet EPA licence and international standard guidelines.

In the main, small to moderate outfall discharges in coastal communities beyond major cities incorporate secondary or tertiary treatment coupled to shore-based outfalls or even discharges to estuaries or rivers.

In any evaluation for sewage/waste management, it is essential that all options and option combinations be considered. There is not a single "right" answer applicable to all locations, the issues are complex and tradeoffs will be required whichever option is chosen.

In general, the ultimate goal of potable re-use is acknowledged. However, it is equally acknowledged that full scale potable re-use has, to date, had limited application in Australia and that in some cases ocean outfalls may be the least–worst interim solution. Health risks and likelihood of environmental and ecological impacts are higher for discharges to estuaries or rivers than to the ocean. Many community and environmental groups are increasingly expressing concerns regarding sewage/waste disposal (irrespective of treatment levels) to local rivers or estuaries.

Increasingly, strategies are being developed to reduce the loading upon outfalls by reducing the input to the system (trade waste management, improved treatment), and/or increasing on-land disposal and/or recycling of the effluent (potable and non-potable).

C.2 Principles of Operation

The operation of outfalls is directed in most instances at mixing the effluent as quickly as possible with the receiving waters in order to reduce its concentration to an environmentally acceptable level. These practices are based upon the hypothesis that most effluents will in fact be recycled by oceanic processes. Consistent with this hypothesis regulating authorities are moving to reduce, and eventually totally remove from effluents, certain non-degradable substances such as heavy metals and some pesticides.

C.3 Impacts

C.3.1 ArealExtent

Most outfalls are located at distances between zero and three km from the shoreline and their impact is generally limited to those particular areas. Estuarine and river outfalls are normally located close to the shoreline.

Effluent from outfalls has an impact upon the water column which is mostly marked at the terminal end of the outfall, which may incorporate a multi-port diffuser section. Any possible impacts decrease with increase in distance from the diffuser because of dispersion. There may be long term impacts upon the benthos near the outfall diffuser whilst construction activities can have short term impacts on the benthos and on the water quality throughout the water column.

C.3.2 Impacts on Beneficial Uses

The following is a list of beneficial uses which may be impacted in a negative fashion by outfalls if careful professional practice were not followed in their investigation, design, construction and operation:

- water contact sports
- recreational boating
- benthic species diversity
- fisheries
- general aesthetics
- industrial water use
- the marine working environment.

The impacts on these beneficial water body uses generally would be the result of some degradation in environmental quality caused by the effluent. Most impacts in fact would occur within the vertical water column with the notable exception of those affecting benthic species diversity.

C.3.3 Water Quality Properties

Ocean water quality will be degraded during effluent disposal by the following factors:

- disease factors, bacteria and viruses
- heavy metals
- bio-chemical oxygen demand
- organochlorides
- nutrients
- turbidity
- grease and oil
- odours
- floating debris
- plankton blooms (restricted to estuaries)
- unnatural colour.

C.3.4 Oceanic Properties

The potential impacts of outfalls on the marine environment are moderated by the following physical properties of the ocean environment:

- bathymetry
- sea bed geology
- regional water circulation patterns
- local and temporal variations to the above
- wind stress
- wave climate
- density structure
- turbulent mixing.

C.4 Investigations

C.4.1 Scope

Investigations into outfalls require measurements or estimates of both the properties and dynamics of the receiving waters and the quantity and properties of the effluent. A prediction is then made of the performance of an outfall of a particular type in mixing the effluent with the ocean and of the effluent's subsequent trajectory in the ocean waters.

C.4.2 Receiving Water Properties

The properties and dynamics of the receiving waters should be measured or assessed over at least one year in order to accommodate all seasonal effects. A longer period of measurement would enable an assessment to be made of inter-annual variations. However, it is not always possible to extend the data collection program for more than one year, but if it were, a three year period would be the next step to be considered. The properties measured over the sampling period should include water temperature, salinity, suspended sediment, turbidity and oceanic flow fields. Measurement of the physical properties at intervals of two to four weeks would be reasonable and an extensive ocean flow field measurement should be undertaken at least once every month. The representativeness or otherwise of the measurement period would be assessed using whatever long term climate data is available for the area.

The flow field measurement should be extensive enough to cover significant features both up-coast and down-coast from the outfall site and normally would involve a distance of some 5 km each side of a large outfall. The measurement field should also extend seaward (if an ocean outfall) to the estimated offshore limit of any effluent field. The monthly measurements over this domain should be detailed enough to define the surface flow field with typical velocities. Techniques for making these measurements could include Acoustic Doppler Current Profilers (ADCPs), towed current meters logged in association with GPS position fixing systems, or drogues deployed over the area at the beginning of each test and tracked either by survey or by fast boat using a GPS system. In situ long term recording current meters (or ADCPs) can be used to supplement the flow field measurements but are not generally sufficient in themselves to provide the data required, largely because of the great number that would be needed to give a good spatial coverage of the receiving waters.

In addition to the regional flow field measurements, it is desirable to have local velocity measurements made at the site of the outfall. When the outfall terminates at or near the shoreline this can be done using dye tracing by field hands located on the shore. However, with an extended ocean outfall (deep water with high initial dilutions) it would be necessary to have at least one in-situ recording current meter to collect the data required.

C.4.3 Effluent Properties

The properties of the effluent that are needed include estimates of average and peak flows, temperature, salinity, suspended sediment concentration, and concentration of prescribed substances such as faecal coliforms, BOD, pH, nutrients, metals, organochlorides, grease and oils, etc. (these are generally set by licensing authorities). These properties are highly variable and hence the probability distribution derived from many measurements is required.

C.4.4 Pre-Construction Baseline Data

In addition to data required principally for the evaluation of the physical and chemical oceanography of outfall performance, there is a need to collect data pertinent to the biological environment. In the first place these data may influence the siting and design of the outfall. A second use would be the definitive description of the biological environment prior to the installation of the outfall. Post-construction monitoring would then reveal any environmental impact resulting from its construction and operation. In the longer term such environmental impact assessment could be useful in establishing a general impact data base for ocean outfalls.

From a biological environmental viewpoint, the benthos warrant most attention, with lesser effort directed at plankton and nektos. In addition, commercial marine species warrant specific attention from the point of view of public health and species survival.

The assemblage of species found will depend on the marine climate. Within Australia this varies from the tropical to the sub-arctic, on the time of year and on the local physical environment such as current speed, nature of the seabed, wave climate and turbidity, all of which should be recorded during the surveys. Again, one year would seem to be the minimum duration of monitoring required so as to include seasonal variations.

C.5 Design

C.5.1 Design Principles

Most outfalls discharge a liquid which is less dense than sea water. In the past, simple outfalls have had operational difficulties because of this. On occasions they tended to produce a density stable effluent field which only slowly dispersed and resulted in high concentrations of effluent in the local ocean waters.

In recent years successful ocean outfalls have been designed on the basis of two principles:

- high efficiency high energy diffusers that mix with ocean water in the area immediately adjacent to the outfall – initial near-field dilutions in the range of 200 to 2000 being typical
- location of the outfall such that the effluent field becomes engaged in the general ocean current field rather than in a local circulation where a build-up of effluent could occur – i.e. deepwater offshore outfalls rather than shoreline locations.

The above principles will often, but not always, apply to outfalls in estuaries. The most notable exceptions are those estuarine outfalls which aim to have effluent advected to the ocean within one ebb tidal cycle. Here it is often more beneficial to have minimum near-field mixing with the effluent field being contained and advected from the estuary via the natural entrance to the ocean.

C.5.2 Near-field Design

The geometry and location of the termination (diffuser section) of the outfall needs to be designed so that significant mixing with the ocean waters will occur within tens of metres of the outfall. This can be achieved either by a high velocity jet in the near surface region, or by discharging the effluent in deep water where its density difference will cause it to rise through the ocean water column effecting mixing. On occasions both techniques have been used at the one site. In addition, multiple jet manifolds have been used in order to reduce the discharge from one particular jet, discharge velocity being one of the principal determining factors for nearfield dilution.

The design of simple single port outfalls can draw upon a wide body of research work concerning the dispersion and mixing of jets with density differences in a variety of current fields. Numerical models are also available to deal with multiple port diffuser outlets. Some more complicated layouts warrant physical model testing in which the density difference is incorporated in the model.

The rise of the mixed plume can likewise be treated using numerical or physical modelling. It is worth noting that on occasions with a density stratified ocean it is possible for the effluent plume to reach equilibrium with the water column without reaching the surface. The most frequent cause for such density stratification is a variation of temperature with depth. This phenomenon produces a submerged effluent field and is amenable to calculation with the more sophisticated numerical models. Whether a submerged field is a desirable outcome is a matter for individual evaluation, taking into account the nature of the effluent and shoreline environment.

An associated problem which can be found in deep outfalls with multiple port/nozzle diffusers is that of purging the system of ocean water when starting up after an extended shut down. The flow required to purge such a system exceeds the flow required for stable operating conditions. The failure to purge can result in effluent flow through some nozzles and the flow of seawater into the system through others. This reduces the effectiveness of the system in diluting the effluent. The use of non-return valves such as duckbill valves can prevent seawater ingress in case of shutdown. Physical hydraulic models may be required to design initial purging.

C.5.3 Far-field Design

The design of an outfall in order to achieve mixing of the effluent with the general ocean circulation can be achieved by a number of means. The outfall can be located at the seaward limit of a prominent headland and discharge at or near the water surface in such a way as to achieve a reasonable initial dilution. The subsequent effluent field will generally be incorporated in the broader ocean circulation. Data collection as outlined in "Investigations" would be needed to establish this fact. A second option would be an extended pipeline generally on the bed or buried in a shallow trench, terminating at a point sufficiently seaward so that the effluent was beyond the influence of local circulations. A third option applicable only to very large outfalls would consist of a tunnel system achieving the same objective as the extended pipe outfall.

