



Engineering solutions for coastal infrastructure

Information Manual 7

**Published by the National Climate Change
Adaptation Research Facility 2016**

ISBN: 978-0-9946053-6-8

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Please cite this Manual as:

Webb, T., 2016: Engineering solutions for coastal
infrastructure. CoastAdapt Information Manual 7,
National Climate Change Adaptation Research Facility,
Gold Coast.

Acknowledgement

This work was carried out with financial support
from the Australian Government (Department of the
Environment and Energy).

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Engineering solutions for coastal infrastructure

Information Manual 7

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Australian Government

Department of the Environment and Energy

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Preface

In 2014, the National Climate Change Adaptation Research Facility (NCCARF) was commissioned by the Australian Government to produce a coastal climate risk management tool in support of coastal managers adapting to climate change and sea-level rise. This online tool, known as CoastAdapt, provides information on all aspects of coastal adaptation as well as a decision support framework. It can be accessed at www.coastadapt.com.au.

Coastal adaptation encompasses many disciplines ranging from engineering through to economics and the law. Necessarily, therefore, CoastAdapt provides information and guidance at a level that is readily accessible to non-specialists. In order to provide further detail and greater insights, the decision was made to produce a set of Information Manuals, which would provide the scientific and technical underpinning and authoritativeness of CoastAdapt. The topics for these Manuals were identified in consultation with potential users of CoastAdapt.

There are ten Information Manuals, covering all aspects of coastal adaptation, as follows:

1. Building the knowledge base for adaptation action
2. Understanding sea-level rise and climate change, and associated impacts on the coastal zone
3. Available data, datasets and derived information to support coastal hazard assessment and adaptation planning
4. Assessing the costs and benefits of coastal climate adaptation
5. Adapting to long term coastal climate risks through planning approaches and instruments
6. Legal risk. A guide to legal decision making in the face of climate change for coastal decision makers
7. Engineering solutions for coastal infrastructure
8. Coastal sediments, beaches and other soft shores
9. Community engagement
10. Climate change adaptation planning for protection of coastal ecosystems

The Information Manuals have been written and reviewed by experts in their field from around Australia and overseas. They are extensively referenced from within CoastAdapt to provide users with further information and evidence.

NCCARF would like to express its gratitude to all who contributed to the production of these Information Manuals for their support in ensuring that CoastAdapt has a foundation in robust, comprehensive and up-to-date information.

1 Context and content

Engineers have long been at the forefront of climate change adaptation practice in the coastal zone. Working together with other professionals, they have been and continue to be responsible for designing and building coastal infrastructure as well as being engaged in coastal planning, design and management. This CoastAdapt information manual summarises engineering functions and organisations and the roles they have played and continue to play in the coastal environment. It should be read in conjunction with the other information manuals in CoastAdapt, as sound engineering decisions cannot be made without solid understanding of climate change processes and other hazards (Figure 1); interaction with the environment, policy, planning and legal frameworks; and the need to engage the community.

A particular focus of this information manual is a series of three coastal engineering guidelines issued by Engineers Australia's National Committee on Coastal and Ocean Engineering (NCCOE). These guidelines provide – not only for coastal specialists, but also for related professionals – methodologies, recommendations and sources of information especially relevant to CoastAdapt. There are several other bodies within or affiliated to Engineers Australia that have a role in this space as described in the following box.

This manual provides information about the following topics:

- the role engineers play in adapting coastal infrastructure and developments (existing or planned) to the possible impacts associated with climate change
- the three coastal engineering guidelines issued by NCCOE on climate change and the broader topic of sustainability
- other standards, codes and guidelines of relevance
- what coastal planners and managers can do to ensure sound engineering practice is adopted, taking into account the effects of projected changes in climate
- some of the traps associated with inappropriate action
- how to decide whether coastal engineering expertise is required
- where to find such expertise.



**ENGINEERS
AUSTRALIA**

Engineers Australia is the national forum for the advancement of engineering. Amongst its many functions is the issuing of policy statements and guidelines. Relevant

groups within its structure include the Environmental Engineering College, the Sustainable Engineering Society and, within the Civil Engineering College, the National Committee on Coastal and Ocean Engineering. There are many other groups within or affiliated with EA that are also relevant – see website www.engineersaustralia.org.au.

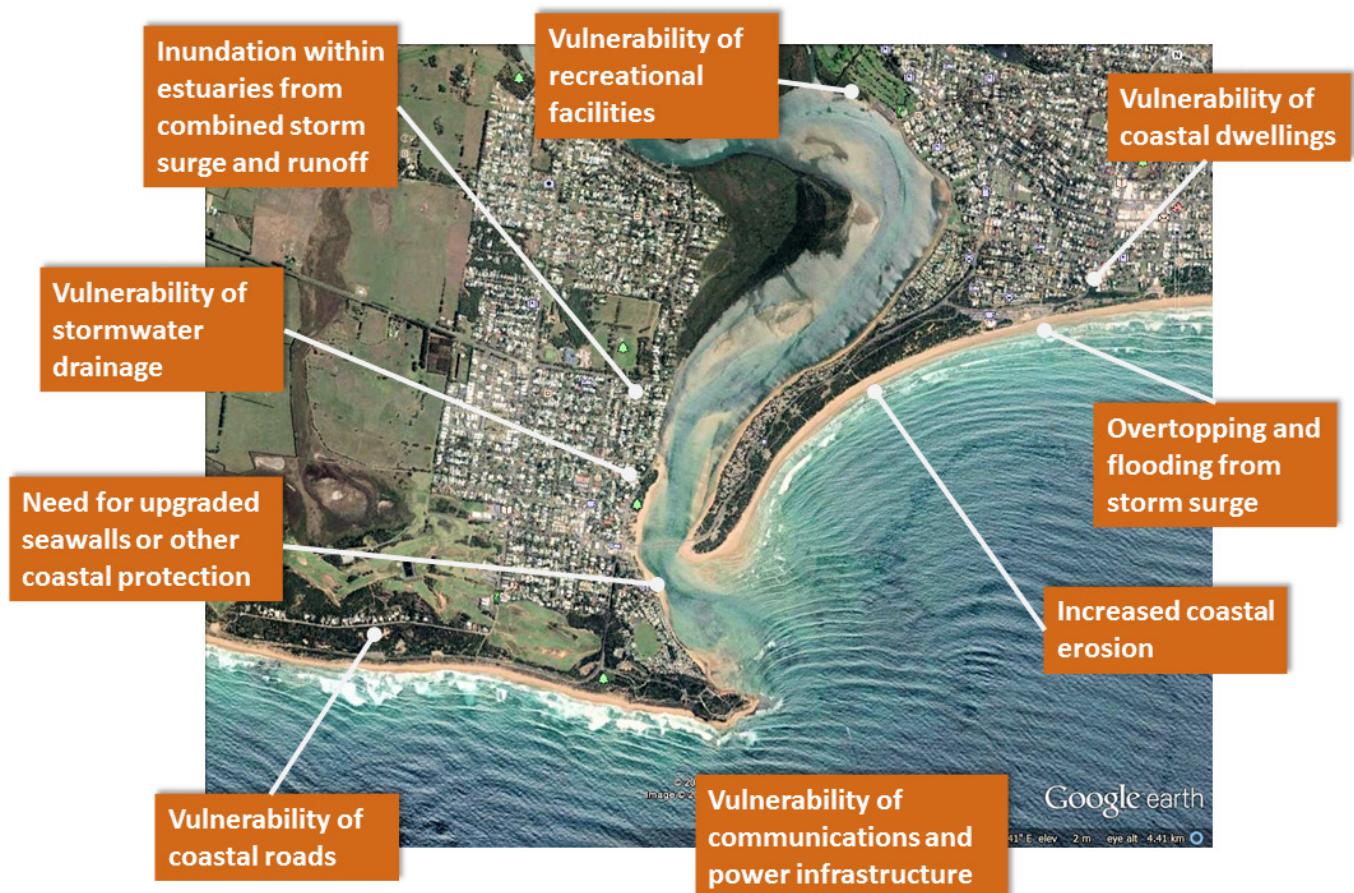


Figure 1: Some issues of relevance to a small coastal community. Source: ©Google Earth.

Disclaimer: The site has been chosen for illustrative purposes only. The issues depicted may not be present at this specific community.

