CHAPTER 6

COASTAL ADAPTATION – TOWARDS A NATIONAL AGENDA

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KEY FINDINGS

- Climate change risks in the coastal zone are large, increasing and in some areas will be felt in the near term. While these risks will unfold over time, there is a case to begin now with early national action to reduce current risks and avoid the building of new exposures.
- Avoidance of future risk is the most cost-effective adaptation response in most cases. Decisions on future development, particularly in areas highly exposed to the impacts of climate change, should not increase risk.
- There is a large legacy risk in the coastal zone from buildings and other infrastructure constructed in the past.
- Natural ecosystems provide valuable ecosystem services and can buffer many of the risks associated with a changing climate in the coastal zone. Planning is needed to maximise system resilience, allow for ecosystem movement and make explicit decisions about tradeoffs.
- Leadership by governments will be necessary if adaptation action in the coastal zone is to be effective. Government roles in planning and setting benchmarks will be central to risk management, and there is a high level of public good assets in the coastal region.
- Issues requiring further attention include developing standards and benchmarks, providing information, auditing infrastructure at risk, agreeing risk allocation frameworks, on-ground demonstrations of adaptation options, and local capacity building.
- States, territories, local government, industry and communities will have a primary role in on ground coastal adaptation action. Where a national response is required, the Council of Australian Governments (COAG) can be an appropriate vehicle to progress reform.
- Major areas of science uncertainty need to be urgently addressed to inform adaptation and risk management in the coastal zone.
- This first pass assessment provides the basis for engagement on the importance of adaptation planning and the roles and responsibilities of governments, the private sector and the public in responding to the impacts of climate change in the coastal zone.

6.1 The case for national coastal adaptation action

Regardless of future reductions in greenhouse gas emissions, society will need to adapt to some level of changing climate and rising sea level. Although significant reductions in global emissions now may slow the rate and overall magnitude of sea-level rise during the mid to late century and beyond, sea-level rise for decades ahead is inevitable. Chapter 2 indicates that climate change will dramatically alter the shoreline around many parts of Australia and that a significant level of change is unavoidable. Chapters 4 and 5 describe risks to the natural environment, settlements and industry which will increase in coming decades. While adaptation policy is a very new field, early studies suggest that investment in adaptation is likely to be very cost-effective.

Projections of the absolute rate and magnitude of sea-level rise are still subject to uncertainty, but new research and information on climate projections have seen estimates generally revised upwards. Should there be substantial melting of the ice sheets sea-level rise of many metres could be triggered.

The magnitude of the coastal adaptation challenge nationally is large; Chapters 4 and 5 describe the

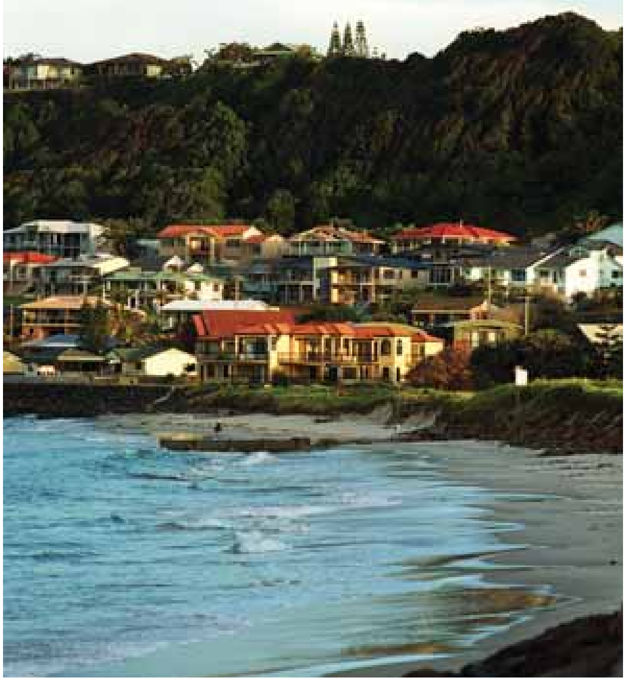

Photo credit: Newspix/Mark Cranitch

Lennox Head, New South Wales.

risks to communities, ecosystems and industry in the zone. Across the six Australian states and the Northern Territory, residential properties alone, identified as exposed to risks from climate change impacts this century, are valued at between $41 and $63 billion. While those residential houses and supporting infrastructure were designed to withstand current climate, the location of many increasingly exposes them to damage from climate change.

While this assessment does not address the full range of risks to infrastructure or the national economy, it is clear even from the subset covered that a lack of effective adaptation to climate change impacts will have large implications for Australian society, national productivity and the long-term sustainability of the coastal zone.

Australians continue to flock to the coast. Rapid and ongoing population growth in coastal areas in the past few decades, which has led to the construction of more infrastructure and greater pressure on coastal ecosystems, has also increased the level of national risk to climate change impacts. Amenity migration is expected to continue for the next 15 years as baby boomers retire to coastal areas. To cater for this growth, developers increasingly purchase land in the coastal zone and seek rezoning for greenfield subdivisions. Some of this development is in low-lying land areas, and some development reflects the growing popularity of canal estate developments. Unless there are constraints on such land use decisions, made now and over the next few years, climate change impacts will exacerbate the risks property owners and governments face in the future. These and other decisions made in recent decades increase the vulnerability of the Australian community to the impacts of climate change.

Climate change risk is increasing at the same time that pressure on coastal development is increasing as a result of the need to meet rising demand for residential properties and associated coastal infrastructure. The rising value and number of coastal properties (as a result of this increasing supply) in turn exacerbates risk exposure from climate change impacts.

In Australia's coastal zone, therefore, existing risk areas are likely to intensify and perhaps expand over the short term, with other at risk areas emerging. In the medium term it is possible that the Australian coast will start to experience more systematic impacts of rising sea levels and eroding shorelines, while over the longer term every coastal region will be impacted.

6.1.1 Need for early action on coastal adaptation

While many coastal communities are affected by current short-term weather events, such as high tides, sea-level rise is likely to have greater impacts on the outcomes of decisions with long-term consequences. Key questions for decision-making are under what circumstances do we need to anticipate adaptation to climate change, and when do we need to take adaptation action.

Consideration of climate change risks in the coastal zone suggests that starting to prepare now for adaptation to likely impacts is justified in a number of areas, particularly as sea-level rise is underway, and it will combine with storm surge and tides to generate more damaging events.

As described in Chapter 5, the near-term impacts of climate change, particularly sea-level rise, will increase for low-lying coastal communities already affected by king tides and current levels of storm surge. The recent and continuing rapid development of towns and cities in the coastal zone is a permanent change in land use that will increase national exposure to the risks of climate change. Similarly, the widespread trend towards constructing new buildings in tropical and subtropical coastal

Photo credit: iStock.com/Patrick Oberem

Canal estate on the Gold Coast.

Box 6.1 Economic and risk concepts for adaptation – a decision framework

Key economic principles and risk management approaches provide a useful framework for thinking about the implications of climate change for decision-making. A significant portion of climate change risk to coastal assets is in the future. In many cases, delaying on-ground action until some future point will be justified based on the assumption that investing to reduce coastal risk is worthwhile only if the immediate cost of the investment is less than the expected return from the investment over time.

The concepts of *uncertainty* and *discounting* are also relevant to decisions about whether adaptation action could be needed now. The level of uncertainty in climate change projections and in the timing of location-specific impacts can tend to justify deferring investment to minimise a risk of 'over-adaptation', particularly if it is assumed that knowledge will improve within a few years. Furthermore, a dollar today is usually preferred over a dollar in the future, and there is a reluctance to invest now to avoid a poorly quantified future cost.

Taking this into account, there are clearly circumstances in which preparing now for adaptation to climate change would deliver a positive net benefit and be justified, including:

- where preparing now costs little compared to the cost of likely future impacts and where other benefits could be expected from the investment
- where near-term impacts are certain and large (or the damage to be avoided is clearly unacceptable)
- where decisions are being made about assets with a long operational life, which can be expected to be around when there is high confidence that the climate will have changed
- where preparing now involves options that allocate (or clarify) risk.