The other aspect of far-field design concerns the dispersion and dilution of the effluent field. The advection of the effluent field can be designed knowing the current regimes and the dispersion calculated from knowledge of the oceanic dispersion parameters. These parameters are generally available for ocean waters and, in particular, a large amount of data has been collected for nearshore Australian coastal waters. The techniques applicable to this part of the design generally involve some type of dispersion driven concentration reductions. At the same time this dispersion increases the extent of the effluent field. Simple calculations or more complex numerical models are generally available to undertake this part of the work. These do require flow field and diffusion data specific to the site.

C.5.4 Combining Dilution Results

It is common practice to calculate near-field dilution which occurs between the outfall terminal and some location nearby. This is frequently the point at which the effluent field achieves density stability with its environment. Licences will generally specify a minimum value for nearfield (initial) dilution.

Far-field calculations are concerned with the way effluent is advected, dispersed and further diluted with oceanic waters. This generally involves field measurement or estimation of some dispersion parameters. On occasions downstream dilutions are referenced to a unit concentration at the nearfield boundary.

Care should be exercised in the way these two values of dilution or concentration are manipulated in order to get an overall dilution at some location downstream in the far-field. The average far- field concentration of pollutant at any location is in fact the pollutant flux at source divided by the flux of the effluent field at that location. The dimensions of the effluent field are arrived at by making some logical truncations (for instance at the 10% of peak level). Peak concentrations can be derived by consideration of a concentration profile (generally Gaussian). With some methods of specifying nearfield and far-field dilutions it is not correct to multiply the two values to get the overall downstream dilution. One simple method of combining nearfield and far-field concentrations is to treat the downstream boundary of the nearfield as if it resulted from a virtual point source of effluent some distance upstream (with respect to the oceanic flow field). Some engineers have referred to this calculated distance as the "headstart". The point source and oceanic dispersion parameters are then the only variables used in calculating downstream effects in the far-field.

C.5.5 Accounting for Variability

As mentioned above, the properties of both receiving waters and the effluent are highly variable and some method is needed to account for this variability. There are three possible approaches:

1. Choose conservatively high (or sometimes low) values for all parameters to use in the design. The resulting combination should incorporate a high but unknowable factor of safety. In most cases a single combination is not

sufficient as it is not always apparent whether high or low values would be conservative. A case in point is the value for coastal current speed for which a high value is conservative for near-field dilution but the reverse may be true for far-field. Various combinations should be tried and the worst chosen for design.

2. Use Monte-Carlo methods whereby the statistics of all parameters are used to generate random values for each parameter in simple models of the outfall behaviour. By carrying out the simulation thousands of times the statistics of the important parameters can be generated to be compared with licence or design targets.

3. Simulate outfall operation for a long period of time. For this method the statistics need to incorporate time series – either measured or generated. The modelling techniques can be as sophisticated (accurate) as can be afforded. The simulation time to generate reliable statistics can be considerable – at least hundreds of years.

C.5.6 Functional Design

This section deals specifically with the design considerations pertaining to the pipelines of outfalls, these being the principal components affected by, and affecting the environment.

Physical design considerations are:

- internal and external corrosion protection
- adequate ballasting for surface laid pipes
- adequate mass to ensure shallow buried pipes do not "float out"
- construction stresses during pipe laying
- ability to accommodate wave and current loads where exposed on the seabed
- ability to accommodate sand level change particularly in the surf zone and at the nozzle/diffuser section.
- Hydraulic design considerations include:
- effectiveness of ports or nozzles in achieving initial dilution
- whether to install outlet valves (duckbill)
- whether the system (outfall pipeline diffuser with risers and ports) can be purged of sea water if outlet valves are not used.

Biological considerations:

- Is marine growth likely to degrade hydraulic performance and the need for, and means of, maintenance?
- Is bacterial corrosion of reinforced concrete likely to weaken the outfall structure? (see Supplement D).

C.6 Construction

C.6.1 Outfall Types

This Section deals generally with the more conventional methods of construction which result in an offshore pipe outfall. Cliff based outfalls have fallen out of favour either due to poor performance or public perception and are less likely to be selected options in future. Occasions on which the latter are likely to continue to be selected are those where there is an extremely prominent headland from which effluent would become immediately entrained in regional as opposed to local flow fields. In this case the construction of the outfall need not impact on the marine environment.

The extended ocean outfalls comprise either some system of buried or surface laid pipe leading to an offshore terminal manifold/diffuser or, a deep tunnel with risers at its seaward terminus.

C.6.2 Fabrication

For most pipe based outfalls an amount of fabrication is carried out onshore, in some cases the majority of fabrication. For large pipelines this may be impractical and it may be necessary to make underwater joints during installation.

C.6.3 Trenched Pipeline Outfalls

Trench Excavation

For those designs where the pipe is to be laid in a trench extending from the shoreline to deepwater, various methods are available for excavating that trench. They include:

clam shell mounted on a trestle or barge

cutter suction dredge

drag line between the shore and an offshore anchor.

When the material is rock or too hard to be excavated by the means above, the options are:

- drill and blast

- the use of templates fitted with shaped charges.

Once loosened, the material can then be treated by the methods above.

In excavating the trench, the most difficult section is that through the surf zone. Here it is often the practice to erect a pile bent trestle and drive sheet piling in order to prevent the trench being filled with sand driven by wave and current action.

Launching

Where the pipe is assembled onshore it can be launched into the trench either by the technique of bottom pull, where the pipe is pulled along the bed of the trench by a barge which progressively moves seawards using its anchors. An alternative is a floating pull where the pipeline is buoyed and a similar technique is used. However, this method exposes the pipe to a greater impact from environmental forces. Another alternative is to join pipe lengths together on a lay barge and as the barge is pulled seaward, to lower the pipe into the trench. To facilitate this, the barges are normally equipped with a “stinger” designed to limit pipe stress during lowering. For large pipes the foregoing are generally impractical and the normal technique involves lowering relatively short lengths of pipe to the bed and having the jointing done by diving.

Backfill

The trench is normally backfilled at first with pea gravel size material and finally with material of a sufficient size to remain in place under the action of waves and currents. Across the surf zone this is normally done from the trestle prior to pulling the sheet piles. Further offshore the materials are placed from a barge positioned as accurately as possible above the trench. A certain amount of spreading of the dumped material should be expected in this procedure. In some circumstances divers have been used to assist the placement, particularly of the smaller material.

C.6.4 Tunnels and Drilled Outfalls

These construction techniques avoid some of the problems of work in the marine environment.

Directional drilling can be used for outfalls up to about 1.5 metres in diameter and for lengths of drilled hole up to about one kilometre. These factors tend to limit its applicability to small/medium outfalls both by reason of the bored hole’s flow capacity and because the limited distance offshore restricts the ability to engage the effluent field in regional as opposed to local flow fields.

The need for adequate working space means that tunnelled outfalls are generally larger than 2.5 metres in diameter. They are appropriate for deepwater outfalls for larger communities.

Progress of construction is frequently monitored by divers or, in deeper water, by remotely operated vehicles (ROV). Ongoing regular inspection is principally directed at the terminal diffuser with checks being made that the seabed profile is not changing to the extent that it will expose the pipeline or bury the diffusers.

C.6.5 Environmental Impacts

The construction of outfalls, as distinct from their operation, has certain environmental impacts. These can be summarised as:

- interruption to alongshore transport by sheet piling
- fish mortality due to blasting
- interference with migratory mammals or fishing operations
- removal of benthos by trenching
- reduced light penetration by induced turbidity
- smothering of nearby benthos during backfill
- change of substrate, particularly in rocky areas.

C.7 Post-Construction Monitoring

C.7.1 Purpose

There are two reasons for post-construction monitoring. The first is concerned with checking theperformance of the outfall against the predictions made during the investigation phase. The second is to monitor changes in the biota and to attempt an assessment of the outfall’s contribution to those changes.

C.7.2 Performance Aspects

Generally, there will be existing environmental standards for the performance of outfalls. These are concerned with dilutions and the concentrations of prescribed substances. These requirements vary with the type of receiving water body. There are also, generally, specific licence requirements for each outfall issued by the relevant environmental authority. Most authorities categorise receiving waters in terms of their beneficial use and set standards accordingly. One example of this is water bodies where swimming occurs. This has a higher standard in terms of allowed bacterial count than do similar waters where there is no swimming. Also among the concepts of beneficial use are pristine waters which are sometimes protected for this characteristic. The field checking of these factors is fairly straightforward.

The other aspect of performance which can be checked, but often is not, is that the system behaves hydraulically as designed. This involves more extensive and complex measurement including environmental parameters of temperature, salinity, current velocity and diffusivity. The reason for this type of check would lie in the objectives of optimising treatment plant/outfall performance as well as improving the investigation and design capability of the industry generally.

C.7.3 Impact on Biota

An environmental management plan (generally a part of an environmental impact assessment process) would normally include a program for ongoing monitoring of the assemblages covered in the pre-construction baseline data. If these data (pre and post) are then subject to a factorial type analysis such as an analysis of variance, it should be possible to isolate from other factors the effect of the outfall on the biota.