2 What is the issue? Why is it important?

Engineering is central to key objectives of local government bodies (of which there are some 200 around coastal Australia) – including land-use planning, infrastructure resilience, community safety, and maintenance of coastal assets such as beaches, dunes, headlands, lagoons, reefs and estuaries. Information manuals 1 and 2 of CoastAdapt establish the need to consider climate change for coastal projects and detail the future scenarios regarding sea-level rise and changes to, for example, storminess and precipitation. Aside from the more obvious impact of sea-level rise, there are also possible impacts from changes to rainfall, wind and wave climate and ocean currents. Of the many issues relevant to coastal authorities

(an Engineering Australia guideline discussed below lists over 80), some are particularly pertinent to smaller coastal communities. Some of the more common ones are depicted in Figure 1.

Engaging engineering expertise is essential if any significant works are to be considered. Engineers' input is also valuable for non-engineered solutions because of the expertise they bring to project management and the facility they have in drawing together diverse resources to achieve a goal.

Among the many types of engineers are a group of dedicated specialist coastal and ocean engineers whose skills are particularly applicable to this problem.

Other specialist engineers who may work in this area include environmental engineers, geotechnical engineers, structural engineers and civil engineers, many of whom work across more than one discipline.

The body within Engineers Australia representing the specialisation of coastal and ocean engineering (NCCOE) has produced a series of three guidelines aimed at assisting engineers and other professionals with coastal responsibilities. They are:

1. ***Guidelines for Responding to the Effects of Climate Change in Coastal and Ocean Engineering*** (NCCOE 2012a) (short title – NCCOE 1: Climate Change Guidelines)
2. ***Coastal Engineering Guidelines for working with the Australian coast in an ecologically sustainable way*** (NCCOE 2012b) (short title – NCCOE 2: Sustainability Guidelines)
3. ***Climate Change Adaptation Guidelines in Coastal Management and Planning*** (NCCOE 2012c) (short title – NCCOE 3: Adaptation Guidelines).

Each of these is now discussed in turn, detailing for whom they are intended, what is in them and how they may be used. (Some of this is adapted from Webb et al. 2014).

What is a specialist coastal and ocean engineer?

- has tertiary qualifications from a recognised institution with courses in coastal and ocean engineering
- is registered with Engineers Australia as a Chartered Professional Engineer (CPEng)
- has State registration where applicable (e.g. Registered Professional Engineer of Queensland)
- has experience in one or more of the sub-disciplines of coastal and ocean engineering

A more complete description is given in Appendix B of Guidelines for Responding to the Effects of Climate Change in Coastal and Ocean Engineering (NCCOE, 2012a).

2.1 NCCOE 1: Climate Change Guidelines

Intended reader: The first guideline (NCCOE 2012a, originally published in 1991, now in 3rd edition) is intended to assist the specialist coastal or ocean engineer considering climate change impacts in the design of coastal and offshore structures.

Content: These guidelines (Figure 2) begin with a summary of the scientific basis of climate change based on the Intergovernmental Panel on Climate Change (IPCC) reports and other studies specific to Australia. It describes impacts and vulnerability in the coastal zone and sets out possible adaptation strategies, translated into the Australian context. The heart of the guidelines is a risk-based methodology for impact assessment. Suggestions are provided for direction of research and monitoring.

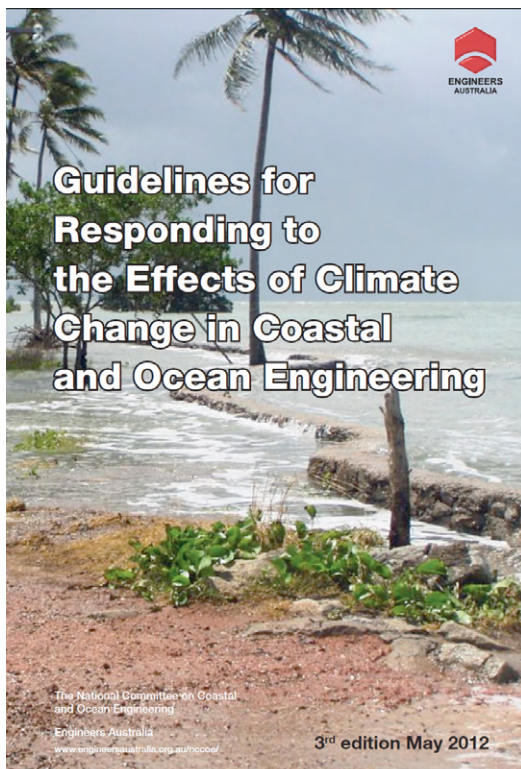


Figure 2: Cover of NCCOE 1: Climate Change Guidelines. Source: NCCOE 2012a (© Engineers Australia 2012).

Methodology: Engineering activities in the coastal zone include structures, beach management, port facilities, protection works and canal estates in just about every type of coastal environment (estuaries, shoreline, nearshore and offshore). The guidelines list some 80 coastal engineering activities potentially affected by climate change.

A methodology for assessment is based on identifying, for any particular activity, key environmental variables to be considered from a choice of mean sea level, ocean currents and temperature, wind climate, wave climate, rainfall/runoff or air temperature. Australian scenarios are given for each of these, including a comment on variability and uncertainty. From these a larger list of secondary (or process) variables is provided to convert the key environmental variable into the local or project-specific context. Examples include local sea level, foreshore stability and coastal water quality.

A risk-based decision flow chart, a simplified version of which is given in Figure 3, indicates the steps to be taken for incorporating climate change scenarios in coastal engineering design processes.

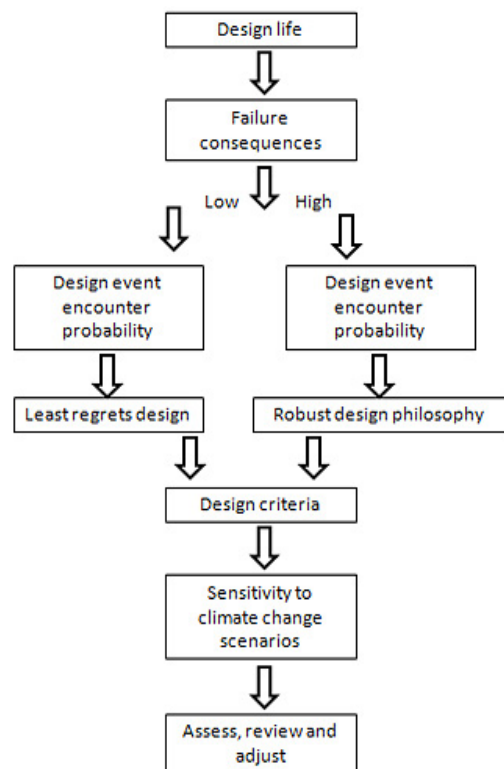


Figure 3: Recommended engineering impact assessment procedure. Source: Adapted from NCCOE 2012a

Worked example: Tourist resort development at a river entrance on the south-west coast, WA

The imagined resort encompasses beachfront luxury villas, high rise hotels, a marina inside the river entrance, restaurants and boutique shops. The ocean is sometimes subject to severe storms, and the river catchment suffers extreme rainfall from time to time. Many of the climate change issues illustrated above in Figure 1 may be present.

Disclaimer: The coastal development depicted in Figure 4 is actually residential rather than a tourist resort and is included for illustrative purposes only

Design life: A major development such as this would typically have a design life of 50 years.

Failure consequences: Destruction of any of the buildings or infrastructure such as marinas would have major economic impact. A slow loss of amenity or need to upgrade due to sea level rise or increased terrestrial flooding would also have financial implications. A particular issue of concern is the performance of stormwater infrastructure, which is sensitive to both increased storm run-off and rising sea level. (Although water supply has been reducing in south-west WA projections of extreme events indicate increased intensity of severe events. Sea-level rises have been above the global average [DoE 2016].) Environmental degradation is also possible, as could be loss of life from, for example, storm surge. This consequence would be classified as 'high' at least for the major structures, facilities and evacuation pathways.

Design event encounter probability: The high risk elements would have a low encounter probability, say 5%. (Such a choice may be dictated by local or state regulations; the reader should ensure they are with these.)

Design philosophy: For the high risk elements, a robust design philosophy would indicate incorporating redundancy (e.g. multiple evacuation options) and gradual failure mechanisms as opposed to catastrophic failure (e.g. sacrificial seawalls) and overdesigning structures that may have to be raised/strengthened in the future.

Design criteria: The combination of 5% encounter probability during a 30-year design life means that a 500-year return period should be chosen for exposure to destructive wave/wind/flooding forces. (Details for such calculations are given in NCCOE 2012a.)