The concept of *real options* can also assist in decisions where risk levels are unknown and not constant. 'Real options' seek to hedge against future risks, build on cost-benefit analysis and recognise that future streams of costs and revenues and the optimal timing for intervention cannot always be confidently predicted. Examples of real options in the coastal zone are leasing residential housing that is designed to be dismantled and relocated, constructing bridges in low-lying areas to withstand complete inundation, and purchasing land for future protection works where these meet a cost benefit test.[1]

regions on concrete slabs, rather than elevated on stilts, has increased the exposure of houses to damage from flooding in low-lying areas. In these instances, there is an immediate need to minimise practices that increase regional or national risk and which then transfers that risk to future property owners or governments.

Most of Australia's cities and industry are in the coastal zone, so the construction or refurbishment of long lived infrastructure is highly concentrated in the region. Ensuring critical and regionally significant infrastructure is built or remodelled to withstand

Photo credit: Chris Sharples

Houses built on bedrock down to the high water mark at Opossum Bay beach at South Arm Tasmania.

future climate will be important. However, there is a considerable lead time for new building standards to be developed and then taken up across the total stock of infrastructure. Work commissioned by the Garnaut Climate Change Review estimated that, with an improved building code in place by 2015, around 20 per cent of buildings would be in compliance with that code by 2030. The proportion would increase to about half by 2070, by which time another amendment to the code, to reflect continuing climate change, would probably be required.[2]

Governments at all levels also need to be aware of the potential future costs of natural disasters, which currently cost around $1 billion per year on average.[3] Many extreme weather events occur in the coastal zone, and climate change will increase their frequency and severity, possibly exponentially (see Chapter 2). This could mean that the costs of natural disasters could double or more in the next few decades. Intervention to constrain increases in exposure to such hazards would be of economic and social benefit.

The combination of large and increasing risk from climate change in the coastal zone, the making of basically irreversible decisions on long-lived assets, and the lag effect in action to reduce risk indicate a need for early adaptation in many cases.

6.2 Barriers to adaptation

While adaptation policy is still a relatively new focus of climate change considerations, there is a growing awareness that aspects of our current approaches to coastal management might be a barrier to effective adaptation in the future. Some of these barriers relate to cultural, and others to institutional factors.

Chapter 1 highlights the relatively short period of European development of Australia's coastal areas during a time of relatively stable geomorphology. Despite a sea-level rise of 17 centimetres over the past century and a half, Australia's coastline has not yet suffered significant erosion in response, although (as noted in Chapter 2) a switch from stable to eroding coasts might not be too far into the future. Australian coastal structures, land use planning frameworks, ecosystem protection approaches and other institutional arrangements have been designed to align to this historical climate condition and a static sea level.

So far Australian coastal planners have not had to deal with the coastal dynamics experienced in other parts of the world, such as the mid-Atlantic coast of the United States, and the coasts of countries bordering the North Sea, such as the Netherlands. Australian experience with coastal hazards has tended to arise from short, sharp shocks, such as the 1974 storms that resulted in considerable damage to several communities along the New South Wales coast. This experience of relative coastal stability has perhaps contributed to why there is not an established coastal planning framework that uses a diverse array of mechanisms to deal with dynamic coastlines and increasing risk, from which adaptation planning could advance.

Photo credit: Newspix/News Ltd

Storm damage to Manly promenade, Sydney 1974.

The recent rapid growth in the coastal zone has given rise to a very large legacy risk and as a society, Australia will face challenges in deciding what to protect, redesign or relocate in the future. A barrier to this challenge is the prevalence of short-term strategies. The costs of planning for hazards like sea-level rise will be felt in part today, while the benefits might not accrue during the tenure of elected governments or project planners. Local officials tend to be responsive to community concerns, but most communities have a range of competing priorities and lack decision-making frameworks that value the avoidance of future risk. Recent social analysis and studies of cognitive dissonance also suggest that people tend to disregard new information on risk if it does not align with their current preferences.[4]

Another barrier arises from 'moral hazard'– the view that when problems arise the insurance industry or government will bail out or otherwise underwrite the costs of those who are imminently threatened or damaged by a natural event. That belief can discourage people and communities from preparing for long-term consequences. Society and governments have often tended to support those whose property has been threatened, rather than allowing them to face the consequences of the risk they assumed when they bought their property.

Diversity and a lack of clarity of roles and responsibilities can also be a barrier. The Australian Constitution sets out the responsibilities of the national government. Land-use planning and coastal management in general falls to the states, which set land-use planning frameworks and benchmarks. In all states, local governments are then responsible for day-to-day administration. One outcome of this has been a range of approaches among states, and that diversity is further magnified across local governments. Many national and state inquiries into coastal zone management have recognised inconsistent and uncoordinated approaches among state and local governments as a barrier to the integrated decision-making that is required.[5]

In recent decades, there has also been a noticeable reduction in the technical capacity of agencies involved in coastal management. This is a particular concern for local governments, which are at the forefront of climate change adaptation in local communities. While some local councils may be well equipped, it is increasingly apparent that many cannot bear the technical and financial burden of assessing the risk to their communities from climate change. Many also lack the resources to identify and implement cost-effective adaptation to reduce damage from inundation and more extreme events.[6]

Box 6.2 Summary of barriers to coastal adaptation

- Current planning and design specifications are based on historical climate and assume a static sea level.
- Short-term thinking often prevails – the future risks of climate change are generally beyond decision-making horizons.
- The expectation that the government or the insurance industry will support people whose property is threatened is a disincentive to prepare for future risk.
- Some parts of the current regulatory system encourage, or do not discourage, development in 'at risk' areas, including existing use rights and the requirement in some areas to pay compensation for changes in land-use decisions.
- The complexity of institutional and inter-jurisdictional arrangements has hindered early consideration of risks from climate change, and the lack of a national mechanism for collaboration will inhibit adaptation if it is not addressed.
- Reduced technical capacity across local government, and some state based, agencies that are responsible for coastal management will impede the mainstreaming of cost-effective adaptation approaches.
- Local governments are at the forefront of local adaptation action, but in a number of areas they lack the capacity to assess and reduce climate risk.

Photo credit: John Baker and DEWHA

Revegetation of foredunes in the Corangamite region, Victoria.

In addition, some parts of the current regulatory framework act to inhibit adaptation to climate change. There is currently little mention of climate change in Australian legislation for local government. Where climate change is mentioned, it is generally as a matter that needs to be taken into account. While a lack of data, tools and capacity has left many local councils unsure about how to tackle climate change, the discretionary legislative framework has meant there is not a strong push for local governments, or indeed other tiers of governments, to fill this knowledge gap.[7] There are also a number of 'perverse' incentives that encourage land development in areas at risk. Aspects of existing use rights are a barrier to the implementation of 'planned retreat' approaches in developed areas. Conversion of Crown land to freehold land in coastal hazard areas can increase existing use rights and complicate planning for risk management. Some planning principles, such as the legal concept of 'injurious affection', can also make it difficult for governments to constrain new development without being subject to compensation claims from affected landholders or developers.[8]

Finally, the lack of an effective mechanism for national coordination of adaptation in the coastal zone, if not remedied, will impede effective risk management. Climate change impacts in the coastal zone will have cross-cutting social, economic and environmental consequences, and narrow sectoral collaboration mechanisms or programs are not adequate. Clarity about the roles and responsibilities of each of the levels of government is needed as a first step in coordinating a national reform agenda. While all levels of government have a role, the Australian Government is not the default policy-maker. Indeed, the Australian Government's main program focus at present is the Community Coast Care Program managed by the Department of the Environment, Water, Heritage and the Arts. It focuses on protecting and rehabilitating coastal environments and critical aquatic habitats rather than the core drivers of increasing risk from climate change in the coastal zone.

Photo credit: John Baker and DEWHA

Revegetated dune area Mereweather Beach, Newcastle.

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6.3 Towards a national coastal adaptation agenda

The economic and social value of beaches, infrastructure, industries and ecosystems in the coastal zone suggests that, while adapting to climate change could be costly in some areas, doing nothing is likely to be more expensive over the longer term as substantial investments and assets are placed at risk.