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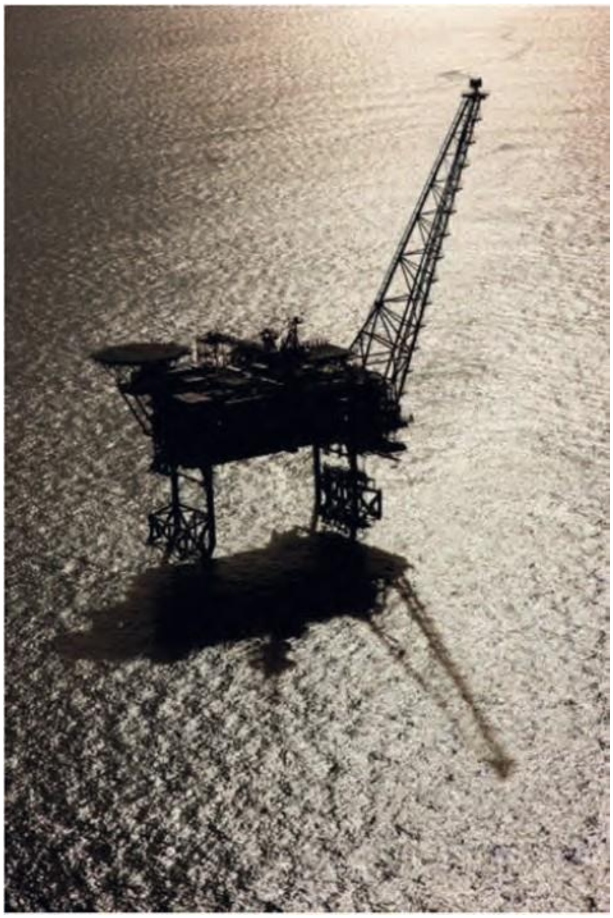
SUPPLEMENT D
CONSTRUCTION MATERIALS FOR THE MARINE ENVIRONMENT



Angel gas platform North West Shelf. IMAGE: WOODSIDE

This Supplement has been prepared by the National Committee on Coastal and Ocean Engineering (NCCOE) of Engineers Australia, to assist professional engineers in the application and use of the Coastal Engineering guidelines for working with the Australia Coast in an ecologically sustainable way.

CONSTRUCTION MATERIALS FOR THE MARINE ENVIRONMENT

D.1 Criteria for use of materials

The choice of materials used in the coastal zone is dependent on an extensive number of criteria of which the most important are listed below:

- type and purpose of structure and design detailing
- structural integrity of material
- material costs and availability
- maintenance and serviceability including potential for corrosion resulting from construction processes
- construction and installation techniques
- aesthetic and environmental suitability.

Materials in common use in the coastal zone include:

- rock
- timber
- concrete
- steel
- aluminium
- plastic and rubber.

While it is recognised these materials are the most commonly used in the coastal zone, new materials are being developed continually and should be given due consideration if shown to perform satisfactorily. Details of the most commonly used materials are discussed in this supplement.

D.2 Rock

Rock is used extensively throughout the Australian coastal zone for seawalls, revetments and breakwaters. Igneous rocks (e.g. basalt, granite and diorite) are the most common rock materials used with sedimentary rocks (e.g. sandstone and limestone) used infrequently in more sheltered environments. In addition to the size, shape, quantity and homogeneous quality of rocks from a quarry, the most important qualities of a rock material to be used in the coastal zone are:

- density
- water absorption (wet density)
- resistance to weathering (Magnesium Sulphate Soundness Test)
- resistance to impact and mineral fabric breakage (fracture toughness or point load strength)
- resistance to abrasion (Los Angeles Abrasion Test)
- block integrity (free of cracks, veins, laminations, cleavage planes, etc)
- impurities (free of impurities which may affect the soundness of the rock).

The Los Angeles Abrasion Test is considered to be overly harsh for sedimentary rock and does not properly simulate abrasive forces within a breakwater, but it is still commonly specified. Sydney Sandstone with estimated Los Angeles Abrasion Losses of less than 40% has been used successfully as armour in Botany Bay. Similarly, limestone has been used successfully as armour in Western Australia, United Kingdom and the Middle East.

D.3 Timber

Timber is used commonly for piles and for wharf and jetty construction. Its relative low cost and ease of workability are attractive for use in small coastal structures. Limitations in its use include:

- lack of large sizes,
- structural strength upper limit,
- if immersed, a relatively short lifespan when not protected against attack from marine borers and fungi.

Timber piles and other timber members subject to immersion usually are constructed from turpentine (*Syncarpia Glomulifera*) or from other species capable of accepting protective treatment. Most other suitable timber species require significantly greater treatment than for turpentine. The most common preservative treatments include creosote (PEC) and copper-chrome-arsenic (CCA). On occasions timbers are treated with both PEC and CCA to provide protection against marine boring organisms. However, experience indicates that CCA treatment of timber cannot be relied upon to protect against marine borers.

Mechanical protective methods also can be used to prevent the entry of water into areas affected by borers. Methods include encapsulation with epoxy or concrete and wrapping of piles/timber members with mastic tape or polythene sheeting.

Timbers suitable (durable) for use in the marine environment above the water line include:

• blackbutt	• mountain grey gum
• brushbox	• tallowwood
• forest red gum	• turpentine
• grey box	• white mahogany
• grey gum	• white stringybark
• grey ironbark	• woollybutt
• jarrah	• yellow stringybark.
• karri	

Preservation of these timbers may be achieved using PEC, CCA, copper naphthenate, boron salts and sealants such as bitumen. Some chemical preservation methods may have impacts upon the marine environment and its ecology. Hence the suitability of any treatment proposed for a specific situation should be carefully assessed prior to adoption.

D.4 Concrete

Concrete is used for many applications in the marine environment including: piles, seawalls, armour units, decking, walkways, ramps, buildings and stormwater pipes.

When properly designed, mixed, placed and cured, concrete is a very good material for marine applications. Specifications for structural marine concrete commonly require:

- a minimum strength of 40 MPa
- a minimum cement content of typically 400 kg/m3
- a low water/cement ratio (< 0.45)
- an aggregate size of approximately 20 mm
- a water reducing admixture to ensure durability
- a minimum reinforcement cover of 65 to 75 mm.

Unfortunately the AS 3600 – 1988, SAA Concrete Structures Code is limited in the guidance it provides for concrete in the marine environment and, as such, a specialist concrete consultant should be employed to provide specific advice on projects.

Poorly designed or constructed concrete may break down and fail. Insufficient cover over steel reinforcement and/or cracking of the concrete will lead to seawater chlorides coming into contact with the steel, resulting in the reinforcement corroding and subsequent spalling of the concrete. Particularly susceptible are joints between slabs and beams, joints between piles and beams and corners where a large arris may reduce reinforcement cover. Particularly close supervision is needed during concrete pours to ensure the steel is not displaced so as to reduce cover. Even protruding wire ties can become a track for rust to penetrate the finished concrete. Precast concrete is often preferred (to onsite pouring) as higher degrees of quality control over the mixing, placement and curing of concrete can be achieved in a controlled environment.

To resist cracking and to increase concrete durability, “Fibrecrete” is sometimes added. Epoxy coated or galvanised reinforcing is available to enhance the durability of the concrete. However, if good mixing and placement practices are employed coating should not be necessary. The protection of steel reinforcement using cathodic protection systems is becoming more common.

Concrete in direct contact with seawater (splash zone) requires special attention. Minimum concrete strength of 50 MPa and a special mix design are required to reduce permeability. Use of additives, such as flyash or silica fume or a combination of these, will decrease the concrete’s permeability significantly and therefore is an option to be considered.

Concrete used for foundations in contact with acid-sulphate soils should be subject to the same high quality controls as when in contact with seawater. Sulphate-reducing bacteria have an adverse effect upon the bond between reinforcing steel and concrete.

D.5 Steel

Steel has a superior load bearing capacity to timber and is often more suitable on large-scale projects involving high design loads. Compared to timber, steel is relatively expensive and is often uneconomical for use on small projects.

Advantages of steel are ease of fabrication, high load bearing capacity, high impact resistance and the large range of shapes and sizes readily available. The main disadvantage of steel is its vulnerability to corrosion. In particular, it is extremely difficult to complete a field weld that does not become a site for future corrosion.

Corrosion prevention of steel can be achieved by several methods, although different types of applications are usually employed between submerged and dry zones:

- Cathodic protection and impressed current systems are commonly used for protection of steel below mean water level (mid tide level). The design of impressed current systems is a specialist's province and should not be attempted without the requisite skills. The interaction
- between such systems and steel hulled ships berthed at the wharves protected by these systems needs to be thoroughly investigated. Between mid tide and high tide level these protective systems are relatively ineffective. Becoming more common is the protective wrapping of steel piles up to the deck level, with anodes inserted underneath the wrapping. By maintaining moisture beneath the wrapping and in contact with the steel and anodes a cathodic protection system is developed.
- Hot dip galvanising is effective for steel which is only rarely wetted by seawater. It is not suitable for fully submerged fixed steel components (e.g. piles) and is particularly vulnerable in the intertidal zone.
- Some epoxy or polyester based paint systems will provide good corrosion protection to steel.
- They are also useful for submerged steel which can be removed for re-application of paint (e.g. pontoons).
- Wrapping with impregnated fabric tape has proven to be successful in the intertidal zone. Inner layers of the fabric contain petroleum jelly and the outer layers are impregnated with bitumen which can be heat-sealed.
- Encasement of steel using fibreglass, fibre reinforced cement and a plastic is also possible. This protective treatment is suitable where flexure of steel piles or members is small.

Stainless steel is rarely used in the coastal zone, with the exception of frequently adjusted fasteners and fittings, owing to its relatively high cost and high corrosion susceptibility in warm ocean waters.

It is common practice to provide a corrosion thickness allowance (factor of safety) in steel design strength calculations.

D.6 Aluminium

Aluminium has a high strength to weight ratio and therefore is often used for the construction of pontoons and gangways. Aluminium is an expensive material and is generally used only where strength and weight limitations need to be considered.

Aluminium suffers from extreme electrolytic corrosion in the presence of metals of different electric potential. A polyurethane paint system is required to protect aluminium submersed in seawater. For aluminium exposed to air protection by anodising or resin coating is recommended.

Only aluminium alloys of series 5000 or 6000 should be used near seawater so as to counter long- term corrosion. Welding and application of protective coatings should be undertaken in a factory- controlled environment, wherever possible.

D.7 Plastics and Rubber

Numerous plastics and rubbers are used in the coastal zone for their resistance to corrosion and their flexibility. However, many are susceptible to damage from exposure to ultra violet light and some are vulnerable to attack from petroleum-based products. Examples of materials used in the marine environment include:

- Butyl
- natural rubber
- Neoprene
- Polyethylene
- Polypropylene
- Polystyrene
- Polyurethane
- PVC.