Sensitivity to climate change scenarios: The most recent IPCC report, together with Western Australia-specific literature, should be consulted to assess possible variations in water level, winds, waves and other relevant variables. Sensitivity to these changes needs to be assessed. For example, it should be noted that stormwater infrastructure performance can be sensitive to even small changes in sea level.

Assess, review and adjust: The proposed design should be checked against the climate change scenarios and accommodated as required. Such accommodation may include strengthening seawalls, providing ready access for machinery should beach sand replacement be required, improving evacuation routes, incorporating a lock at the entrance to the marina that could double as a storm surge barrier and allowing for future construction of dykes and stormwater storage and pumping facilities.



Figure 4: A beachside development in Western Australia. Photo: Tony Webb

2.2 NCCOE 2: Sustainability Guidelines

Intended reader: The second NCCOE guideline (NCCOE 2012b) was written to address the broader issue of sustainability, for which climate change is only one of many issues (Figure 5). While the first volume was intended for the coastal specialist, this document recognises the broader range of professions responsible for decisions affecting the coastal zone: managers, planners and scientists as well as coastal and ocean engineers.

Content: These guidelines provide a foundation by describing the Code of Ethics of Engineers Australia (Engineers Australia 2010) from which flows the Sustainability Policy (Engineers Australia 2014a) and the Climate Change Policy (Engineers Australia 2014b). The geological, geographical and ecological features of any site must be fully understood before any development is considered; to this end, a generic methodology is given for incorporating sustainable principles applicable to any type of development for any coastal region in Australia. Any such development must be carried out within the context of national and state policy frameworks; an appendix summarising these is included. Six supplements provide more detail

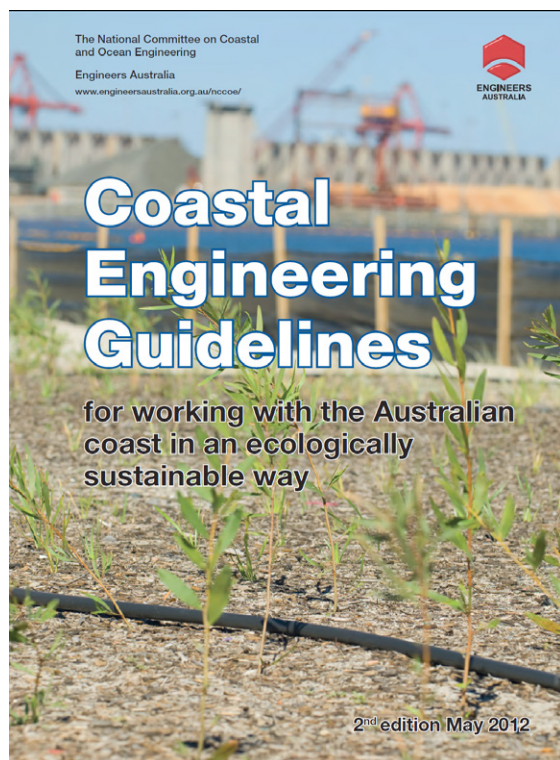


Figure 5: Cover of NCCOE 2: Sustainability Guidelines. Source: NCCOE 2012b (© Engineers Australia 2012).

on particular topics namely: beach replenishment, marinas, outfalls, materials, desalination and integrated coastal zone management.

Methodology: The heart of these guidelines is the section on coastal engineering methodology, which takes the reader through the various phases of an engineering project, including conceptual design, data collection, modelling, detailed design, contract preparation, construction, operation, performance monitoring and decommissioning. At each stage (and elsewhere in the guidelines) checklists act as memory joggers aimed at ensuring proper consideration is given to all aspects of sustainability including, of course, climate change. An example checklist (one of 14) is given in Figure 6.

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?

Figure 6: Example checklist from NCCOE 2: Sustainability Guidelines. Source: NCCOE 2012b (© Engineers Australia 2012).

Case Study: Tilba Road NSW – What can happen without attention to sustainability

As coastal communities established on Australia's coastlines, roads were developed to overcome difficulties operating in the frequent poor conditions at some of the ports. Such roads built in the nineteenth century – obviously without today's planning controls – have not always stood the test of time. One such example is the former main link for

bringing produce such as cheese from Tilba and gold from Wallaga Lake to the wharf at Bermagui. This road, on a narrow strip of dune between the sea and a coastal swamp, was often overwashed by sea spray. Despite being sealed in the 1960s, the road finally succumbed to erosion in storms of 1971 and 1975 (Figure 7). Although the road served a useful function for over a hundred years, this exemplifies the danger of constructing infrastructure in vulnerable areas.

It should be noted that much major infrastructure utilises the public coastal lands. Not only roads, but also stormwater and wastewater run through or along the back of beaches. These can be exposed and damaged in major storms.

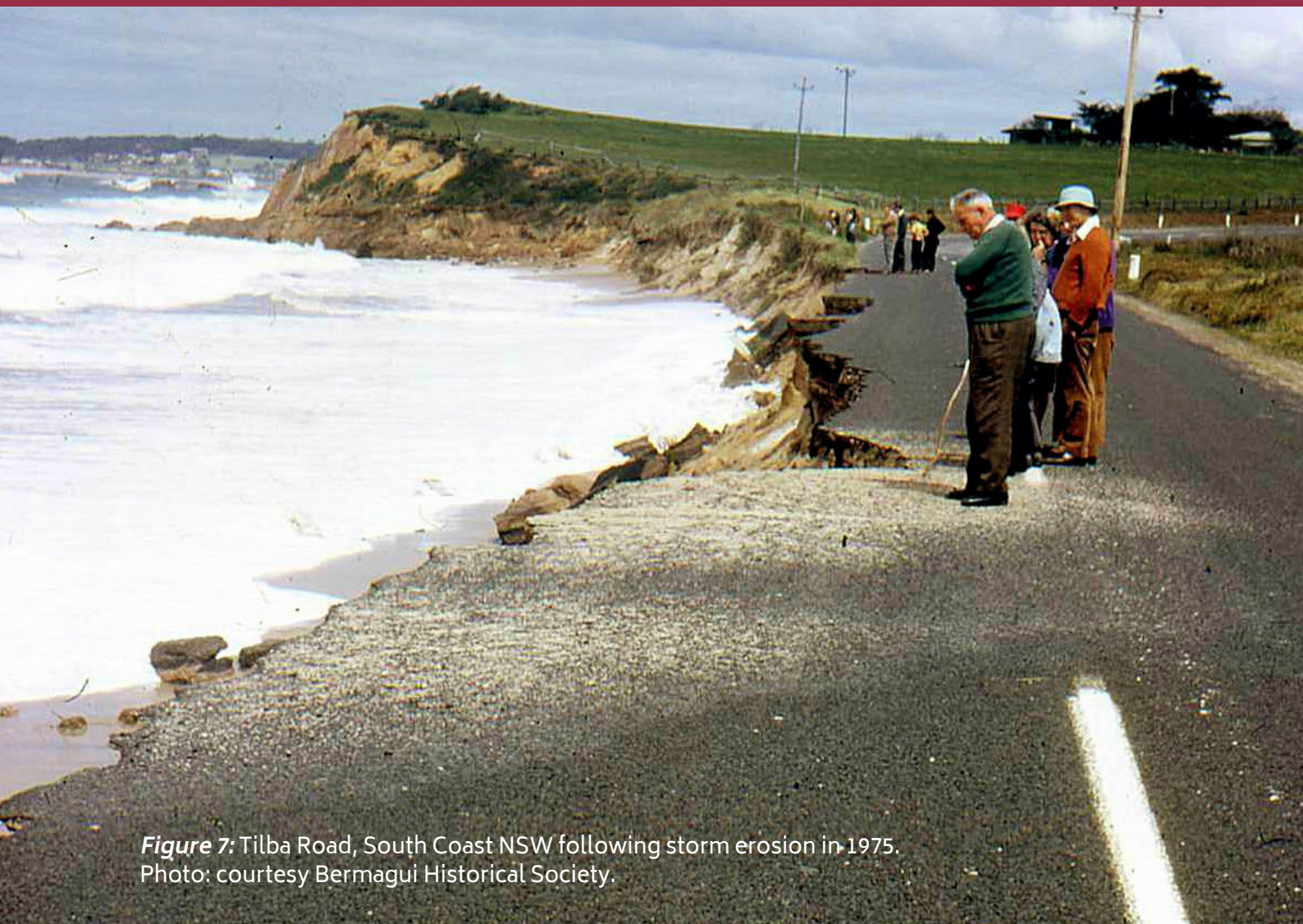


Figure 7: Tilba Road, South Coast NSW following storm erosion in 1975.
Photo: courtesy Bermagui Historical Society.