Planned adaptation is part of a balanced and prudent response to climate change. Fundamentally, it is about proactively building our capacity to minimise, adjust to or take advantage of the consequences of that change. A number of common themes and characteristics lead to good adaptation in the coastal zone. These include the need to:

- develop a framework for understanding and managing risks, including understanding how climate change will affect current risk and the vulnerability of coastal assets, and any critical thresholds
- incorporate flexibility (that is, adaptive management) to deal with changing risks and uncertainties, and recognise the value of a phased approach (Figure 6.1)
- adopt a sequential and risk-based approach to factor climate change into new planning and investment decisions
- adopt the precautionary principle and avoid actions that will make it more difficult to cope with climate risks in the future
- make more conscious decisions about the extent to which risks are being transferred to future generations, and the basis on which tradeoffs between the built and natural environment are made
- maintain natural coastal defences and buffers as much as possible and encourage mechanisms for their enhancement
- realise the benefits from low-cost adaptation options that reduce future risk.

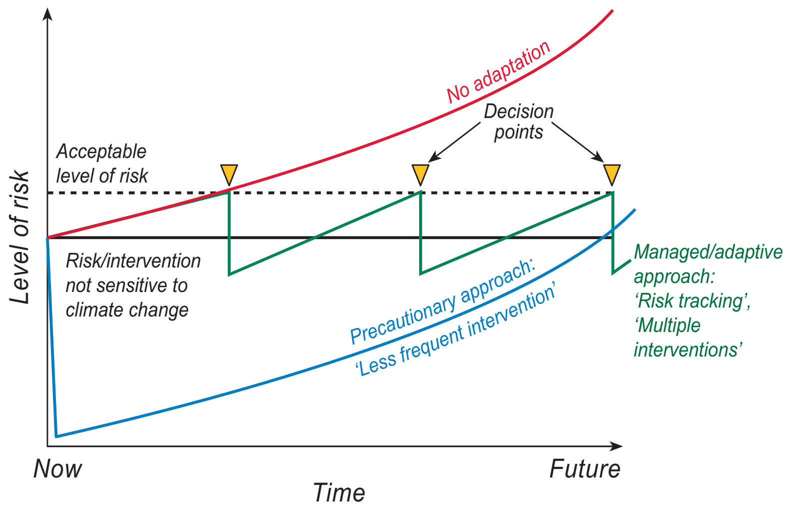

Figure 6.1 Different approaches to adaptation and their effects on the level of risk over time.
Source: New Zealand Ministry for the Environment[9]

Photo credit: Mackay Regional Council

The coastal buffer zone is visible in this aerial photo of Bucasia Beach, Mackay, Queensland.

6.3.1 Roles and responsibilities for coastal adaptation

Governments will have an important role in enabling coastal adaptation.[10] Land use planning frameworks and building codes will be fundamental in reducing future exposure and there are high levels of public interest and public good values in the coastal zone that will require some level of adaptation. Governments will also need to be involved in building adaptive capacity and setting the right conditions for efficient investment decisions to be made. This includes providing basic information and appropriate regulatory settings that promote efficient risk management. While not all adaptation action will require a national response, where a national response is required, the Council of Australian Government (COAG) can be an appropriate vehicle to progress reform.

The different levels of government are responsible for managing or regulating a large number of assets in the coastal zone. The Australian Government has a limited set of powers in coastal planning and management compared to the states. Each state government has, in turn, devolved some of its powers under legislation to local councils. States, territories, local government, industry and communities will have a primary role in on ground coastal adaptation action.

The principle of subsidiarity has generally been applied, such that councils have power over matters at a local level, while strategic directions and plans are generally set at state level. In addition, some states retain coastal zone decision-making power over development that is designated to be of state significance. Various non-government sectors, such as water utilities, port authorities and insurers, all have roles that relate to the management of coastal areas and facilities. The critical question now is how the nation can best define those roles in a world of climate change within the constraints of current governance arrangements and still provide for effective adaptation.

The complex governance arrangements in the coastal zone can produce inertia (see Section 6.2), but leadership, clearer roles and responsibilities, and investment in critical national capability to enable government and corporate decision-makers to take an informed approach to managing climate change risks can overcome this.

The extent of the potential impacts will also require a role for individuals, business and the community in many adaptation responses. Policy approaches that clarify the limits of public sector capacity and/or willingness to protect coastal properties in areas of medium to high risk might also reinforce the private incentive to internalise coastal risks, which can reduce the expected value of damage over time.[11] Individuals will need to take responsibility for managing the risks to their property, including through insurance. It will be important to ensure that the actions of individuals do not lead to adverse implications for adjoining properties and the natural environment.

The insurance industry has a particular role in managing risk in the coastal zone. Higher insurance premiums and lack of access to insurance can send a powerful signal that provides a disincentive for investment in assets in high-risk areas and, where investment proceeds, can clarify the adaptation strategies that will be required. While insurance can be an efficient market-based economic tool to distribute and reflect actual risk for coastal properties, it is based on historical information and does not necessarily reflect long-term changes in risk. Its efficient application may also require detailed risk assessment relevant to the property level, much of which is currently not available. A key issue for governments is to ensure that there is no distortion to the market signal from insurance premiums.

6.3.2 Guidance for risk management

Adaptation planning should be developed on the basis of the best science and be updated periodically as new science becomes available. As outlined in Chapter 2, atmospheric and oceanic evidence for climate change is pointing more and more to what had previously been perceived as worse-case rates and extent of sea-level rise, ocean temperature warming, changes in rainfall and runoff patterns, and the intensity and distribution of extreme events. In the light of that evidence, it is appropriate to clarify national frameworks and standards to address risk from climate change impacts in the coastal zone.

There is clearly a relationship between the nature of a risk that confronts a particular place and the need for society to take steps to manage the risk. As the likelihood and consequence increase, the need for more restrictive provisions on land use will increase. The provisions may vary with regional and local circumstances, but a set of standards for land use planning and construction would be a key part of national capacity to manage the impact of extreme events and the long-term creep of rising sea levels. Without effective standards, in the decades ahead Australia will be continually confronted by the consequences of community conflict, environmental degradation, damage to property and infrastructure and loss of social amenity in coastal areas. Application of standards in land use planning and engineering to increase Australia's resilience to climate change risks will require a strong knowledge base on how risks will change in the future.

Risk based land use zoning

Risk based vulnerability zoning for land use planning is one approach the community may wish to consider as part of a broad risk management framework for the coastal zone (Table 6.1). The illustrative approach described in Table 6.1 is based on an assessment of best practice in Europe, New Zealand and the United States. Importantly, it recognises that risks and hazards can change over time, that risks will vary spatially, that the lifespan of assets in the coastal zone will vary in longevity and be of different value to society, and essentially that a one-size-fits-all approach will not work.

As well as spatial location, the different longevity, or asset life spans, and value of those asset requires consideration of a different but complementary tiered response in addressing rising sea levels. For example, long lived and critical assets (such as hospitals, roads, port infrastructure and airports) require different standards from medium-lived assets (such as residential housing), while a reduced standard is appropriate for short-lived and lower value assets (such as recreational facilities).

Table 6.1 Potential approaches to land use zoning based on a hierarchy of risk standards.

Risk category	Application and planning response
Low risk areas	Defined by areas where there is little or no risk of erosion, flooding or long-term inundation at less than 1-in-1,000 year return periods under worse-case climate change scenarios to 2100. Planning response: no constraints on land use planning because of physical climate processes.
Medium risk areas	Defined as shorelines, tidal watercourses and low-lying lands subject to erosion, inundation and flooding at a 1-in-500 to 1-in-1,000 year return period. Planning response: no new construction of essential and critical infrastructure and public utilities unless designed to be capable of remaining operational during extreme climate events (suitable for most other development).
High risk areas	Defined as coastal areas likely to be affected by erosion, inundation and flooding at a return interval of between 1-in-500 and 1-in-100 years. Planning response: approval only for developments that can be relocated or designed to withstand the impacts of extreme events or flooding without causing adverse consequences for adjoining coastal areas.
Very high risk areas	Defined as coastal areas subject to erosion, inundation and flooding at a return interval of 1:100 or less under worse-case climate change scenarios. Planning response: approval only for developments that are compatible with a high degree of land surface disturbance; existing high value assets in such areas should be the subject of restrictions on new development and on the management of potential adverse consequences on adjoining areas, in the light of the ability of the community to protect those assets and support their relocation over time.
Note: Current planning is generally based on assessing risks from a 1-in-100 year event. Events less frequent than this, e.g. a 1-in-1000 year event, are significantly larger in magnitude.	