D.8 Geotextiles

Geotextiles are commonly used in coastal applications as a filter medium between finer sand/silt sediments and coarser gravel/armour rock used in breakwater or to cover pipelines. Generally coastal construction techniques and operational exposure conditions are more severe than those encountered in land based applications of geotextiles:

- Abrasion and puncture resistance properties need to be stronger and carefully selected for the specific application – field trials can be useful.
- Permeability/hydraulic conductivity will reduce significantly due to clogging of the geotextile by silts and marine fouling, repetitive tidal and wave driven fluctuations in water pressure accelerating the process. Designs dependent upon high geotextile permeability should be avoided.
- Tensile strength requirements are dictated by construction methods.
- Many geotextile products deteriorate when exposed to Ultra Violet light – in such situations UV resistant products should be used.

In recent times, an expanding range of concrete block mattresses (utilising geotextiles as the matting base or container) has been increasingly used for seabed scour protection. The products have restricted application as surface wave protection layers in seawalls or breakwaters.

Geotextile containers of varying shapes and sizes can be successfully pumped with sand and used in temporary or permanent coast structures – the performance of "geo-bags" is dependent upon not only the bag shape, size and sand density, but also the alignment and packing/placement arrangement. Specific applications include:

- temporary bunding for reclamation
- submerged reef construction
- toe scour protection for seawalls
- groynes
- back-beach seawalls.

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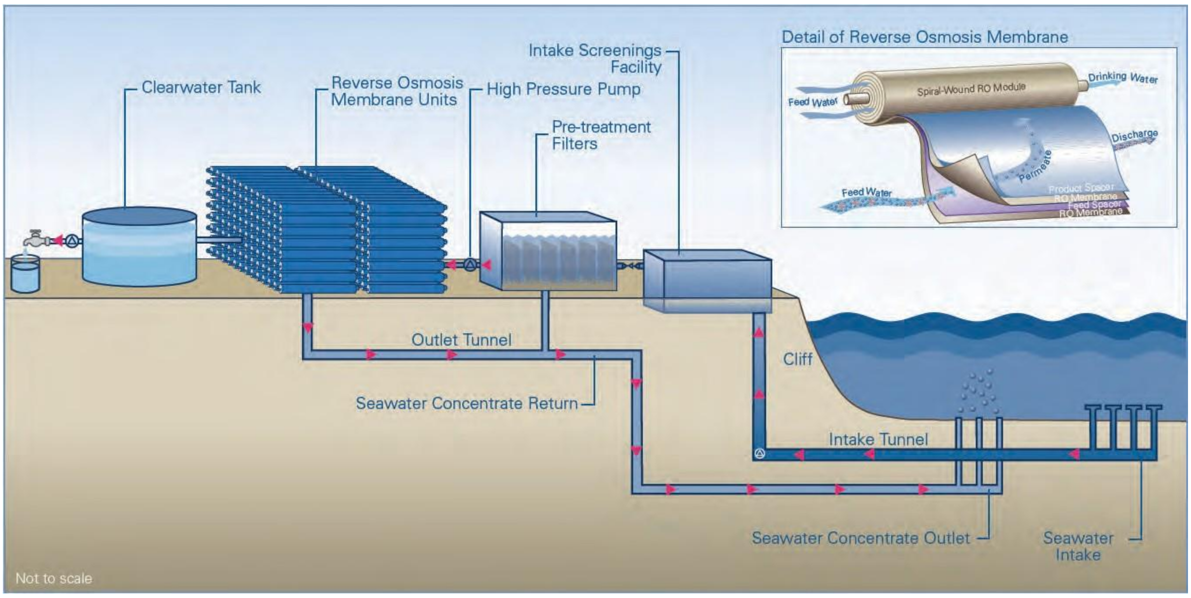
The above reference list has been added to as recent publications in Coastal Engineering Construction have appeared. The text of the supplement does not necessarily refer to nor is it necessarily consistent with these references.

SUPPLEMENT E
DESALINATION MARINE STRUCTURES



Schematic of marine structures associated with a desalination project.

Source: Sydney Water, 2005, Summary of Environmental Assessment

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DESALINATION MARINE STRUCTURES

E.1 Overview

Desalination is the process of removing dissolved salts from a water source (seawater, estuarine water, groundwater, or treated sewerage effluent) to improve the water quality. The result of desalination is two streams of water: one with a lower concentration of dissolved salts (fresh water), and one with a higher concentration of dissolved salts (brine or concentrate). The intended water use may be for drinking water, irrigation, or use in industry and mining. In Australia, desalination is primarily seen as a method of turning seawater into potable water to meet Australia's growing population water needs in an environment prone to drought with scarce water resources.

Desalination generally uses either a reverse osmosis or thermal technique but regardless of the method, the water based environmental considerations are very similar. Approximately 2.5 times the desired production volume is drawn from the ocean or estuary into the desalination plant. The total mass of salt is then returned to the ocean or estuary in a brine of only 1.5 times the production volume. Hence the salinity of the brine is elevated above that of the surrounding water body.

The location of a desalination plant is influenced by a large number of variables including available land, power, delivery of freshwater to the consumers, source water quality and discharge water conditions. The overall success of a desalination plant is critically dependent on intake and outlet considerations, much of which fall within the province of the coastal/ocean engineer.

Intakes are required for a desalination plant to convey source water from the water body to the plant. Consideration of both the volume and quality of the water entering the plant is required. Design needs to be optimised for intake water quality, while ensuring that entrained marine biota is minimised. Specific considerations need to be made of the variability of the source water and the volume of marine material to be screened.

Brine is created by maintaining the same mass of salt within a reduced volume of water. This brine must be disposed of and it is common to discharge back to the original water body. Satisfactory dilution of the disposed brine needs to be achieved to avoid increasing local levels of receiving water salinity and stratification, both of which have the potential to have adverse environmental effects. Although salt is the primary constituent of concern, all toxicological effects from brine disposal need to be considered.

Within this supplement, the principles of the operation of intakes and outlets are discussed as they pertain to sustainability in environmental protection and engineering design. The discussion covers:

- environmental considerations when locating intake and outlets
- key considerations for intake design
- key considerations for outlet design
- data collection programs for measuring environmental impacts and optimising design.

E.2 Environmental Considerations

E.2.1 Intakes

The aim of the intake is to draw water for the desalination plant in sufficient volumes to supply fresh water demand. The primary environmental consideration is to minimise the entrainment and entrapment of marine life. A secondary environmental consideration is to ensure that changes to the overall velocity regime in the region are not altered.

Entrainment of marine plant and animal life has a detrimental environmental effect, but it is also an undesired operational impact. Hence the management of the environmental effect will also have operational benefits.

For inert marine biota (plankton, weed, etc.), it is not possible to restrict entrainment as the material is drawn into the intake with the surrounding seawater. The intake may be screened in the ocean to minimise this entrainment, however regular cleaning of these screens is required. This is discussed in Section 3 on the design of intakes. On the other hand, in the case of fish, the approach velocity, measured just in front of the face of the intake should be small enough so that fish can escape the intake. This requirement will be part of the consideration for the size and design of the intake structure to ensure velocities remain below required thresholds (Sydney Water, 2005). It is commonly adopted that fish can escape an entrainment velocity of 0.1 m/s.

The intake can further reduce the entrainment of sensitive marine biota by ensuring the intake is a distance off the bed to restrict the drawing of bed materials into the intake. This should be of particular environmental consideration when the intake is located over a reef or rocky seabed.

The volume of water required by a desalination plant can be large and an environmental consideration must be the possibility of changes to the surrounding currents. In many instances this environmental consideration can be removed by locating the intake in a region of open and moving currents. However, an extreme case would be locating the intake in the back of a bay where the tide may still go up and down, but now currents only ever flow into the bay!

In the particular instance of a subsurface seawater intake (i.e. below ground such as beach wells), the environmental consideration must also include changes to the saline fresh water interface in the sandy aquifer below and behind the beach. Sub surface intakes are discussed further in Section 3.

E.2.2 Outlets

The aim of the outlet is to dispose of the brine from the desalination plant and ensure mixing occurs with the receiving water as quickly as possible in order to reduce its concentration and hence minimise environmental impact (Roberts et al., 1997). It is often asked why not remove all of the freshwater from the intake volume and only have solids (or near solids) to dispose back to the ocean. While there are ongoing changes in desalination research which may allow this, the volumes of salt are very large. For example a 250 ML/day production desalination plant would create 4.5 tonnes of salt per minute[1].

The target salinity concentration for a brine discharge is commonly less than 2ppt above background and often 1ppt or less above background. The environmental considerations for this are threefold: reduce the direct ecological impact from raised salinity, reduce the density differences with the surrounding seawater to avoid stratification and other baroclinic flows, and dilute any other constituents in the brine to levels below toxic effects. A dilution in order of 30 times is required to achieve 1ppt above background when discharging 65 ppt brine into 35 ppt seawater.

There is no Australian generic guideline for elevated salinity, and hence guidelines for water quality in the vicinity of the outlet require site specific investigations. The performance required by the outlet is generally defined as a target maximum concentration at a given distance from the outlet. Inside this distance the environmental targets will not be met, hence minimising this distance is also a priority. The ANZECC (2000) guidelines recognise that a point-source discharge will result in a mixing zone inside which limited environmental impacts are considered acceptable. However outside the mixing zone, environmental targets apply. This specification results in a target minimum dilution at a target distance. Environmental targets relating to brine discharge may also include (Sydney Water, 2005):

- visible amenity – the discharge plume must not be visible from the water surface
- stratification – the more dense brine does not result in increased stratification which in turn reduces dissolved oxygen levels
- ecotoxicology
- long term build-up of salinity – prevailing currents do not result in the brine concentrating on the coastline.

Each location considered to date in Australia has had subtly different environmental conditions and as such the approach to determining the regulatory requirements was different. In Perth, discharge was to Cockburn Sound where the annual fluctuation in natural salinity levels was more than 3ppt, but a natural stratification exists which might be exacerbated by discharged brine. In that case, the salinity requirements were determined by balancing stratification with natural environmental mixing such as winds (van Senden & Miller, 2005). However, in open coastal discharges such as Sydney and Melbourne, the salinity requirements were determined through the natural variation in background salinity.