2.3 NCCOE 3: Adaptation Guidelines

Intended reader: Reader feedback from the first two NCCOE Guidelines suggested a need for an engineering guide for non-specialist engineers, local government engineers, managers and planners as well as elected representatives and interested members of the general public.

Content: The third guideline (NCCOE 2012c) (Figure 8) expands on concepts introduced in NCCOE 1: Climate Change Guidelines, particularly the engineered options to mitigate hazards arising from climate change. While placed within the broader context of planning-based solutions, the focus is on constructed works that are the particular province of engineers. Those options include:

- **shoreline options:** seawalls, beach nourishment, groynes
- **offshore options:** breakwaters (attached and detached), submerged artificial reefs
- **estuary options:** storm surge and tidal barriers, entrance breakwaters, training walls, dredging, sand bypassing
- **emerging technology and novel approaches:** multipurpose artificial reefs, natural defences, beach groundwater manipulation.

(A description and examples of some of these structures are given in the appendix of this information manual of CoastAdapt.)

Methodology: One of the aims of these guidelines is to demystify some of the jargon that people working for a local government authority might encounter and improve their understanding of options they can take when offered some unproven 'solutions', such as dewatering. Several tabular comparative summaries and checklists provide a ready reference to assist the decision-making. The example checklist (Figure 9) applies to 'emerging technology and novel approaches'. For many options, the advantages and disadvantages are summarised and they are placed within the broader context of planning approaches that would include other non-engineering options such as relocation and strategic land-use planning.

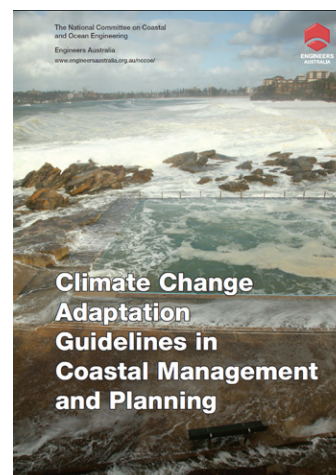


Figure 8: Cover of NCCOE 3: Adaptation Guidelines. **Source:** NCCOE 2012c (© Engineers Australia 2012).

Check List: Emerging Technology and Novel Approaches

- Is there a sound basis in physics for the new technology to perform in the manner claimed?
- Has the proposed technology been applied in the field?
- Where and what were the design wave and water level conditions?
- Did it perform as expected?
- Was the intervention independently monitored? For how many years?
- What is the cost compared to a traditional intervention?
- How would it perform during a storm event?
- Is scouring at the base likely?
- Is settlement expected?
- What is the design life?
- What is the design event?
- What is the durability of the material?
- Are there any adverse impacts on adjacent foreshores?
- How adaptive is it to sea level rise and climate change?
- What is the cost of removal in the case of failure?
- Will there be a hazard to the public?
- Will there be a hazard to the environment?
- Any public liability issues?

Figure 9: Example checklist from NCCOE3: Sustainability Guidelines. **Source:** NCCOE 2012c. (© Engineers Australia 2012).

Worked example: Townsville Hazard Adaptation Strategy – Townsville North (GHD 2012)

A pilot project undertaken by GHD and national, state and local government authorities explored the impacts of extreme events and climate change to the year 2100 for Townsville and the surrounding coastal communities. The main objective was to assist the local authorities with their decisions regarding responses to those hazards. The key components included identifying regions at risk from inundation and coastal erosion, assessing the vulnerability and risk to key Council and community assets, developing adaptation options and assessing the viability of those options through stakeholder engagement and economic assessment.

One of the 23 districts studied was the industrial area of Townsville North. The starting point for any such study is a thorough understanding of the physical processes leading to the threat of inundation and coastal erosion. In this case, several detailed studies had already been conducted into the combined effect of tides and storm surge (Figure 10).

By comparing the results of those studies and exhaustive surveys of the properties in the district, it is possible to assess the impact. For example, from tide alone – including projected sea-level rise of 0.8 m to 2100 – over 250 properties in North Townsville are predicted to be potentially inundated by the Highest Astronomical Tide (HAT). Additional risk was identified for land inundated by more than 1 m of depth during a defined storm event taken as a 1% annual exceedance probability in 2100. Erosion-prone areas were also included in maps of such high hazard areas.

The result is a series of maps for property and infrastructure showing levels of risk defined as acceptable/tolerable/unacceptable. The example in Figure 11 shows unacceptable risk to airport, wastewater treatment plant and some beachside and marina facilities.

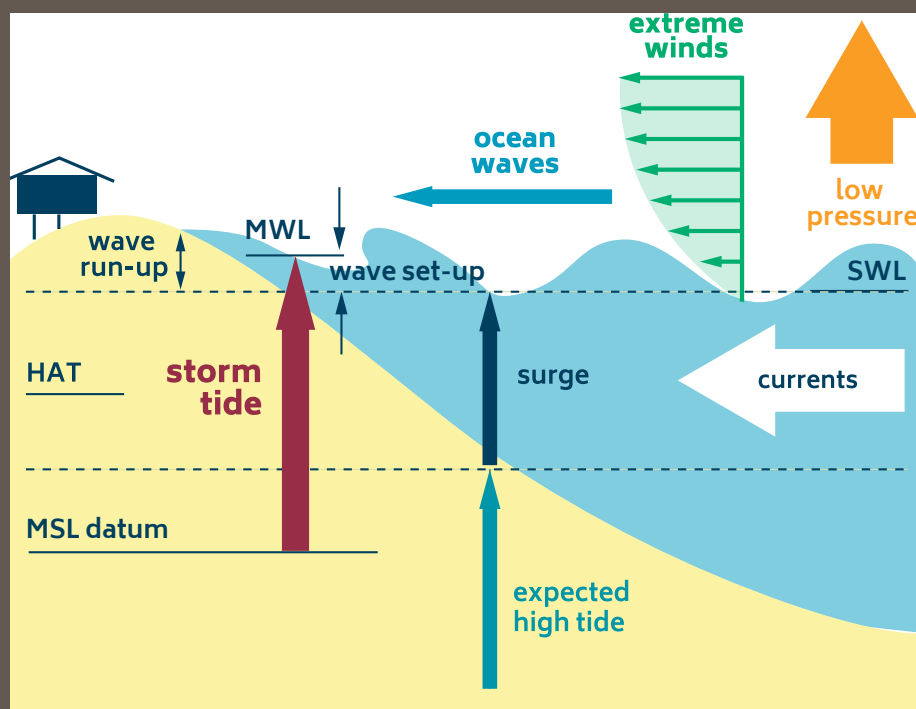


Figure 10: Water level components of an extreme storm tide. Source: After Harper 2001.

Worked example: Townsville Hazard Adaptation Strategy – Townsville North Continued

Options for adaptation include defend, accommodate, retreat or maintain the status quo. Choices between these depend on economic analysis together with community consultation. Using a combination of multi-criteria analysis (MCA) and cost-benefit analysis (CBA), the study was able to compare the relative merits of the various adaptation options.

From the MCA it was determined that the preferred option for infrastructure was to defend. Defending options were then examined in detail using CBA, incorporating statistical simulation of thousands of years of potential storm tide impacts, including sea-level rise. Defending the infrastructure and

property in Townsville North was found to have a significant positive net value. Sensitivity analyses were undertaken for discount rate, sea-level rise projections and population growth assumptions. An example of the defence options is a seawall surrounding the wastewater treatment plant (Figure 12). For other areas, defence structures include sea levees and storm tide barriers. For many areas, the preferred option is to retreat, with land purchase and resumption, or maintain the status quo, including letting nature take its course. It should be noted that this was a pilot study and hence a first step in a continuing process to find the optimum adaptation strategy in the future.