Some states have started to incorporate a risk hierarchy in their planning guidelines. For example, Queensland's draft Coastal Plan 2009 describes a Development Assessment Code which links a range of guidelines for allowed development to coastal hazards under climate change conditions.[12]

Further, while planning for the potential impacts of sea-level rise out to 2100 and beyond may seem too long-sighted, a timescale of centuries is an appropriate benchmark for considering the footprint for major cities (Rome, Venice and London have existed for many hundreds of years and are now regarded as global cultural assets). Under a changing climate, with plausible sea-level rises of over 1 metre per century, this timescale has implications for the urban design and planning for most Australian capital cities. Additionally, land-use planning decisions may provide for the development of a house that has only a 50–60-year lifespan, but the zoning of that land has a far longer lifespan and signals the ability to build and rebuild indefinitely on the site into the future. Figure 6.2 illustrates an approach to considering timeframes for various decisions and developments.

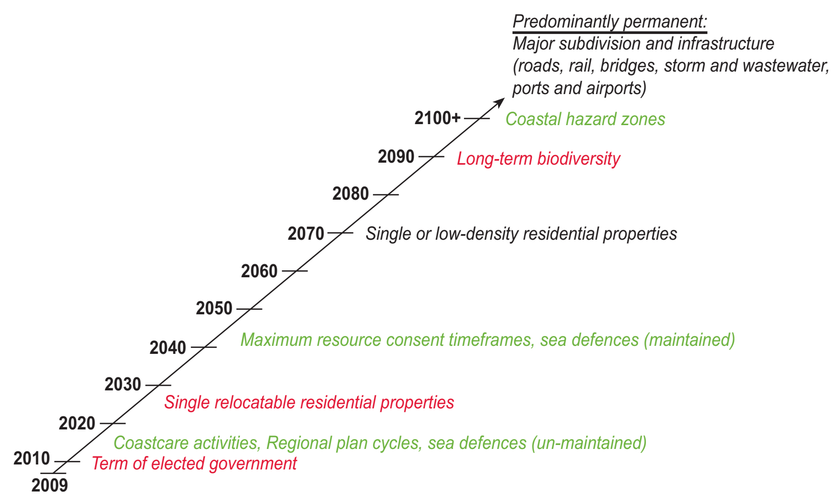

Figure 6.2 Timeframes for decisions and developments in the coastal zone.
Source: Adapted from New Zealand Ministry for the Environment[13]

Building and engineering codes and standards

The magnitude and geographic spread of climate change risks also suggest that we need to regularly review and update the regulatory framework for building, plumbing and construction, possibly every 15 years. The current building code is based on historical climate risk data, which over time could lead to an increasing risk of harm to building occupants. This is particularly important, given that projected changes in the frequency and intensity of extreme events are non-linear, and there is an increased risk of coincident climate events (see Chapter 2). Technical and engineering specifications, including specifications for the resilience and life of building materials, also need review and updating.

Early analysis is suggesting that the current building Standard for design under wind action (AS/NZS 1170.2:2002) may be inadequate under climate change conditions, particularly when considering the combined hazard of cyclonic and non-cyclonic winds for a number of densely populated regions including Brisbane, Sydney and Perth.[14]

The experience in the US in managing the impacts of Hurricane Katrina has led to reconsideration of engineering specifications for infrastructure. In particular risks to infrastructure emerged in places where they weren't expected, for example transverse stresses in bridges. Given the magnitude of legacy infrastructure in the coastal zone, there is a need for a national audit of critical infrastructure which may be subject to damage from climate change impacts.

Approaches to cost-effective risk management

There are likely considerable benefits from the application of planning and building regulations to the future costs of managing climate change impacts. While there has been little research in this area, CSIRO have developed a preliminary estimate of the costs and benefits of the uptake of strengthened planning and building regulation on inundation of residential buildings for a 1-in-100 year storm surge event in south-east Queensland.[16] The analysis allows for population growth, and an increase in the height of storm tide due to sea-level rise and with that, the change in the return period for what was previously defined as the 'extreme event' but with the increase in sea levels would occur more frequently in the future. Table 6.2 shows the impacts of varying adaptation options in 2030 using today's dollars.

Taking a precautionary approach to planning new development, infrastructure and services to avoid coastal hazards over their lifetime is the most effective

Box 6.3 Houghton Highway Bridge Duplication Project

Hurricane Katrina in the United States provided many lessons that were taken into consideration during the design of the Houghton Highway Bridge duplication, between the Redcliffe Peninsula and Brisbane's northern suburb of Brighton in Moreton Bay. The Houghton duplication is one of the few bridges in Australia likely to be adversely affected by a storm tide, as it is at the southern edge of the tropical cyclone region and is also susceptible to east coast lows. The possible effects of high tides, storm surge, wave run up, and sea-level rise from global warming were included in the design considerations.

The bridge structure is designed to be above tide and wave height during a 1-in-2,000 year storm event. The bridge deck is 4 metres higher than the current Houghton Highway and it will be bolted down as an additional storm-immunity measure. The designers also considered the risks of wave loading, which led to the destruction of several bridges during Hurricane Katrina.

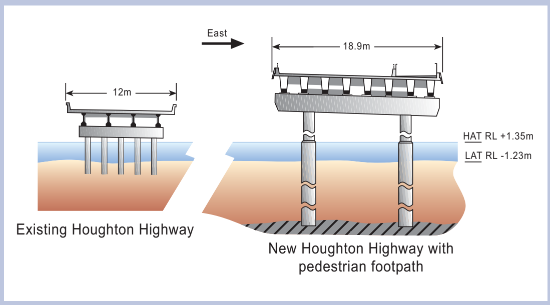

Figure 6.3 Existing (left) and duplicate (right) Houghton Highway Bridge.
Source: Cummings et al. 2008[15]

Table 6.2 Estimated costs and benefits of residential adaptation in south-east Queensland for 2030.

Adaptation option	People affected 2030	Buildings affected 2030	Total cost 2030
Business as usual (same planning and building regulation as today)	616,000	124,800	$4 billion
Planning regulations tightened to allow no further risky development, building stock under same regulation	378,000	83,200	$2.6 billion
In addition to planning regulations tightened as above, retrofit/reclaim to maintain existing level of risk	270,000	47,900	$1.5 billion

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and sustainable long-term approach. For greenfield sites, appropriate regional planning can ensure that new development is outside defined hazard or risk zones. How to deal with existing development in identified at-risk areas is a more complex planning issue. In such cases, it will probably be impossible to avoid the risk and a mix of risk reduction and risk transfer approaches will be required. Figure 6.4 shows the relative contribution of risk management activities in adapting cost-effectively to coastal climate change risks.

Risk transfer – insurance

Risk management through avoidance and reduction action will not completely remove coastal risks from climate change. There will remain some level of residual risk that will need to be addressed, often through risk transfer. The primary approaches to managing residual risk are insurance and risk acceptance, including coping with any associated consequences through emergency and disaster management.

Insurance is an important market mechanism which could support coastal adaptation. It can lessen the adverse impacts of climate change, particularly through extreme events, for businesses and households. If premiums reflect risks appropriately insurance can also provide incentives to take adaptation actions to reduce exposure to climate change impacts.

There are considerable gaps in insurance cover in the coastal zone as mentioned in Chapter 5. At present insurers generally have exclusions for 'storm surge', 'action of the sea', 'high tide', as well as for 'erosion and subsidence'. A key reason for this is the lack of risk data on which to base premiums. Nearly a quarter of the population is also without building or contents insurance. Approaches to improve insurance cover of properties in the coastal zone need to be considered in developing a coastal adaptation response.