There are also a number of chemicals which are used during the operation of a desalination plant, such as biocides to prevent growth in the plant flowpath, dechlorination chemicals (e.g. chorine), antiscalants (e.g. sulphuric acid), coagulants (e.g. ferric chloride and polymers) and particulates collected in pre-treatment or the reverse osmosis filters. Any chemical used during the process, that is to be disposed through the outlets needs to be considered for adverse and potentially toxic effect to marine environment. A target concentration and hence dilution needs to be specified for each chemical that will be present in the outlet brine. This includes physical measures of water quality such as turbidity, pH, and temperature (especially if the plant is thermal). Eco-toxicological studies that have been undertaken at major Australian sites have determined 30 times dilution would be more than adequate to minimise toxic effects (Miller, 2005). However, this must be undertaken on a site by site basis and the timeframe required to undertake adequate baseline ecotoxicological studies should never be underestimated.

It is common practice for desalination plants in Australia to aim to meet all water quality objectives at the limit of the near-field. The above discussion is not exhaustive as environmental concerns will vary from site to site and on the outlet chosen. Although all environmental concerns need to be addressed, the dilution targets for the brine salinity will generally govern.

E.3 Intake Design

Desalination intakes either draw water directly from the source through a pipeline, tunnel or channel, or indirectly, by drawing water from the ground surface through the use of a well. The selection of the type of intake will be dominated by the volume of intake water required, the variability in source water and the surrounding geology.

[1] (1024 – 998) kg/m^3 * 250ML/day * 1000 m^3/ML = 6.5 x 10^6 kg/day

E.3.1 Direct Water Based Intakes

Direct water based intakes will involve an underwater structure which has a direct opening to the source water. These can range from channels to tunnelled pipes with large intake structures which rise out from the seabed.

Issues to be considered to optimise the intake location are whether (AWWA, 2011):

- the occurrence of known pollutant sources likely to be drawn into the plant
- the variability of the seawater quality (in particularly turbidity) as this will affect the plant's efficiency
- the intake is likely to draw elevated salinity levels by recirculating the discharged brine concentrate.

Extensive field data collection, hydrodynamic and water quality modelling are required to properly address these three criteria for locating the intake. A three-dimensional hydrodynamic model would predict scenarios of the brine plume dispersion and transport to assess the intake location. Further, the potential for recirculation is reduced by the outlet having higher near-field dilutions (see Section 4).

The primary concern for plant operation is to optimise water quality and ensure this water quality is consistent to enable ease and efficiency of operation. Intakes should be placed so that entrainment of bed sediment and inert marine biota is minimised. This involves choosing a physical location for the intakes in an area where these potential concerns are minimised. In addition, the intake head should be above the seafloor to avoid sand and seaweed being drawn in and below the ocean surface to prevent air entrainment and allow boats to pass safely overhead. The key water quality parameters for efficient operation are suspended solids, turbidity and the silt density index.

The intake structure often needs to be quite large to ensure reduced velocities at the face of the intake. The intake velocity at the face can be calculated as the volume drawn in divided by the open area.

Screening the intake waters is necessary and the volumes of screened material can often be large. Screens placed on the intake face must include some cleaning either through backwash or surface based removal via lifted screens in sets. There are some active screens which allow backwashing with compressed air, but careful consideration must be made of the practicalities of air volumes and delivery distances. More commonly, the intake waters are screened at the plant using conventional drum screens and any screened material is disposed of (to land or back through the outlet).

If intake pipes are not to be buried, they need to be designed to ensure that they do not interrupt the longshore movement of sand. If pipes are to be buried, the depth needs to be sufficient to avoid exposure in a design storm.

E.3.2 Subsurface Intakes

For subsurface intakes, the desalination plant pumps water out of a central (or several) collection wells and hence surrounding subsurface groundwater flows back into these wells either directly or through lateral wells and infiltration galleries. Several subsurface intakes have been built overseas, however we are unaware of any being built in Australia. Detailed investigations and modelling (Anderson et al., 2004; 2005) were undertaken for a possible desalination plant at Lakes Beach, Gosford, NSW which was never built.

Subsurface intakes consist of a screened pipeline below the beach or seabed with no direct contact with the source water body. By removing water from the pipelines, seawater is drawn though from the sea with the sand acting as a filter for the intake. An advantage of this type of intake is that entrainment and entrapment of marine life is avoided. However, subsurface intake design is very site specific and relies on suitable aquifers being present below the water body for the extraction of sufficient volumes of water.

The design of subsurface intakes will also require the consideration of known pollutant sources that are likely to be drawn into the plant and consideration in design to ensure sediment in not entrained in the intakes.

For large subsurface intakes, in order to meet the environmental targets of minimal impact on beach vegetation, three-dimensional density driven groundwater modelling may be required to predict the groundwater table drawdown due to the intakes and the potential changes in the distribution of salt and fresh groundwater interfaces. A significant amount of site investigation will be required for the creation of a three-dimensional model. This includes an elevation survey, water quality assessment, water table monitoring and pump testing as well as information on the geology of the site through drilling.

Often the subsurface intakes will need to be laterally tunnelled out under the seabed to ensure that fresh groundwater under and behind the beach is not altered. This is becoming more practical as directional drilling techniques are improved and the possible distance increased.

The amount of flow the subsurface intakes will be able to draw will need to be quantified through the use of empirical and analytical equations, and refined using numerical groundwater modelling. In general though, the use of subsurface intakes is limited to small desalination plants or where there are very extensive sandy bed areas.

Water quality assessments must be made to ensure that the sand does not become clogged with filtered marine material or changed biochemical reactions within the intended lifespan of the intake.

Beach erosion and sea level rise will be particularly relevant in these sandy beach conditions to ensure that the intake structures are not exposed.

E.4 Outlet Design

The desalination plant produces both fresh water for use and brine which is returned to the receiving water. The brine will contain additional substance as a result of the desalination process including back-wash water from the pre-treatment filtration, waste from the cleaning desalination process equipment and chemicals from the treatment process. All these substances and the chemical associated with them will be disposed of with the brine through the outlet. However, it is the brine's increased salinity (well above background levels) that is the primary environmental concern. The brine is denser than the receiving water and hence has a tendency to settle on the seafloor where mixing processes due to the wind and ocean current are least prominent (significantly less than at the surface).

The purpose of the outlet is hence to ensure that the concentration of the brine is decreased as quickly as possible in the receiving waters.

E.4.1 Outlet Types

As the desalination plant is on land, and generally at a higher elevation to the receiving water, outlets operate under gravity, with the energy driving the brine a result of the difference in elevation between the desalination plant and the outlet (as well as the density difference between brine and seawater). The outlet location is often constrained by the plant location, however ultimately the outlet type and location is governed by the necessity to meet environmental targets. It is also necessary to ensure that the brine moves away from the point of discharge and does not concentrate in a particular area of the receiving water body. It is often preferable to discharge into the ocean where the fast moving currents are likely to quickly dilute the discharged brine with the outlet diffuser located above the bed to limit entrainment of marine biota. Outlet designs fall into three broad categories based on the whether dilution is to be achieved in the near-field, far-field, or a combination of both.

An outlet dominated by far-field mixing has brine ejected out of either single, or multiple pipes. There are no jets on the end of the outlet and the velocity of the brine exiting is small. The bring is ejected at the top of the water column as it is more dense than the receiving water and mixes as it moves down due the density difference. Ocean currents play a large role in diluting the brine. This design results in a larger impact area than a design which focuses on dilution in the near-field (Miller, 2008).

An alternative to the above is to use a number of small nozzle diffusers along the length of the outlet. The small nozzles create jets of fast velocity brine which entrain the surrounding water. The outlet is laid on the bottom of the water body and the jets are aimed upwards. The vertical orientation of the nozzles ensures that the brine does not concentrate on the water body bed but instead entrains water as it rises. As the plume loses velocity the density difference causes additional mixing as the plume falls. Figure 1 shows the near-field operation of a model diffuser nozzle. Ambient ocean currents are relied upon to ensure the plume is taken away from the nozzles diffusing the brine even more as it does so. Consequently, this method of outlet design relies both on near-field and far-field mixing.