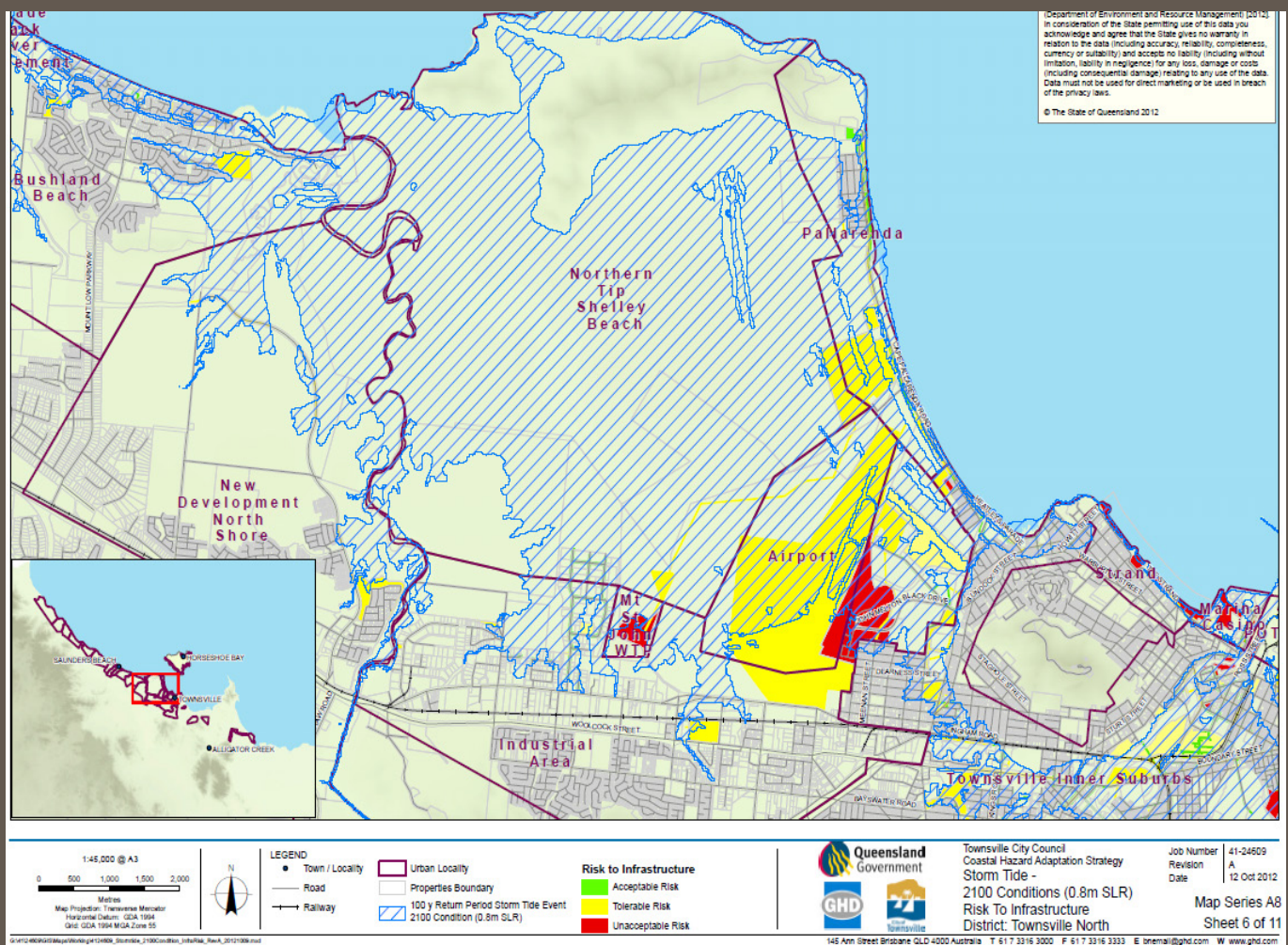


Figure 11: Townsville North Risk Assessment Storm Tide 2100 Conditions. Source: GHD 2012, Appendix A - Vulnerability and risk assessment (Part 3).

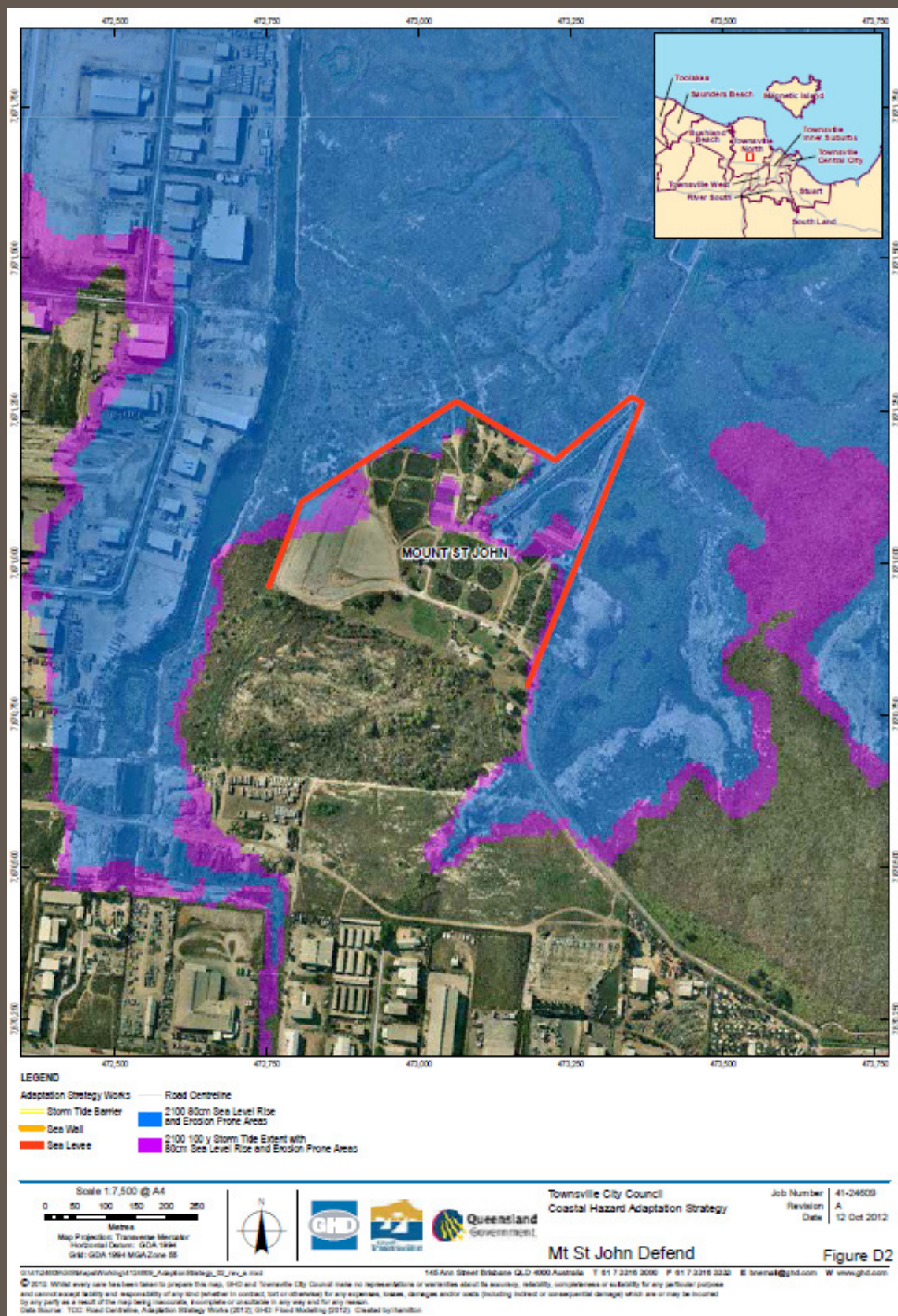


Figure 12: Example defence option for Mt St John Wastewater Treatment Plant (Note: this is a possible future option not as yet adopted by Townsville City Council). Source: GHD 2012, Appendix D - Extent of selected adaptation options.

2.4 Standards, Codes, Manuals and Guidelines

The NCCOE guidelines introduced above contain many references, some of which provided additional guidance, if not prescription, for dealing with climate change and other environmental issues in the coastal zone. A key document covered extensively in information manuals 1 and 2 of CoastAdapt is the IPCC's Fifth Assessment Report (AR5) (IPCC 2015). It is therefore not discussed here. A selection of some other relevant documents is given below.

Engineers Australia's Climate Change Policy (Engineers Australia 2014b)

The most recent pronouncement by Engineers Australia is a definitive document that leaves no doubt as to how Australian engineers should react to the threat of climate change. It points out the ethical responsibility to play a key role in limiting greenhouse gas emissions, mitigate the effects of climate change, take part in studies to understand the causes, incorporate appropriate risk analysis in all work carried out and maintain currency in advances in climate change science. The NCCOE coastal guidelines discussed above, although predating this policy release, are fully compatible with this policy.