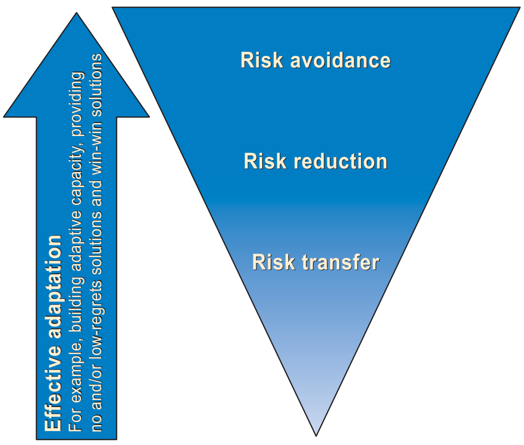

Figure 6.4 Contribution of risk management activities for effective adaptation to coastal climate change risks.
Source: New Zealand Ministry for the Environment[17]

The insurance industry is proposing a potential new measure for public consideration to help build community resilience to climate change impacts – coastal land value insurance.[18] Land value can represent the major component of a coastal property's overall value, especially for vulnerable and expensive beach-front properties, yet land is not currently insured under home or contents building insurance policies. The industry suggests that an insurance fund could be established into which owners of low-lying coastal land would pay a regular levy so at to enable compensation when rising sea levels lead to their land becoming unusable.

Emergency management

Australia's coastal settlements are exposed to a range of extreme weather events that draw heavily on Australia's emergency response services. Over the last decade and despite the implementation of disaster reduction strategies, severe coastal storms, floods and cyclones have stressed the capacity of emergency services to respond quickly and cost the economy, communities and individuals many billions of dollars in lost lives, productivity, homes and infrastructure. In June 2007, severe flooding along New South Wales' mid to north coast caused $1.35 billion in damage[19] and left many hundreds of people stranded.

The Ministerial Council for Police and Emergency Management (the Council) has recognised climate change as a very significant and strategic issue for emergency management[20] and is developing a national disaster resilience framework to foster more informed and safer communities. As part of its disaster reduction strategies, the Council has commissioned the Australian Emergency Management Committee to develop a climate change action plan. While still under development, the plan acknowledges that much of the work in preventing disasters lies in the planning and building regulation sectors of society and government.

Establishing links between land use planning, climate change and emergency management may help to introduce precautionary and consistent land use planning principles that reduce communities' exposure to risks such as flood and bushfire. Improving the links between the development of building standards, climate change and emergency management, may increase the resilience of the built environment to extreme weather, such as storm and cyclone generated winds.

Knowledge to support risk management

The effective management of risk in the coastal zone by all spheres of government, industry and the community will require continued investigations of adaptation strategies and decision-support tools. In some areas scientific research will be vital in underpinning the development of these strategies and tools. Table 6.3 outlines key knowledge gaps and associated research tasks for risk management in the coastal zone.

Table 6.3 Knowledge Gaps and Related Research Needs for Australian Coastal Adaptation.

Knowledge Gap	Associated Research
Significant uncertainties regarding future rates of sea-level rise, particularly related to ice sheet processes. Wide range of current projection makes planning adaptation measures difficult.	Improved understanding of global averaged sea-level rise, including particularly ocean thermal expansion and the response of ice sheets to global warming. Improved understanding of the regional distribution of sea-level rise. Probabilities of plausible change.
Significant uncertainty of the amount and rate of coastal erosion that would occur with climate change including if and when a threshold change from accreting to receding beaches may occur around Australia's coastline.	Analysis of historical and geological coastal erosion. Improved quantitative models of beach erosion and linkage to improved estimates of global-averaged and regional sea-level rise. Improved knowledge of changes in ocean wave conditions and how they impact on coastal erosion. The relative contribution (in different regions) across the frequency spectrum from tidal periods and weather related events to decadal changes.
Significant uncertainties regarding the fate of El Nino Southern Oscillation dynamics under anthropogenic climate change.	Continued exploration of ENSO behaviour within coupled global climate models as well as improvement in ENSO forecasting and prediction systems. Implications for cyclones.
Potential implications of coincident events on coastal systems, such as combined effects of storm surge, wave action, extreme rainfall on coastal erosion and flooding.	Analysis of changes in the frequency of extreme events. Quantitative methods linking sea-level rise, storm surges, river floods, ocean waves and coastal erosion. Scenario analysis to identify where critical infrastructure is at risk of failure, during coincident, extreme events.
Access to high quality, high resolution topographic and bathymetric data for coastal modelling of biophysical and socio-economic impacts.	Increased acquisition, integration and dissemination of high resolution data sets to inform modelling and decision-makers of at-risk communities, particularly for settlements around estuaries and lakes. Vulnerability mapping.
Decision-support systems and tools to incorporate climate information into coastal management.	Analysis of urban design and planning frameworks to identify new approaches to adaptation for coastal settlements. Establishing criteria for new buildings and infrastructure to increase resilience to climate change across different regions. Design options for adapting existing buildings to climate change in different locations. Triggers for increased response to manage risk.
Little known about social vulnerability, cost-benefit of adaptation options and their social acceptability.	Development of social vulnerability criteria, and analysis of geographic spread of vulnerability and trends. Analysis of social diversity and resilience and effectiveness of incentives. Exploration of community attitudes to adaptation.

Source: Based on CSIRO submission to House of Reps Inquiry[21] and the draft National Adaptation Research Plan on Settlements and Infrastructure[22]

6.3.3 Scoping on-ground adaptation action

Every part of the Australian coast will be affected to some degree by the forces of climate change. While this national assessment of risk across Australia's coastal zone highlights some key areas of immediate risk, and areas where risks are likely to escalate into the future, there is also some risk in other areas. To ensure that we are well prepared and able to implement adaptation measures that protect public safety and valuable coastal assets, assessments across national, regional and local scales will be required. Ideally, those assessments will be 'nested' to some degree to improve information sharing and priority setting.

Regional assessments are likely to be the most cost effective approach to identify valuable assets that need to be protected or accommodated over time, including critical and regionally significant infrastructure. Regional assessments can also identify where socially vulnerable communities are, the limits to their adaptive capacity and areas of future risk where development should not occur. For areas that are already flood prone, an understanding of flooding

Photo credit: Newspix/David Clark

Sand pumping at Palm Beach, Queensland.

processes and the interaction with rising sea levels will be imperative. A key outcome of regional assessments will be information that supports the identification of adaptation options, and the triggers when an increased on-ground response is needed.

On the basis of known areas of existing and the projected extent of rise in sea level, it is evident a number of coastal regions will encounter increased risk faster than the average (for example from rapid population growth). Some of these areas suffer from relative socio-economic disadvantage or span