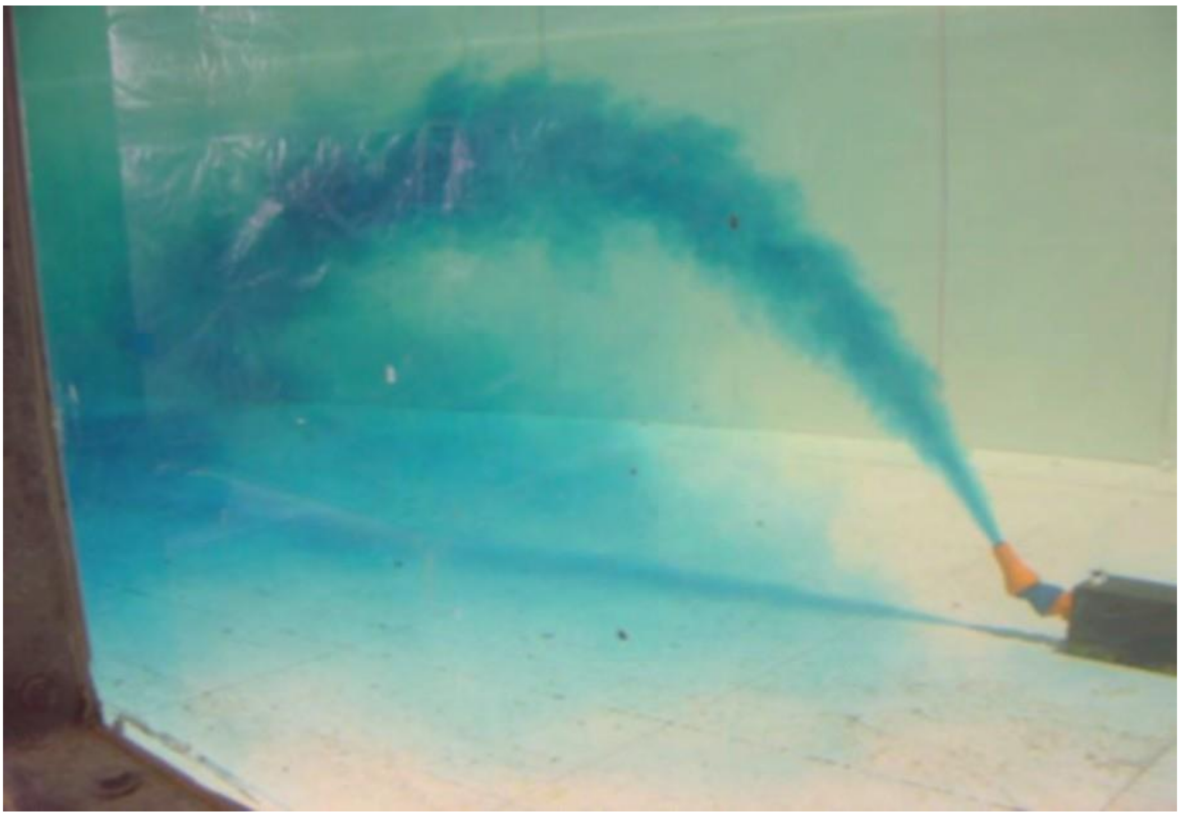

Figure 1. Laboratory model of a desalination brine dispersing in the near-field. SOURCE: WATER RESEARCH LABORATORY, UNSW

The use of rosettes which contain several very high velocity vertical nozzles all aimed in different horizontal directions relies almost solely on near-field mixing. The outlet is tunnelled with riser tunnels leading to the diffusing rosettes. The very high velocities at the rosettes result in a large amount of entrainment and dilution, however due to the close arrangement of nozzles plume interaction is a major consideration (Miller, 2007).

E.4.2 Operational Considerations

The performance of outlets is generally specified in terms of meeting a certain constituent concentration by ensuring sufficient dilution of the brine and ensuring the plume does not intersect the water surface. However the receiving body conditions and plant operation will rarely be constant. Outlet design hence needs to consider all operating conditions and as a minimum, conservative assumptions regarding the receiving environment. A more robust design would be to assign probabilistic dilution targets and perform long-term modelling and statistical analysis to ensure targets are met. Statistical analysis can be performed:

- Analytically – using measured data and known operating procedures to calculate the probability of environmental targets being met.
- Through numerical modelling – running long term scenarios and analysing the results on a statistical basis.
- Using Monte Carlo statistical modelling – running large numbers of scenarios statistically to determine probability distributions of dilution and environmental targets being met.

Changes in operating conditions in the desalination plant will result in both discharge volumes and discharge densities varying as the concentration of salt in the brine changes. These changes in the brine can be a result of:

- plant operation varying from capacity due to fresh water demand changes
- periods of backwash for maintenance
- discharge of produced fresh water.

Decreasing the amount of brine discharged will reduce velocities in the outlet and nozzles and hence reduce dilution. Decreasing the density of the brine being discharged, for example, by the inclusion of backwash, increases the height of rise of the plume, and the plume may intersect the surface.

In order to meet environmental targets due to changes in plant operation the following controls may be used:

- allowing for bypass flow, i.e. ensuring the plant has the ability to add source water to the brine stream to maintain outlet flows and also allow the ability to control the brine density
- using divers to physically cap selected outlet nozzles to reduce the total outlet area to ensure the velocities in the nozzles remain sufficiently high
- using nozzles that have an orifice which decreases in size with reduced flow (duck bill valves) thereby ensuring the velocity does not decrease as substantially.

E.4.3 Outlet Design

The design of outlets for a desalination plant needs to be incorporated into the design of the overall plant as the plant design will govern outlet design. In particular the design of the outlet is constrained by the:

- available hydraulic head (energy)
- water depth of the receiving body
- density difference between brine and receiving water
- geometry of the outlet including the following:
    - diameter and number of discharge nozzles
    - vertical angle of the discharge nozzles
    - horizontal angle between the discharge nozzles
    - spacing between risers
    - height of the outlet above the bed.

There are several competing variables in the design of the outlet (Tarrade, 2010). For example the greater the water depth the greater the dilutions that can be achieved in a closer proximity to the outlet. However, water depth is generally minimised to reduce tunnelling and pipeline costs. Similarly, smaller diffusers will result in larger velocities and greater dilution, but the energy requirements to drive the brine through the diffuser also increase. In general the maximum velocity for the outlets is determined from the available hydraulic head. Then the number of nozzles required to discharge the brine is determined based on achieving target dilutions. This initial design is often performed analytically using empirical relationships. Refinement of the design and verification of target dilution is then carried out by computer or laboratory models of the near-field.

For a single nozzle outlet empirical or numerical techniques may suffice. However, if more than one nozzle is used and plumes are likely to interact, numerical models will often over-predict dilution, necessitating physical model testing of the nozzle configuration. Physical modelling predictions have matched extremely well with field tracer experiments (using fluorescent dye) on the completed outfalls in Sydney (Smith et al., 2011) and Perth. CFD modelling of interacting multiple brine plumes has been attempted, however these methods require extensive computing resources, time and representation of turbulence understanding of turbulence and caution is warranted in their application Examples of physical modelling of different nozzle configurations is presented in figure 2.

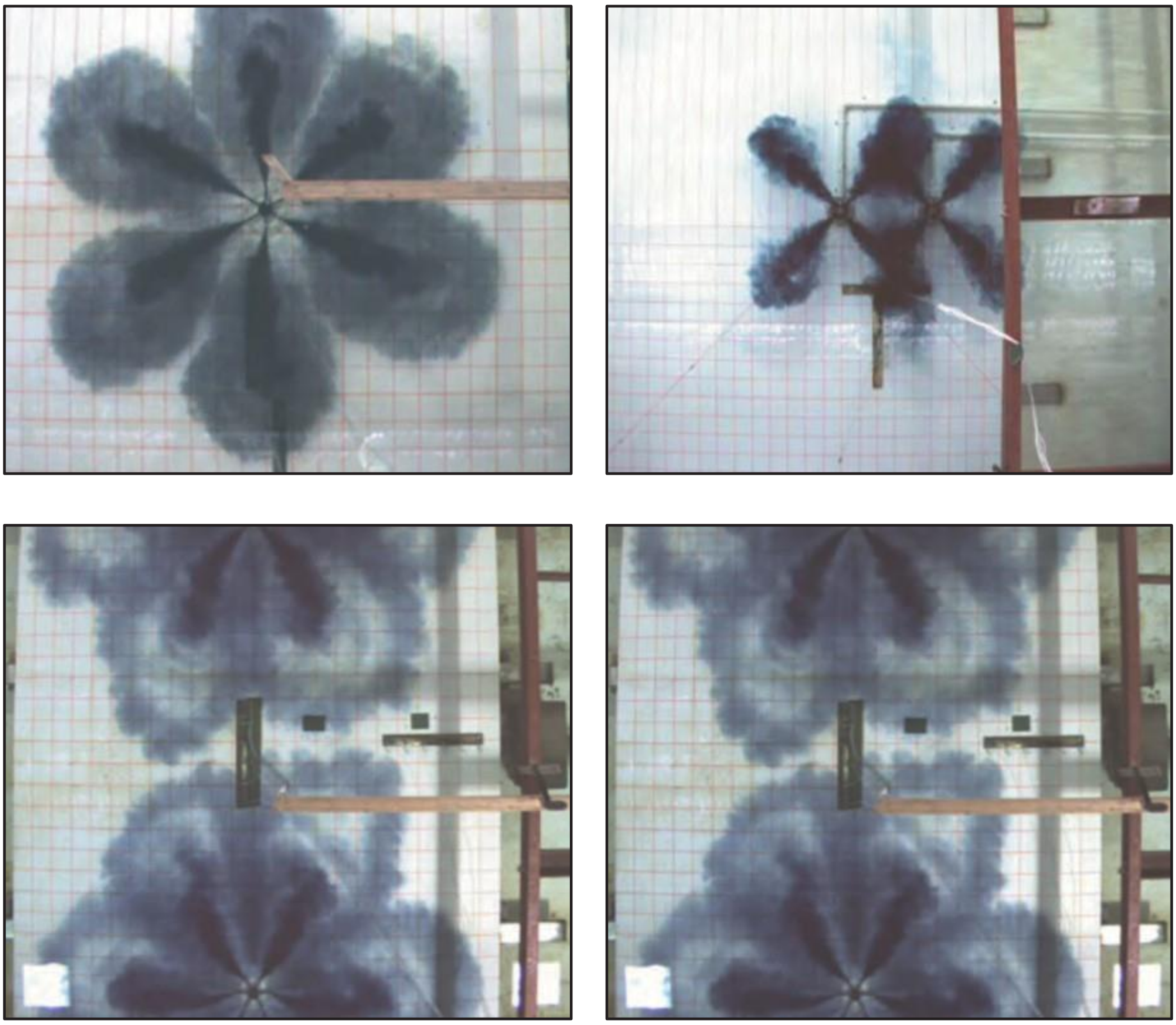

Figure 2. Plan Views of Physical Model Experiments with different Rosette Configurations.

WATER RESEARCH LABORATORY – UNSW

In order to ensure the brine does not concentrate in the receiving water body, far-field numerical modelling is necessary, (Miller, 2005). This will utilise a 3-D hydrodynamic model including baroclinic forcing to predict the movement of the brine as a response to its density as well as temperature and ocean currents. Two dimensional models are not considered appropriate for brine far field modelling as the brine stratifies the water column and can move significant volumes of water from the top to the bottom of water column. Random walk models can also be used to track brine movement through the use of the currents simulated in the 3-D hydrodynamic model. It is generally preferable to dispose of brine into a high energy environment thereby ensuring that dilution and dispersion are maximised and environmental impacts are minimised.