Australian Standard, AS 5334-2013, Climate change adaptation for settlements and infrastructure – A risk based approach (Standards Australia 2013)

This Standard is a general and widely applicable framework relevant to local government planners and managers responsible for infrastructure development or operation. It provides principles and generic guidelines about how to identify and manage risks as well as giving a systematic approach to adaptation. The overall approach is summarised in the flowchart given in Figure 13. Advice is given on how to deal with uncertainty and on the importance of reliable data. While applicable to settlements and infrastructure in general, it is particularly relevant to coastal developments. A list of definitions related to adaptation, risk and resilience provides a very useful reference. Sensitivity matrices and tables provide methods for aiding sound decisions.

Australian Standard, AS 4997-2005, Guidelines for the design of maritime structures (Standards Australia 2005)

The Australian/NZ Standards for loading on structures, AS/NZS 1170 series, Structural design actions, while generally applicable, do not make specific reference to coastal structures, for example, there is no mention of wave forces nor consideration given to climate change. Australian Standard AS 4997 goes part way

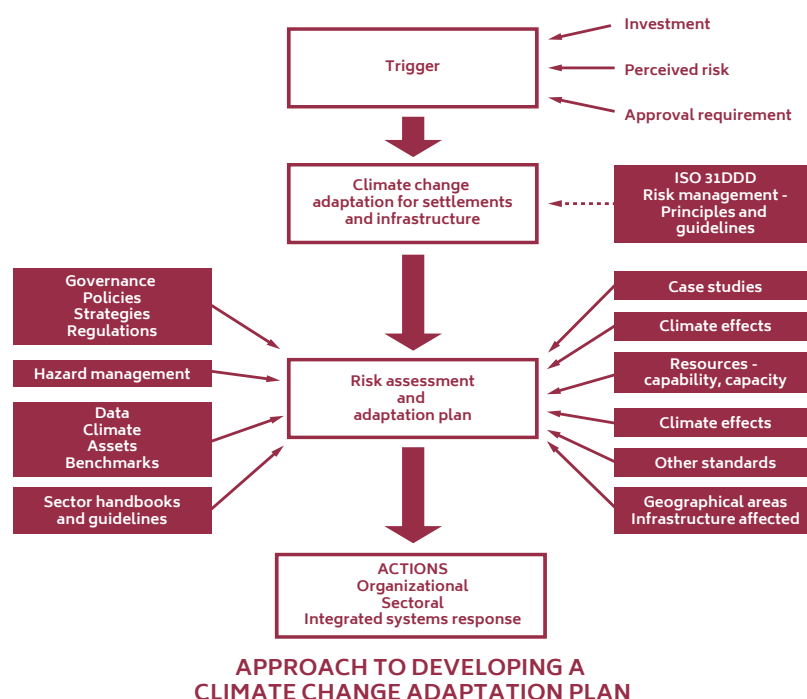


Figure 13: Australian Standard AS 5334-2013 overall approach. Source: Standards Australia 2013.

to covering that gap by providing guidelines to the design of jetties, wharves, seawalls and some other, but not all, coastal structures. Some types of infrastructure not covered include pipelines, marinas (see below), offshore structures and rock armoured walls. Design requirements are given for stability, strength, serviceability and durability. The actions considered include coastal-specific issues such as currents, waves, ship contact, propeller wash and the corrosive effect of sea water. Recommendations are made regarding allowance for sea-level rise (although comment is made that they are subject to updating).

Australian Standard, AS 3962-2001, Guidelines for the design of marinas (Standards Australia 2001)

This guideline deals specifically with facilities for berthing small vessels (up to 50 m in length). It covers investigations, dimensioning, loading (including waves and currents) and other more general design criteria. No specific consideration is given to climate change.

Australian Rainfall and Runoff (ARR 2015)

A major revision is underway of Australia's principal guide for flood estimation. The fundamental underlying rainfall analyses (Intensity-Duration-Frequency curves) have been undertaken and are available on the Bureau of Meteorology website. Various chapters of the new ARR are available on the ARR website (arr.org.au). Climate change is given due consideration throughout the documents, including Project 1 of Stage 3 being wholly devoted to this topic. Another particularly relevant section (Project 18 of Stage 3) is wholly devoted to the topic. This examines the joint probability of storm surge occurring with run-off from an extreme rainfall event. It gives a methodology for how this may be estimated and taken into design considerations.

United States approach 1: Adapting to Climate Change: A Planning Guide for State Coastal Managers (NOAA 2010)

The US agency for climate and oceanography, NOAA, has provided a framework for US state coastal managers to assist with climate change adaptation programs. It is based on needs assessment and a wide variety of resources specific to climate change, sustainability, resilience,

general hazard mitigation and natural resource management. It summarises climate change as it relates to the coasts, the planning process, vulnerability assessment, adaptation strategies and the implementation and maintenance of plans. While some sections – such as appendices on funding sources, relevant laws and regional climate summaries – are specific to US application, the approach taken provides guidance and support for how such issues can be addressed in Australia.

United States approach 2: U.S. Global Change Research Program

This program, established by Presidential Initiative in 1989, aims to 'assist the Nation and the world to understand, assess, predict, and respond to human-induced and natural processes of global change'. Within this extensive program, a 2014 report includes a chapter called 'Coastal Zone Development and Ecosystems' (Moser et al. 2014), which highlights the vulnerability of coastal infrastructure such as water and energy supply and evacuation lifelines, as well as the threats to economic activity of nationally important assets such as ports, tourism and fishing sites. As with the NOAA planning guide, the principles, if not the US-specific detail, are very relevant to the Australian experience.

United Kingdom approach: The Coastal Handbook: A guide for all those working on the coast (UK Environment Agency 2010)

The UK Environment Agency provides a very practical guide for UK operational managers that sets out how to develop policies and strategic plans; who has what responsibilities; where to go for information; where to look for funding for projects; how to conduct asset management, mapping and monitoring; and what legislation applies. Recommendations are given on likely changes due to global warming, including relative sea-level rise, surges, waves, coastal morphology and socio-economic change. Practical advice is given on adaptation, resilience and land management. While the handbook is written specifically for a UK audience, the approaches adopted provide a benchmark for Australian practice.

3 Calling in the specialist

Advice from specialist coastal engineers should be called whenever there is the prospect that coastal works may be required. Table 1, taken from NCCOE 1: Climate Change Guidelines, lists the types of development that should trigger such a consideration. It includes all major and many minor coastal projects.

To find an appropriately qualified individual or organisation may require some effort. There are no tertiary degrees called 'Coastal Engineering'; rather, it is a specialisation within civil or environmental engineering (there may be other pathways). As described above in section 2, the specialist coastal

engineer needs to have studied coastal/ocean subjects, often at postgraduate level, and gained experience in those disciplines. If such experts are not already known, then a starting point for a search can be found on Engineering Australia's NCCOE web page: www.engineersaustralia.org.au/coastal-ocean-engineering/groups (accessed 28 March 2016). Calls for tender should always elicit responses from appropriate agencies, particularly if Australia-wide. Some guidance is given on contract documentation in NCCOE 2: Sustainability Guidelines. The registration status of an individual can be checked on the National Engineering Registration Board: <https://www.engineersaustralia.org.au/portal/ner/search> (accessed 28 March 2016).

Table 1: Coastal and ocean engineering activities that may be affected by climate change
Source: NCCOE 2012a (Table 3).

Offshore (>60 m)	Nearshore	Beach and shoreline	Estuary and tidal lake
Anchor systems Deepwater mining Ocean outfalls Pipelines Structures - Fixed - Floating Risers Submarine cables Subsurface facilities Tethered systems Towing systems	Aquaculture Coral reef environments Breakwaters - Fixed - Floating Dredging and disposal Extractive industry Marinas Marine parks Mooring systems Navigation aids Navigation channels Offshore disposal Outfalls Ports and harbours Power station cooling Reclamation Sediment processes Stormwater disposal Structures - Fixed - Floating Underkeel clearance Wharves/jetties	Artificial surfing beaches Beach management Beach mining Beach nourishment Beach stability Boating facilities Coastal zone management Development - Commercial - Industrial - Infrastructure - Residential - Tourist Groynes Marinas Reclamation Revetments Sand by-passing Sediment transport Structures - Fixed - Floating Vegetation protection Stormwater outlets	Aquaculture Boating facilities Bridges Canal estates Channel stability Causeways Development - Commercial - Industrial - Infrastructure - Residential - Tourist Dredging and disposal Entrance management Estuary/lake management Flood mitigation Marinas Mining Navigation Power station cooling Reclamation Shore stability Stormwater disposal Structures - Fixed - Floating Submarine crossings Tidal barrages Training works Vegetation protection Water quality control Wetland management

4 Tips and traps

Dealing with uncertainty:

Predicting climate change effects inevitably has a high degree of uncertainty. Even if the science were known exactly, the widely varying options available to governments (most of which change over periods of three to five years) would alone lead to widely varying scenarios. For that reason, any action taken at local government level must incorporate a considerable safety factor and be robust enough to accommodate any scenario that starts to emerge. This includes such actions as building moveable structures, designing sea defences to allow later increased crest height and aligning lineal elements such as roads perpendicular to the coast so that losses will be minimised.