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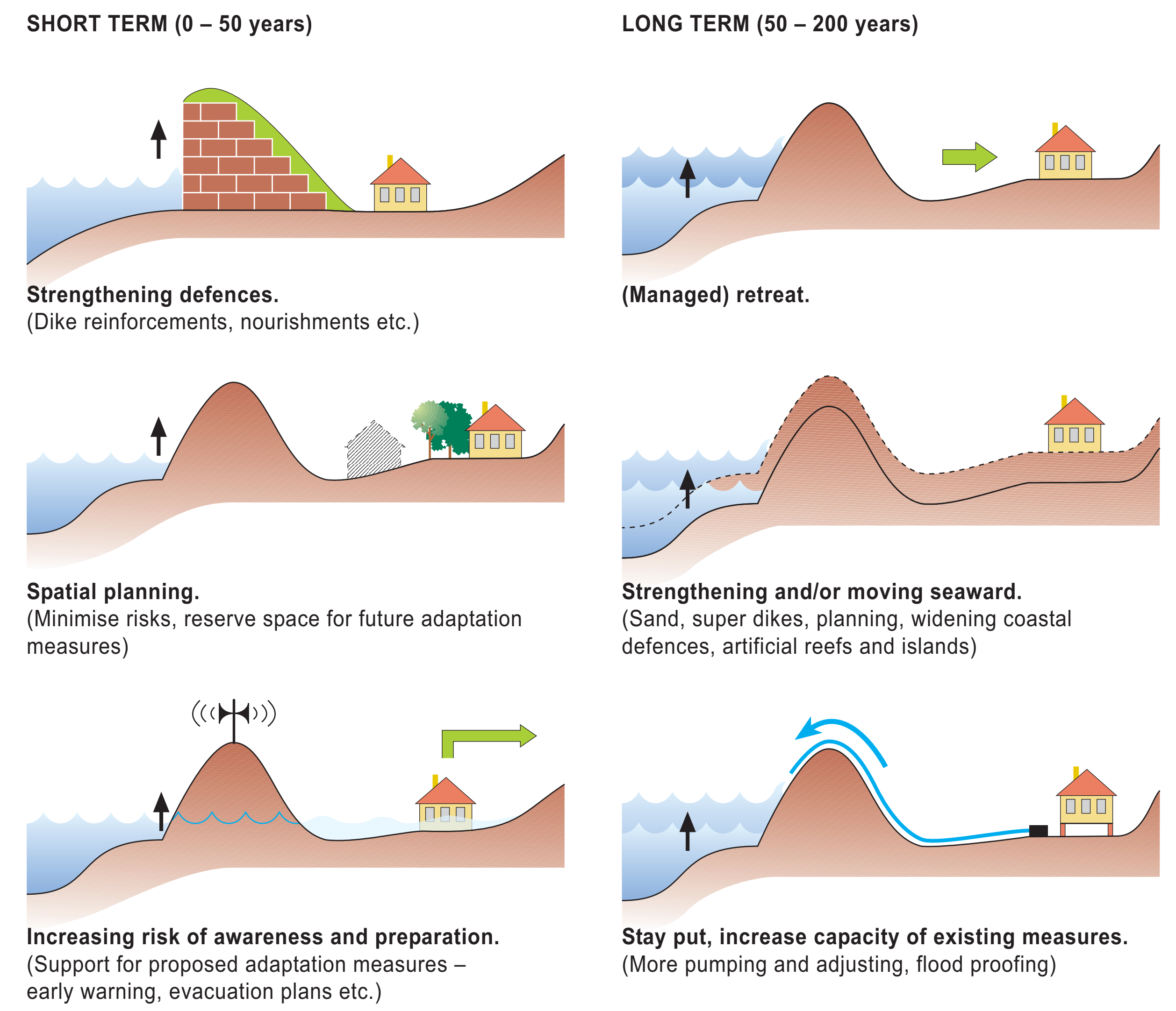

Figure 6.5 Adaptation options for coastal building.
Source: Adapted from Dutch Ministry of Transport[23]

Indigenous communities with strong cultural links to ‘sea country’. The development of a targeted adaptation strategy is a high priority for these regions to identify and analyse the costs and benefits of adaptation options (such as accommodating climate change, retreating or abandoning), reduce barriers to adaptation, and drive partnerships to enable its implementation.

Countries that have had to develop adaptation strategies such as The Netherlands distinguish short or near-term adaptation options from the long term (greater than 50 years). Figure 6.5 illustrates options for adapting a particular building, including how those options can change over time. They indicate ways in which the threats facing communities are generally addressed in low-lying regions of countries.

In Australia, it is important to examine the local and regional relevance of the three common approaches to managing the built environment in the coastal zone: protect, accommodate and retreat. For each approach the costs and benefits must be identified and evaluated (Appendix 1).

Protection involves construction of seawalls, dykes and other ‘hard’ engineering defences for the purpose of maintaining coastal assets in their current location. ‘Soft’ protective works such as nourishment of beaches are also included, but may necessitate repeated access to sand sources to maintain the beach extent.

Accommodation requires modification of existing structures such as building floor levels and various minor works including the installation of tidal flood gates on drains. It also involves provision of setbacks and buffers and preparation of emergency management plans all of which will allow continued or extended use of risk areas.

Planned or managed retreat as shown in Figure 6.5 provides for the relocation of built assets from a high risk to a lower risk site. Decisions about where to apply protection, retreat and accommodation measures will be difficult to make. In densely populated or highly capitalised areas, coastal protection is also likely to be preferred and, in some cases, will be cost effective even over the longer term. Particularly at risk are heavily capitalised shorelines, such as the Gold Coast where both hard and soft protection works are used. Seawalls are the most common form of shoreline protection in Australia – they have been constructed according to existing engineering standards or placed illegally to protect private housing. Larger engineering solutions may also be cost effective especially when the totality of private and public assets become threatened in major urban areas requiring dykes, barrages, pumps or some combination of works. The up and down-shore impacts of protective works can be considerable and need to be factored in any cost-benefit analysis.

Photo credit: Andy Short

Rock seawall along Adelaide's West Beach.

Box 6.4 Barrages to protect major coastal cities – lessons from Europe

Various protection measures have been taken in other parts of the world to reduce the impacts of sea-level rise and storm surge. That experience can help us to identify preferred approaches to protection in Australia. Examples include the barriers and barrages described in the table below.
All these barriers close only when required and are left open at other times. This has the advantage of allowing ships to pass through and environmental flows to be released from rivers draining into the bays.

Name	Country or location	Completed	Structure	Cost (approximate)
Thames Barrier	London, United Kingdom	1982 after 30 years	Built across a 523 metre wide stretch of the Thames estuary, the retractable barrier divides the river into four 60-metre and two 3-metre navigable spans and four smaller non-navigable channels between nine concrete piers and two abutments.	A$956 million (£534 million)
Maeslantkering	Hoek van Holland / Maassluis, Netherlands	1997	Two retractable gates are housed in drydocks when not being used and automatically close when needed. The gates span a 360-metre gap.	A$746 million (€450 million)
MOSE Project	Venice, Italy	Expected 2012	MOSE consists of a system of retracting oscillating buoyancy flap gates able to isolate the Venetian Lagoon from the Adriatic Sea when the tide reaches above an established level.	A$7,080 million (€4,272 million)

Photo credit: Photolibrary

The retractable barrier on the Thames River, United Kingdom.

Photo credit: Rijkswaterstaat (part of the Dutch Ministry of Transport, Public Works & Water Management)

The Maeslant Storm Surge Barrier, The Netherlands.

This ensures that shipping and port activities continue as normal for most of the time and it maintains the ecological integrity of the bays. The barriers and barrages are usually raised or closed when storm surges or high tides reach a predetermined level.

Source: Advice from AECOM 2009[24]

Building a protective structure of modest height is often quite affordable, but the cost of these structures rises significantly with the square of the height; a structure twice as high costs four times as much. Given sea levels are projected to rise for hundreds of years, protective structures may only play a role in protecting very high value assets and in transiting to a planned retreat phase for many locations around the coast that will be unable to sustain the ongoing and increasing expense of such structures. Already we can learn from Europe and Asia where major works have been undertaken to protect coastal assets.

Long lead times are required to plan, design, and gain the necessary approvals and to construct major infrastructure. For example, the design and implementation of the measures for the physical safeguarding of Venice commenced in 1982, but the MOSE project, which is subsequently being constructed to protect the city, is not expected to be completed until 2012. Given these constraints, planning and design considerations would need to be undertaken early to position Australian cities to respond effectively to future sea-level rise. This should include early identification of locations likely to require major works, in order that public and private sector urban and waterfront development proposals receive timely scrutiny during approvals processes.

The potential impacts of extreme sea-level rise on the infrastructure which underpins the functions of society can be extreme. Sewage treatment plants, airports, coastal roads and rail, buildings, ports, industrial facilities and cultural icons could be inundated either permanently or regularly, the latter through high tides and storm surges. Clearly, decisions have to be made to adapt infrastructure over time. This might include protecting low-lying assets with seawalls, dykes, storm surge barriers or tidal barriers or relocating to higher ground. Protecting low-lying assets will be costly. For example, providing dykes or sea wall protection around low-lying areas of Port Phillip Bay in Melbourne is estimated to cost up to $5 billion.[25] To prevent flooding along river catchments, flood/tide gates would be required on every river system feeding into the Bay, which would be likely to double the cost.

Box 6.5 Barrages or dykes for Sydney and Melbourne by 2100?