Prediction and modelling of brine movement in both the near-field and far-field requires a comprehensive data collection program prior to the design of the outlets. In summary the design procedure is as follows:

- data collection to determine the receiving water quality as well as the oceanographic conditions
- analytical and empirical design of outlets based on plant operation
- numerical modelling of dilutions and plume movement
- physical modelling of the final design to ensure environmental targets are met.

The outlet pipes need to be designed to ensure that they do not interrupt the longshore movement of sand. In addition the pipes need to be buried at a depth so that they will not be eroded. The design criterion is usually for the pipes to have sufficient cover to prevent exposure in a 1 in 100 year storm.

If hydraulic head loss through riser cap is a concern for the design, physical model testing of the outlet structure for head loss can give reliable estimates. Adding the theoretical individual components of head loss has been found to be a poor estimate of the total head loss.

E.5 A Note on Structural Design and Other Considerations

Although the focus of this supplement is on sustainability issues, structural integrity of the intake and outlet are obviously of vital importance. Apart from the financial loss from structural failure there could also be significant environmental impact.

Often the area where the intakes and outlets are to be constructed are on the open coast in challenging physical environments. As discussed, the outlets and intakes will be in sufficient water depths (say 20 m) to allow for environmental impacts to be minimised and intake water quality optimised, but this leaves these structures exposed to potentially high wave orbital velocities and even breaking waves. Intake structures are likely to have a greater exposure due to their elevation off the seabed and large diameters. Such large intake structures will need to have structural and vibrational analysis undertaken under a range of tides, wave, current and storm conditions.

With such a large investment in the structure, the ocean currents should be assessed by deploying a current meter (such as an ADCP) on the site for a minimum of two months. A suitably configured ADCP will also measure bursts of wave orbital velocities during this period.

Waves will have orbital velocities, oscillating in direction and with short possibly extremely high peak velocities. An experience coastal engineer will need to assess the range of water levels (tide, storm surge and climate change), offshore wave heights and wave periods occurring at the site. The entire “envelope” of conditions should be assessed to determine the worst case conditions for the structure.

Non linear wave theory is an appropriate desktop method for determining wave orbital velocities from non-breaking waves. Predictions using Cnoidal Wave Theory (1st order and 2nd order) as well as Fenton’s Fourier Series Approximation are discussed in the Coastal Engineering Manual (2008).

Solitary Wave Theory (also discussed in the Coastal Engineering Manual) is a desktop estimate of the peak horizontal velocity for a breaking wave. Note, however, that desktop methods are particularly sensitive to the breaker index, which defines the size, depth, and likeliness of breaking waves. While there are numerous desktop techniques to determine the breaker index, with extremely high peak horizontal velocities being possible, physical modelling may be warranted to give significantly more reliable predictions than any of desktop methods.

Physical modelling allows for the direct measurement of currents and forces on a structure under attack from breaking and non-breaking waves. Such flume testing should use random waves to consider the possible coincidence of wave conditions that cause a wave to directly plunge onto the structure. Flume testing allows the designer to better understand the forces and vibrations expected, while also providing greater understanding of the risk that damage will occur.

In Australia, the recently built large intake and outlet desalination structures are yet to experience conditions near their design events so limited knowledge is available of how they will actually perform. However, the experience from many effluent outfalls (Grace, 1978) damaged over many years throughout the world should caution a designer from underestimating these challenging ocean environments.

The ocean currents and wave conditions should also be assessed for the construction period to have a greater understanding of the working periods available for moving barges, having divers operate and to understand the risk of a damaging event happening during construction.

Suitable construction materials are discussed in the Supplement “Materials for Construction”.

E.6 Field Investigations and Data Collection

Investigation and data collection purposes are multiple. Prior to detailed design and construction, they provide information for the design of efficient and environmentally safe intakes and outlets. In addition, investigations need to be carried out to ensure a suitable location for the intakes and outlets is found, and that the location is optimised for minimal environmental disturbance. Post- commissioning, they form a basis for which the correct operation of the plant infrastructure can be verified, as usually required as part of the licensing conditions. These three different purposes for data collection are presented below, however the data collection exercises need not be performed separately as all have similar data requirements.

E.6.1 Intake and Outlet Location

There are competing criteria for desalination plant location, and the optimal location for the intakes and outlets may not dictate the location of the plant. However, once plant location is chosen the intake and outlet location should be optimised within the available constraints. This would involve collecting information on the:

- bathymetry – to identify an appropriate depth for the intakes and outlets
- ecology of the receiving waters – to minimise environmental disturbance

- receiving water bed and water quality – to ensure adequate water quality of the source water
- receiving water flows and currents – to maximise mixing of the brine.

E.6.2 Establishment of a Monitoring Programme

The Marine and Estuarine Monitoring Plan developed by Sydney Water Corporation describes the objective of a data collection exercise for the establishment of a monitoring programme as the following:

"*To provide a comprehensive and robust program of baseline and post-commissioning monitoring of marine and estuarine environmental conditions to confirm quantitatively that there are no adverse effects to the marine and estuarine environment resulting from the operation of the desalination plan*t."

It is important to initially establish a monitoring program prior to desalination plant construction. The purpose of this is two-fold. It firstly allows for the quality of the source water to be established which in turn guides the level and types of treatment required. However, it also allows for background water quality to be established which can then be statistically compared to the water quality post desalination plant commissioning. This will ensure that environmental impacts have been kept below target thresholds. This data collection should not only focus on water quality characterisation but also on ecological assessment such as reef habitat and fish surveys. Sampling to establishing background environmental conditions should be performed in a statistically designed manner to ensure a comparison can be made pre and post desalination plant construction and commissioning. The development of an environmental monitoring program capable of validating the environmental performance of the outlets is an important consideration of desalination plant construction as regulators will require evidence that target environmental considerations have been met.

E.6.3 Detailed Intake and Outlet Design

It is necessary to collect data so that a numerical model of both the intake and outlet can be established to aid design. This numerical model would be used to ensure that short-circuiting of the outlet brine to the intakes does not occur as well as predict outlet performance. For the adequate simulation and modelling of the intakes and outlets, as a minimum, the receiving water needs to have its salinity, temperature and flow fields measured. A detailed bathymetry of the receiving waters is also required. For numerical modelling on a subsurface intake detailed information on the geology of the site, as well as topography, and water quality will be required.

The discharge brine also needs to be categorised for modelling. This requires estimation of the temperature, salinity of the brine as well as the concentration of any likely chemicals to be present. The amount of brine to be discharged needs to be estimated, as well as the likely flow rates. Average flow rates are not sufficient, but rather the entire spectrum of operating conditions needs to be known for detailed prediction of outlet performance.

Any data collection exercise must recognise that the coastal environment is highly dynamic, and hence the source and receiving water properties need to sampled at intervals to measure this natural variability. All measurements must be spatially sufficient to be able to adequately simulate the likely area of impact from the desalination plant intakes and outlets. Likewise the temporal resolution of the data collection needs to be able to adequately capture all natural variability.

E.6.4 Post Construction Performance Monitoring

Post construction the outlet design should be verified as achieving designed dilution levels. Field tracer studies should be undertaken to validate the size of the near-field zone and concentrations post outlet commissioning (Smith, 2011).

It has already been established that the development of an environmental monitoring program capable of validating the environmental performance of the outlets is an important consideration of desalination plant construction as regulators will require evidence that target environmental considerations have been met. This monitoring should continue for the life of the plant in the form of a routine monitoring program. This ensures the successful plant operation is continually monitored and potential issues are proactively addressed. Monitoring of the hydraulic performance of the intake and outlet also will ensure potential problems are identified and addressed readily.

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SUPPLEMENT F
INTEGRATED COASTAL ZONE MANAGEMENT

Adelaide's Living Beaches (SA) Case Study

Adelaide coast south of Adelaide Shores boat haven.

PHOTO: COAST PROTECTION BOARD

This Supplement has been prepared by the National Committee on Coastal and Ocean Engineering (NCCOE) of Engineers Australia, to assist professional engineers in the application and use of the Coastal Engineering guidelines for working with the Australia Coast in an ecologically sustainable way.

INTEGRATED COASTAL ZONE MANAGEMENT

F.1 Introduction

The Australian National Cooperative Approach to Integrated Coastal Zone Management (2006) points out that the fundamental goal of Integrated Coastal Zone Management (ICZM) is to maintain, restore or improve the quality of coastal ecosystems and the societies they support. According to the Framework, a defining feature of ICZM is that it seeks to address both development and conservation needs within a geographically specific place – a single community, estuary or nation – and within a specified time frame. Harvey & Hilton (2006) list the key elements of integration in coastal management as:

Figure 1. Access management, Tennyson Dunes. Photo: Coast Protection Board

- intersectoral integration (horizontal integration) between different government sectors: such as industry, conservation, recreation, tourism, beach protection and integration of policies between different sectors of the economy
- community integration with government producing effective community participation and involvement in coastal management
- spatial integration between management of the land, ocean and coast
- integration between science and management, particularly between different disciplines; scientists and managers; including economic, technical and legal approaches to coastal management
- international integration between nations on trans-boundary coastal management issues.

Any particular project may involve all or just some of these elements.

This supplement describes how the Adelaide's Living Beaches project of the South Australian Government, in partnership with the Coast Protection Board and the Adelaide and Mount Lofty Ranges Natural Resource Management Board, is establishing ICZM across metropolitan Adelaide's coastline. The Adelaide case study provides a template that can be adapted to other regions provided sufficient attention is given to local environment, society and politics.

The Adelaide's Living Beaches Strategy covers an area that extends 30 kilometres and describes management actions being undertaken during the period between 2005 and 2025. The main purpose of the Strategy is to ensure the long-term future of Adelaide's sandy beaches through five main components:

1. maintaining beach replenishment
2. recycling sand more effectively using a pipeline Sand Transfer Infrastructure system
3. adding coarse sand from external sources
4. using coastal structures in critical locations
5. integrating sand bypassing at harbours with beach management, thus reducing the impact of coastal management on beach users and seaside residents, as well as the remaining coastal ecosystems.