Weighing risk:

Projections of climate change are described in IPCC AR5 using scenarios of four Representative Concentration Pathways (RCP). In exploring migration options a selection from this range should be considered, including some at the higher RCP. Choices can then be made based on the chance of a particular RCP eventuating and the cost associated with adopting a particular RCP.

Moveable policy:

Be wary of the shifting policy of some state and national governments. Sections on government policy in both NCCOE 1: Climate Change Guidelines and NCCOE 2: Sustainability Guidelines require significant updating each time the guidelines are revised. The most recent policy in any jurisdiction needs to be addressed; where it fails to address climate change sufficiently, additional measures may need to be taken.

Modelling without data:

Models of many types are frequently used in design and to predict impact under various scenarios. All too frequently, such models are presented without mention of the necessary simplifications and approximations that must be made and without detailing the level of uncertainty. Such models must always be supported by data, both to help adjust model parameters and, more importantly, to verify the skill of the model in making predictions. (See Appendix A – At What Price Data? in NCCOE 3: Adaptation Guidelines.)

Unsupportable 'innovations':

Progress in engineering comes from creating novel solutions, usually evolutionary but sometimes revolutionary. Before being adopted on a wide scale or in a sensitive development, such solutions need to be thoroughly tested under a range of environmental conditions and over a considerable period of time. A discussion of some such innovations tried for coastal protection is included in NCCOE 3: Adaptation Guidelines.

5 What you can do to respond

An approach for planning by engineers or others who may need engineering expertise is given in NCCOE 3: Adaptation Guidelines. In summary, it includes the elements outlined in Figure 14.

It is important to understand the exposure and risk:

- What is the time frame of the project? The longer the life of the project, the more exposed it will be to climate change impacts.
- What is the inherent vulnerability of the project? This can be determined by developing a sound grasp of the concepts covered in the other information manuals of CoastAdapt. Vulnerability will be affected by, for example, proximity to shoreline, elevation above high tide and expected storm surges, stability of beach/dune/cliff, fragility of ecosystems, alignment and grading of infrastructure and development pressures.

NCCOE coastal guidelines provide useful guidance to help decision-makers determine whether engineering expertise is required for projects that may be affected by climate change. Reputable coastal engineering firms or agencies should be engaged if expertise is not available in-house. Climate change impact is, of course not the only risk to be assessed: other issues to be considered that are not necessarily associated with climate change include tsunamis, tectonic movements, changing land-use and infrastructure deterioration. Some of these are covered in *NCCOE 2: Sustainability Guidelines*.

Decisions should be based on as complete knowledge as possible, using all available data ([Information Manual 3: Available datasets](#)) and by commissioning project-specific studies. Externalities should be addressed through community consultation ([Information Manual 9: Community engagement](#)). Decisions, once made and implemented, must be monitored (this may require a data program) and amended if necessary. The uncertainty associated with climate change impacts is one reason that adaptation programs need to be robust.

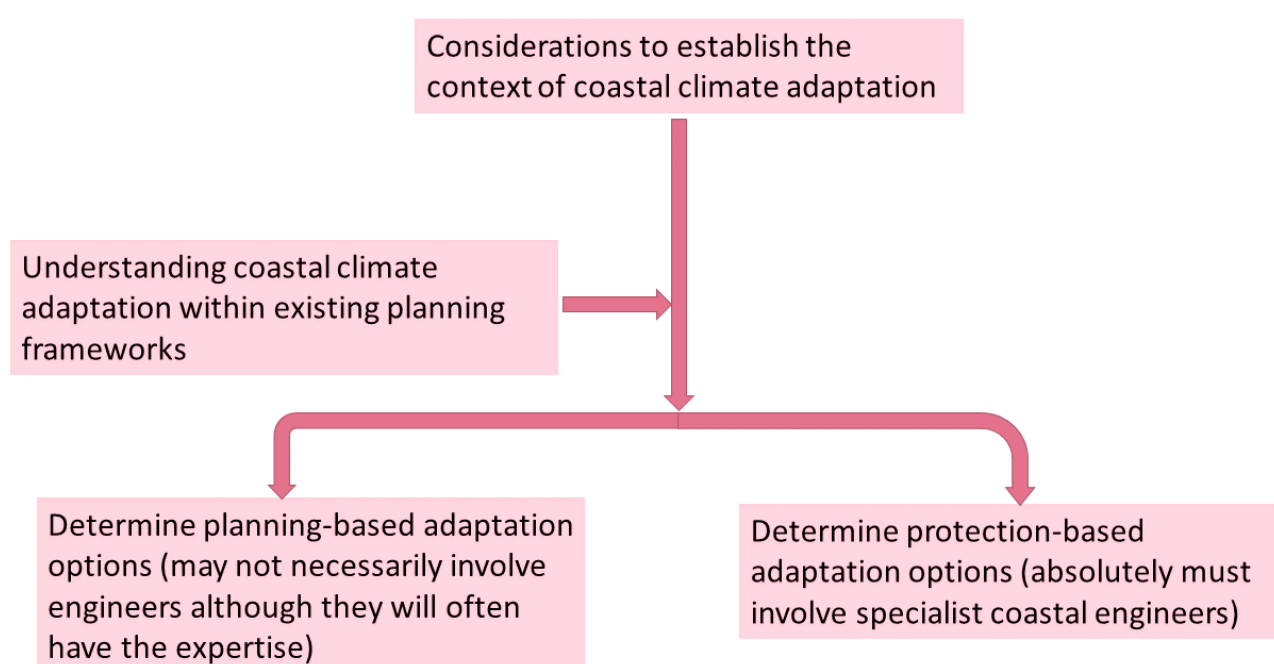


Figure 14: Planning approach for coastal climate change adaptation. Source: Based on the NCCOE 2012b.

The recommended steps in this process are summarised in Figure 15.

While some key lessons can be learned from past engineering practice in the coastal zone, it is only in recent decades that climate change been considered in coastal developments. Even today there is confusion and uncertainty in how to proceed. Developments (or the surrounding environment or local society) can be exposed to unexpected impacts if not enough consideration is given to risks that may affect them. On the other

hand, over-protecting or constructing works too early can greatly increase cost unnecessarily. The key is to be aware of the potential risks and factor them into design and decisions with enough robustness that any of the likely climate scenarios can be accommodated as they develop.