Many cities in Australia are built close to the sea and are therefore particularly vulnerable to rising sea level. The impacts on low-lying coastal cities could be very large. Residential, commercial and industrial zones of major cities could be inundated either permanently or regularly by high tides and storm surge exacerbated by climate change, disrupting services and damaging the local or even national economy. Choices clearly have to be made to adapt cities over time, by either protecting low-lying assets or moving them to higher ground.

As extreme storm surges on the Australian southeastern seaboard are in the order of 0.5 metres, storm surge barriers, such as those on the Thames or in Holland, would not be cost effective against a rise in sea level of several meters. Therefore, if it were necessary to protect cities such as Sydney or Melbourne, dykes would potentially need to be constructed around low-lying lands or across estuary entrances, as is done in the Netherlands.

A dyke across the entrance to Port Phillip Bay would be challenging to construct. ‘The Rip’ between the heads would require a dyke some 3 kilometres long and constructed in some 20 metre water depth. Despite this distance, ‘The Rip’ is relatively narrow compared with the circumference of the rest of the Bay, which is around 220 kilometres. The dyke would need to have locks to allow water and ships to pass. The locks would then be shut if a storm surge or high tide was forecast. However, because of the powerful currents and swells, constructing a dyke stretching across ‘The Rip’ would be a difficult engineering challenge and would be very expensive.

The Sydney metropolitan area comprises four major estuaries including Broken Bay, Sydney Harbour, Botany Bay and Port Hacking. Constructing dykes across these four estuary entrances would be a colossal undertaking. Thankfully, however, the foreshores, typically, are relatively steep and rocky, thereby having already some considerable allowance for future sea-level rise. Nevertheless, there are still low-lying foreshore areas that may need to be protected from inundation by dykes or seawalls, and major infrastructure, such as Sydney airport, which has runways extending well into Botany Bay, may need to be raised.

A project of comparable ambition and scale has been proposed for the Thames Estuary in England as rising sea levels there may cause the Thames Barrier to become inadequate by 2070. The proposed dyke would stretch up to 16 kilometres across the Thames estuary, making it one of the largest engineering projects Britain has undertaken. It would include locks to allow water to flow in and out of the Thames estuary according to the tides, but engineers would be able to shut the locks if a storm surge occurred. The dyke may also include a road and hydroelectric power station.

Source: Advice from AECOM 2009[26]

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Glenelg, Adelaide.

However, even if the cost of protection was $10 billion for Melbourne alone, it would still be a lower cost alternative to losing low-lying infrastructure, building assets and the cost of disruption to the local economy and society.

In the long term there will be a need to assess appropriate protective works for Sydney, Melbourne, Brisbane and other major urban centres. Bathymetry, land topography, tidal range, and expected storm surge elevation are factors to consider in any analysis of the costs and benefits of protecting urban assets. Dykes and pumps may be more cost effective than storm surge barriers or tidal barriers that could also provide an opportunity to harness tidal power. Although the financial and environmental costs of constructing major projective structures for our major cities would be high, the savings achieved by avoiding these cities becoming inundated could be large.

Climate change impacts on the Australian coast will require the implementation of many adaptation strategies. As many as 500 popular beaches may lose sand as sea level continues to rise. Communities will call for action to nourish depleted beach stocks. Already a program is in place in northern New South Wales and the southern Gold Coast to bypass the blocking Tweed River training walls and send up to 500,000 cubic metres of sand each year to the north. Adelaide's beaches have been replenished with sand since 1973 and the strategy for 2005–2025 involves continuing the existing program of beach nourishment and maintaining channels at Glenelg and West Beach harbours. The cost of implementing the strategy over the 20 years of its life was estimated to be about $70 million in today's dollars. This has since been reduced, possibly to around $56 million, by pumping sand onshore from near shore deposits.[27]

For many low-lying villages, towns and cities a progressive retrofit of public utilities will be required as sea level inundation impacts take greater effect. Roads, railways, electricity and sewerage networks are subject to increased frequency of tidal inundation. Invasion of more saline waters into these networks will also have effects. Adaptation planning to address these likely impacts must commence in the near future to maximise the capacity to align with planned maintenance and retrofit cycles.

Chapter 4 outlines the likely impacts of climate change on coastal ecosystems. Coastal policies need to maximise the resilience of coastal habitats, and regional plans should also allow for habitats to move in response to a changing climate and continue to provide ecosystem services and a buffer to likely impacts. Of particular importance are coastal habitats such as internationally recognised Ramsar sites (for example Kooragang Island in the Hunter River delta) located in highly developed areas are at risk and will require careful management to protect their values.

There has been very little analysis of costs and benefits of action to protect ecosystems from climate change impacts. One example is a study that evaluated the costs and benefits of options to prevent the intrusion of salt water into the Mary River wetlands in the Northern Territory. The wetlands have high biodiversity and are also highly productive, making a large contribution to the territory's barramundi and threadfin salmon yields and supporting cattle grazing in the dry season. The capital and maintenance costs of chokes and barriers were identified and compared with tangible and intangible ecosystem benefits. For each option assessed, the benefits of protecting ecosystem function significantly exceeded the costs of the barrier. The study concluded that salinity mitigation in the Mary River is economically sensible.[28]

6.3.4 Issues requiring further attention

The magnitude of risk from climate change in coming decades in the coastal zone highlights the imperative for a national debate on adaptation. As a society, Australia needs to discuss how high a risk is acceptable in coastal areas, and how the burdens of managing threatened coastal assets can be shared.

Coastal adaptation will be a long-term and changing agenda. The number of areas exposed to risks from current climate in the coastal zone, and the lead time for reducing risks to communities and infrastructure, indicate that we need to start preparing for climate change now.

Not all of the issues will require a national response and some will need to be pursued by individual states and territories and local government. Where a national response is required, COAG can be an appropriate vehicle to progress reform.

The following emerging issues are worth considering as part of any national coastal adaptation reform agenda. Progress in some of them is occurring in some states and territories including regional risk assessments. They are not in an order of priority and should not be considered a definitive list.

1. National standards and benchmarks for coastal development

Australia needs national standards and benchmarks to constrain future risk and address exposure of existing assets in the coastal zone. Clear planning rules and guidelines that define no-go zones for certain types of development must be shown in planning instruments and guidelines. Priorities include setbacks and sea-level benchmarks for different risk standards, and planning horizons that take into account the link between climate change and coastal geomorphology.

2. Regional risk assessments

Every part of the coast will be affected to some extent by climate change. Near-term and more distant climate change impacts on communities, industry, environments and infrastructure in all regions need to be better understood to manage future risk, particularly where current planning can assist in avoiding future development in high risk areas. Regional risk assessments also need to identify where there is a lack of adaptive capacity, and engage the community on future adaptation action plans, including protection of community values such as public access to the shoreline. Triggers need to be identified when increased on-ground response is needed to manage increasing risk. Importantly regional risk assessment and its incorporation in planning is not a one-off or short term agenda, risks will continue to increase for decades or more.

There is benefit in regional risk assessments for adaptation linking to regional disaster risk reduction strategies. Regular reviews will be needed of emergency management approaches at regional scales to incorporate changing risks from climate change.

3. Demonstration strategies for areas exposed to high or extreme risk

For regions and communities with very high or extreme risks from climate change, there is a need to develop strategies that identify the on-ground action needed to manage those risks. Plans need to identify where climate change risks can be accommodated, where protection is required, how planned retreat could be undertaken, and the costs and benefits of early or delayed action. The offsite consequences and trade-offs of particular types of actions should be analysed. Importantly, trigger points relating to each key risk that would signal the need for a particular type of response need to be negotiated with communities. Significant community engagement in working through on ground options will be essential.

4. Review and update Building Codes

Building codes and engineering specifications for infrastructure in high-risk areas in the coastal zone will need to be upgraded. The Building Code currently includes no provisions to minimise the risk of inundation from sea-level rise, and cyclones and wind speeds are also projected to change with climate change. Given that the climate will continue to change, ongoing review, for example every 15 years will be needed.

There is an opportunity to explore performance based responses in forward-looking standards that maintain acceptable levels of risk over the life of the structure.

Photo credit: Andy Short

The surf club had to close and move when the seawall was built at Warilla.