The project is instrumental in achieving the following objectives of ICZM in metropolitan Adelaide:

Improving coordination and horizontal integration among levels of Government (local, regional and State)

The management of Adelaide's beaches is integrated with harbour management by bringing two different agencies' responsibilities under one project. The seagrass rehabilitation aspect of the project enables better coordination and integration of initiatives on stormwater management and sewage treatment – effluent disposal between different agencies and a regional body due to the common interest in maintaining healthy coastal ecologies, particularly seagrass.

Figure 2. Mutton Cove Conservation Reserve, Lefevre Peninsula. Photo: Coast Protection Board

Establishing land uses and guidelines to achieve conservation of remaining coastal ecosystems

whilst undertaking coastal protection works.

The Adelaide coastline has limited opportunity to conserve coastal ecosystems, as the majority of the coastline has a sand dune width limited to little more than about twice the one in a hundred year exceedance probability storm erosion take. Conservation is encouraged on the understanding that the dunes must be considered ephemeral.

The contribution to better land use and planning is derived from the understanding that coastal protection works rely on sand dunes being maintained as the primary benign means of protecting foreshore property, and maintaining recreational beach width. Rock protection walls are used as the last line of defence against the hazards of erosion and flooding. The Development Act 1993 and associated Coast Protection Board powers are the most effective legislative instruments to preserve these areas.

Figure 3. Sand carting by truck for beach replenishment.
Photo: Coast Protection Board

Integrating management activities that impact on coastal processes

The management of Adelaide's beaches is undertaken in a holistic manner, taking account of all of the coastal processes operating over the length of the metropolitan coast. The management of the coast under the umbrella of the Coast Protection Board has replaced the past sectoral-based management undertaken by local councils. Adelaide's Living Beaches Strategy is ensuring that this holistic approach continues as the pressure of sea level rise increases.

Beach replenishment is used as the primary protection method to make the best use of the finite sand supply for the whole coast. Additional sand from external sources is planned to be regularly placed into the beach system to

Figure 4. Communication stand demonstrating information kits and supporting resources available for Reception t Year 12 and tertiary education levels Photo Coast Protection Board

counter the impact of sea level rise by maintaining beach and dune volumes. The grain size of imported sand is being researched to ensure that the best value for money is achieved to withstand cross- shore and along-shore sand movement, whilst maintaining other beach qualities such as safe bathing conditions and beach infauna. The sand grain size will also have an impact on the sand pumping characteristics for the Sand Transfer Infrastructure, which will be constructed in 2011, and this aspect is expected to change over the 20 year design life.

Providing up-to-date information, technical and educational services to various stakeholders.

State, regional and local governments have been active in providing general coastal information to the public through a variety of avenues, including beach signage, information booklets, web sites and involvement in local events. Organisations such as the Geography Teachers Association, Science Alive and the NGO – Marine Discovery Centre are supported with funding and information. Project representatives attend seminars for teachers as a way of ensuring coastal education of future generations.

Figure 5. Seagrass restoration trials – monitoring seedling growth
Photo: Coast Protection Board

Establishing restoration and rehabilitation of critical coastal habitats (seagrass and sand dunes) through partnership between different institutions.

Over the last half century, seagrass has retreated by up to 2 kilometres through impaired water quality from the discharges of sewage treatment works and stormwater systems.

Expanding knowledge and understanding of coastal processes and ecosystems through research. Over the last four decades the State government conservation agency has been researching coastal processes

Over the last four decades the State government conservation agency has been researching coastal processes relating to the Adelaide coast. The knowledge developed has enabled the decision making process for beach replenishment operations to be made responsively and effectively for protecting the foreshore and maintaining beach amenity.

More recently, the Adelaide and Mount Lofty Natural Resources Management Board has initiated further research into local reef health in collaboration with the university. Investigation work is also being undertaken between the State government conservation agency and university on the impact of beach replenishment on beach infauna.

Figure 6. Adelaide Coast Protection Strategy Review 1984. Photo: Coast Protection Board

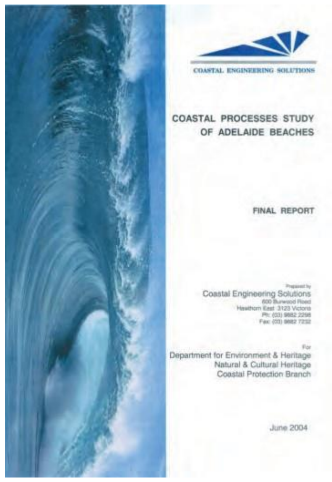

Figure 7. Quantifying Adelaide Coast Protection Alternatives 1. Photo: Department of Environment and Heritage

F2 Lessons for other applications

F2.1 General principles for ICZM

The following text describes principles for ICZM, according to the RAC Coastal Zone Inquiry (1993), which the Adelaide Living Beaches Project is applying:

Strategic assessment and decision making – environmental, economic, social and cultural values of coastal resources have been identified, and the effects on those values have been determined, as far as practicable, before decisions about resource uses are made; use of coastal resources are being monitored to ensure assumptions made for impact assessments are correct.

Allocation of costs and benefits – the costs arising directly from use of coastal resources are being borne by users rather than by society as a whole.

Public participation – Effective and high-quality public consultation and participation is being encouraged before decisions are made, and approvals to proceed are obtained. Public involvement in the development of strategies and the detailed proposals for implementing them has proven to be paramount for gaining acceptance. The value of widespread public engagement cannot be underestimated, but a distinction must be clearly made up front on whether they are information or consultation sessions. At some point of course a decision has to be made as to whether a project proceeds and in what form. Public participation can be effective even after this stage, particularly in the monitoring programs and in sharing responsibility for management of local coastal resources both natural and cultural.

Sustainable use of resources – The interdependence of terrestrial and marine systems and the need to conserve their biological diversity and natural processes are taken into consideration in the use of coastal resources; the desirability of maintaining natural habitats and sites of ecological, cultural, archaeological, historic and scientific significance are taken into account. Where resources such as sand and gravel, minerals, etc. are exploited, they must be managed in an ecologically and environmentally sustainable way. Coastal stability must not be compromised, ground and surface water must not be polluted, heritage sites must be respected and biodiversity needs to be maintained.

Public access – public access to the coast is being maintained and enhanced for recreation and other public activities. From the earliest days of settlement and survey of South Australia's coastal and riparian environment, provision has been made for public access. However, this is often under threat of loss due to erosion or private development gaining access to these public frontages or denying public improvements such as coastal pathways. Vigilance is required to maintain the public right of way.

Coastal discharges – the disposal of liquid waste (wastewater, desalination brine, stormwater etc.) is being limited to the quantity and quality that the receiving environment can assimilate without suffering long-term degradation. (See Supplements C and E of these Guidelines). The priority of governments should be to reduce the level of contaminants discharged by reducing the thresholds allowable and improving management of all such discharges, including, where possible, their complete elimination through, e.g. re-use.

F.2.2 *Mistakes to be avoided*

The management of Adelaide's coast over the last four decades has demonstrated the need for maintaining a record filing system that can be easily accessed to draw on past experience. Rigorous attention to the induction of new personnel is necessary to achieve the full benefit of such a system. For example, good records of rock revetment construction can avoid future costly investigations to determine the integrity of protection works.

The temptation to leave the supervision of coastal works to personnel with only a general or peripheral knowledge and experience of such work has often led to inadequate construction resulting in later costly collapse.

Linking projects that have some commonality, such as utilising the same coastal corridors, can sometimes be unproductive if one of the projects has significant public opposition. The benefit of such cooperation needs astute assessment.

F.2.3 *Importance of public participation*

Public participation in the development of strategies and the detailed proposals for implementing them has proven to be paramount for gaining acceptance. The value of widespread public meetings to provide information on approved works cannot be underestimated, but a distinction must be clearly made up front on whether they are information or consultation sessions.

F.2.4 *Importance of understanding natural processes including extreme events and climate change*

Access to scientific and engineering knowledge and experience for making informed decisions not only results in optimum proposals for public consideration, but is often later relied upon to provide rigorous support of integrity in the ensuing political debate.

Climate change increasing relies on robust and adaptable solutions to coastal hazards because of the likely changing coastal processes. Benign actions such as beach replenishment, rather than coastal structures are often more resilient and readily adjustable. It is for this reason that beach replenishment is the mainstay of Adelaide's protection strategy (Townsend and Guy 2017). The means of achieving this is in part through a pipeline Sand Transfer Infrastructure which has been designed to deliver a broad throughput of sand volume and variable sand grain size.

F.2.5 *Importance of data programs*

From the start of the Adelaide protection strategy in 1972, the works have been underpinned by an extensive beach and seabed monitoring program. This has enabled:

- regular assessment of protective sand dune buffers to development
- assessment of walkable beach widths for monitoring beach amenity
- mapping bathymetry for modelling coastal processes
- identifying areas of seabed stability for potential seagrass restoration sites
- providing well researched information on long term coastal process changes to the public to support strategy development and coastal works programs.

Inevitably over the years the monitoring program has come under a number of funding reduction demands. The critical scrutiny has on occasions refocussed the program with improvements but, of importance, the program has required robust defence to maintain its valuable longevity for informed decision making.

F.2.6 *Issues beyond the case study*

While Adelaide's Living Beaches case study encompasses many aspects of ICZM, it does not touch on all. The Australian Government's National Cooperative Approach to Integrated Coastal Zone Management (Natural Resource Management Ministerial Council, 2006), proceedings of workshops or monographs both international and national provide exposition of these broader issues. The reader is referred to European Commission (2010) and Lazarow et al. (2006) in particular for discussion on many of the challenges for coastal planning and management. The perspectives provided in these and other similar publications should permit an organisation embarking on ICZM within their jurisdiction to judge the applicability of the lessons learned from the Adelaide case study and what additional considerations may be needed.

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