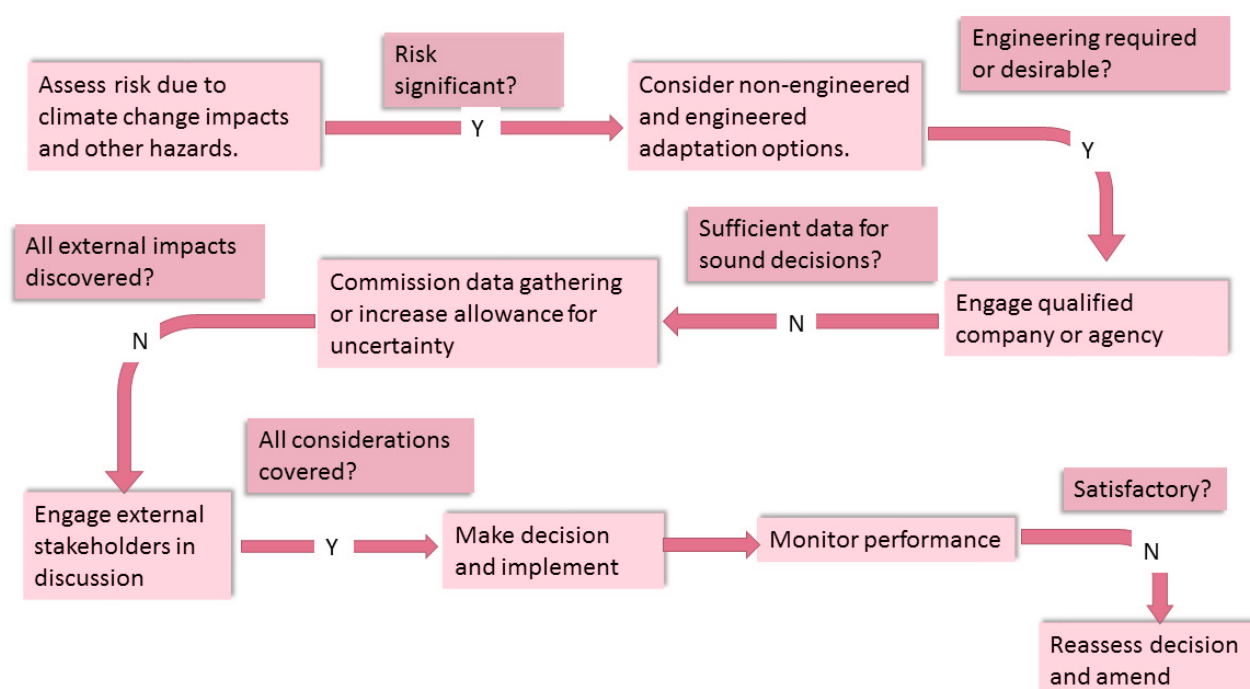


Figure 15: Decision pathway for a coastal project. Source: Developed by the author.

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Appendix: coastal engineering structures

The terminology for any specialisation can be confusing for those without the relevant training or experience; hence extensive glossaries have been included in NCCOE guidelines (NCCOE 2012b and NCCOE 2012c). Some terms relating to coastal structures particularly relevant to CoastAdapt are given here, along with examples and additional commentary.

Armour units: rock or concrete blocks designed to form the outer protective layer for a breakwater or seawall. They may be randomly placed (Figure 16) by dumping from, for example, a truck or a crane, or they may be pattern-placed to maximise the interlocking of units (Figure 17). Either type may be adapted to climate change provided that foundations are suitable for possible increase in crest height and that unit sizing allows for future possible increase in wave energy. Rubble mound (rock) breakwaters, commonly used on Australian coasts, are typically built in regions where the wave heights are limited by the depth of water just offshore. They are therefore particularly sensitive to rising sea levels, and the required armour size may, in time, exceed the available quarry rock, resulting in a change to concrete units (Li and Cox 2013). See **Revetments**.



Figure 16: Random-placed rock armour protection – Half Moon Bay, CA, USA. Photo: © 2007 Tony Webb.



Figure 17: Pattern-placed concrete armour units (Seabees) – Cronulla, NSW. Photo: © 2005 Tony Webb.

Beach replenishment: the process of replenishing a beach with material (usually sand) obtained from another location; also referred to as artificial nourishment or beach nourishment (Figure 18). In some cases this solution, possibly in concert with other methods, may be able to keep pace with sea-level rise and changes to wave and wind climate. This process has been used on Gold Coast beaches since 1974 (Gold Coast City Council 2015), and current plans for improvement – including seawall construction and groyne extension – incorporate extensive sand nourishment (Gold Coast City Council 2013). While such methods may be a viable adaptation option for densely populated areas, funding difficulties may be experienced for smaller regional settlements.



Figure 18: Sand nourishment pump in action, Woorim, Bribie Island. Source: © The State of Queensland (Department of Environment and Heritage Protection).

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. They may be attached to the coast, or detached, forming an offshore structure (Figure 19). They normally have a crest exposed above high tide but on occasions may be submerged, providing partial protection. Because of openings for navigation, breakwaters cannot mitigate against impacts from sea-level rise; however, the design of breakwaters must take into account future sea levels and changed wave climate by having the capability of raising the crest height and having suitably sized armour units.



Figure 19: Detached breakwaters, Kwinana, WA. Source: Oz Aerial 2008.

Groyne: a shore protection structure built (usually perpendicular to the shoreline) to trap littoral drift or retard erosion of the shore. Such structures are often accompanied by sand nourishment to prevent or repair erosion. The satellite image below shows five of the 16 rock groynes (described as a groyne field) placed at Silver Beach, Kurnell, NSW (Figure 20). Whether groynes are placed in groups such as this or singly, as is often done, great care is needed to avoid unwanted erosion on the downdrift side.



Figure 20: Part of the groyne field at Silver Beach, Kurnell, NSW. Source: ©Google Earth.

Revetment: a facing of a material such as stone or concrete, built to protect a scarp, embankment or shore structure against erosion by wave action or currents. Examples are given above in Figure 16 and Figure 17 (see Armour units).

Sand bypassing: Hydraulic or mechanical movement of sand from the accreting updrift side to the eroding downdrift side of an inlet or harbour entrance (Figure 21). The hydraulic movement may include natural movement as well as engineered transfer by pumping.



Figure 21: Tweed entrance bypassing scheme. Source: © The State of New South Wales (Tweed River Entrance Sand Bypassing Project) 2016.

Sea levee (dyke): a barrier constructed to contain sea water from entering low-lying land. The Netherlands has been particularly successful at using such structures to prevent flooding of reclaimed land (Figure 22). As with other structures, ongoing maintenance is essential, as evidenced by the flooding disaster of New Orleans during Hurricane Katrina in 2005.

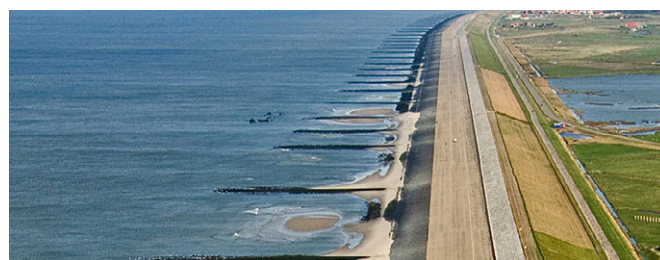


Figure 22: Dyke at Petten, the Netherlands, with additional groyne protection (currently buried following sand nourishment). Source: www.dutchwatersector.com/news-events/news/8756-boskalis-and-van-oord-to-reinforce-coastline-by-creating-beach-in-front-of-sea-dike-the-netherlands.html (accessed 19 May 2016).

Seawall: a structure separating land and water areas, primarily designed to prevent erosion and other damage due to wave action (Figure 23). This may be one of the most common structures used for adaptation to climate change in built-up areas.



Figure 23: Seawall at Fairy Bower, NSW. Photo: ©2003 James Carley, Water Research Laboratory, UNSW Australia.

Tidal barrage (storm surge barrier): type of floodgate placed in an estuary to prevent flooding from elevated ocean water levels. The tidal locks depicted in Figure 24 are managed during a cyclone by a strict protocol to manage flooding either from storm surge or run-off. Barrages without opening gates have been built at several locations to prevent salinity intrusion or to retain fresh water for agriculture. Tidal barrages may also be associated with tidal power generation, as has been mooted for several locations in Northern Territory and Western Australia.

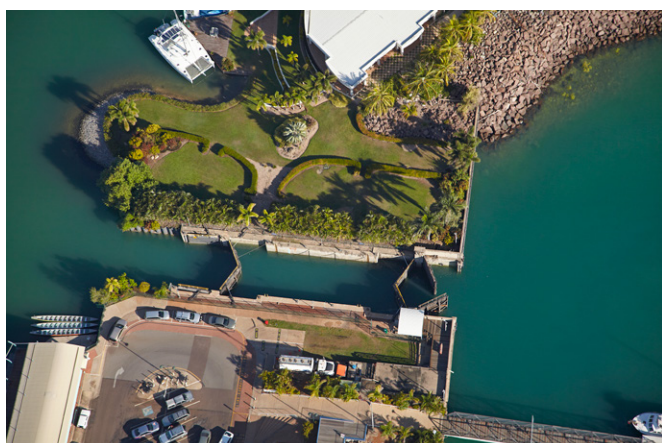


Figure 24: Tidal lock at entrance to Cullen Bay Marina, Darwin, NT. Photo: © davidwallphoto.com

Trained entrance: estuary entrance fixed by artificial rock or other armour material walls, often extending seaward of the adjacent shoreline (Figure 25). In addition to controlling the position of estuary entrances, the structures act as seawalls for the banks of the estuary.



Figure 25: Trained channel entrance – Dawesville Cut, Wannanup, WA. Source: © Google Earth.



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