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5. National audit of critical infrastructure in the coastal zone

Much of the infrastructure that underpins our society and economy is in the coastal zone, but little information is available about how climate change will affect its functioning and the services that it provides. An audit of critical national and regional infrastructure in the coastal zone is required.

6. Provision of information and tools essential for decision-making

Private and public decision-makers currently lack the information and tools, such as inundation modelling, needed to address climate change in many decisions. This assessment highlights the importance of having national science-based information, and reveals considerable gaps in readily accessible tools. Priorities include national scenarios on climate change targeted for the coastal zone and hazard mapping based on combined risks of erosion and inundation over time.

7. Research to reduce uncertainty about the magnitude of coastal risk from climate change

Research in key areas of science where uncertainty currently hinders effective risk management would be of net benefit. Hydrodynamic inundation modelling, informed by both climate science and geomorphology, is important in high-risk areas where significant assets could be threatened. Science to underpin integrated risk assessment is needed, including science that shows how the risks will change over time. There is also a need to better understand sea-level rise processes, with a particular focus on regional variation, ice sheet dynamic, trigger points for ice sheet melt and switching points to eroding rather than stable coastlines.

8. Risk allocation and insurance

Efficient decision-making will require clarity and communication about risk allocation and the degree of risk borne by asset owners. A risk allocation framework is needed to help governments, businesses and communities understand and manage the risks they face. The coastal zone is one of the key areas that would benefit from a national risk allocation framework. The insurance sector will be a key partner in these discussions.

9. Ecosystems review

Many ecosystems of national or global significance are in the coastal zone. While there is a widespread recognition that coral reefs are threatened by climate change, the risks to many other ecosystems are not well understood. There is a clear need to assess what is required to build the resilience of important ecosystems to climate change. This could involve identifying where horizontal or vertical movement might need to occur, ensuring that regional planning allows for such movement, and determining critical thresholds for sustainability or ecosystem service provision.

10. Community engagement

Much of the Australian population lives in the coastal zone. Adaptation strategies around the coast will require the engagement and support of the broader community. The success of that engagement is linked to broadscale information provision and risk education. Wide sharing of information on risks, risk allocation, adaptation options and responsibilities will facilitate informed engagement in the difficult decisions that some communities will need to make in the medium term.

11. Build capability of local government

There is a need to build the capacity of those charged with management in the coastal zone to ensure that they have the knowledge, tools and skills to manage risk. Local government is responsible for key planning and land-use decisions that are critically affected by climate change risks and in many cases will not have the capacity in terms of resources and skills to do this effectively.

12. Inter-jurisdictional cooperation

The complexity of cross-cutting climate change risks in the coastal zone requires an effective inter-jurisdictional reform effort. The complex mix of roles and responsibilities in current governance system can be a source of confusion and inertia, creating potential barriers to efficient adaptation. A new national agenda will be needed to clarify roles and responsibilities and identify priority actions. This will require collaboration across jurisdictions on policy and technical matters, and will need to effectively engage local government.

Appendix 1: Adaptation options for buildings – protect, retreat, accommodate

Protection

Protection of the shoreline typically involves the construction of seawalls or other defences to maintain coastal assets in their current location. It includes the repeated nourishment of beaches with sand and engineering works, such as tide gates, to constrain flooding.

Many protection works will have a decadal life, as they will be constructed to a particular standard that will be exceeded over time with climate change. As indicated in Chapter 2, the effectiveness of beach nourishment will decrease over time as beaches switch from being stable to eroding.

Areas where ongoing coastal protection is a long-term option include highly developed urban areas with a long history of protection, and areas where there is a need to preserve irreplaceable cultural, Indigenous and heritage values.

The public will often call for protection when private property is threatened by coastal erosion. However, the use of protective structures can also lead to a false sense of security and encourage greater development in areas behind protective structures, than for similar locations that do not have protective barriers. Protection should only be considered as a long term option as part of a wider management plan for the area.

Costs	Benefits
• Construction and ongoing maintenance costs could be high • Expectations that area will continue to be protected can limit the flexibility of retreat options in the future • Costs are likely to be much higher if structures fail, because their construction encourages development in protected areas compared with similar but unprotected areas • Impacts on areas upstream or downstream of protective works include loss of coastal and marine habitats	• Avoided damages or loss of land and structures • Continued public access to beaches and other recreational areas • Improved public safety

Accommodation

Accommodation includes a range of usually minor works to allow continued or extended use of at risk areas. Measures include elevated floor requirements, increased setback requirements, and preparation of emergency evacuation plans.

Accommodation measures are often cost-effective in a transitional strategy. They are suitable for areas with modest to higher value assets where exposure to climate change risk is low to medium. An example is The Honeysuckles, Ninety Mile Beach, Victoria where new residents are required to provide a response plan to climate change, identifying how structures would deal with possible flooding and storms for the next 60 years, and a caveat is included on the property title to warn future owners of risk. While accommodation strategies may also generate a false sense of security, they do start to signal restricted access or development requirements and begin a difficult task of managing private ownership development expectations.

Costs	Benefits
• Marginal additional construction costs • Costs from loss or damage that may occur if measures not adequate • Possible reduction in investment values	• Continued use of land and infrastructure • Generally less impact on surrounding environment than protection measures • Generally cheaper than protective measures • Increased public safety • Promotes risk management

Planned retreat

Planned or managed retreat involves a decision to withdraw, relocate or abandon assets that are at high risk of being affected by climate change hazards in the coastal zone. In the longer term, planned retreat often provides the most cost-effective approach to managing risks to medium to high-value assets exposed to inundation or erosion risk.

Planned retreat, which can occur on a range of scales, can involve increased setback provisions, relocation of structures within properties, and rezoning of land (for example, to constrain ribbon development in high risk areas or to provide for horizontal migration of wetlands). It can include buyouts of properties.

At present there have been few experiences with planned retreat to deal with climate change, with the exception of Byron Bay. Lessons can also be learned from property relocations caused by the construction of new dams. In some areas, early community consultation suggests that there could be opposition to the early adoption of planned retreat. Options for implementing planned retreat would probably include a mix of regional planning, constraints on property title, financial instruments and insurance incentives.

Costs	Benefits
• Lost value of land, infrastructure, and social, economic and environmental values • Potential compensation costs for loss of land or infrastructure • Management costs associated with retreat plan (for example, removal of septic tanks as houses retreat)	• Increased public safety • Significantly lower ongoing maintenance costs than for protection measures • Reduced need for costly adaptation measures in future, should risks increase • Potentially allows for greater space for ecosystems to horizontally adapt

Glossary

Accretion	Growth of coastal shorelines by steady addition of sediments.
Adaptation	Adjustment in natural or human systems in response to climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities.
Adaptive capacity	Ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences.
Anthropogenic	Produced by human beings or resulting from human activities.
Average Recurrence Interval and Annual Exceedance Probability	The Average Recurrence Interval (ARI) and the Annual Exceedance Probability(AEP) are both a measure of the rarity of a rainfall event. ARI is defined as: *The average, or expected, value of the periods between exceedances of a given rainfall total accumulated over a given duration.* AEP is defined as: *The probability that a given rainfall total accumulated over a given duration will be exceeded in any one year.* How AEP relates to ARI with ARI expressed in years: AEP — ARI 2% — 50 year 1% — 100 year 0.2% — 500 year 0.1% — 1000 year 0.01% — 10000 year
Barrage	An artificial obstruction, such as a dam or irrigation channel, built in a watercourse to increase its depth or to divert its flow.
Bathymetry	Refer to the depth of the ocean. A bathymetric chart will show the depths of the sea floor.
Biodiversity	The numbers and relative abundances of different genes, species and ecosystems in a particular area.
Calcareous	A sediment, sedimentary rock, or soil type which is formed from, or contains a high proportion of, calcium carbonate in the form of calcite or aragonite.
Calcernite	A rock formed by the percolation of water through a mixture of calcareous shell fragments and sand causing the dissolved lime to cement the mass together. The calcarenite material is often a conglomerate varying from little shell material to nearly all fossil shells with little sand.
Carbon dioxide	A colourless, odourless gas that occurs naturally and is also emitted by fossil fuel combustion and land clearing. The atmospheric concentration of carbon dioxide has increased by about 31% since the Industrial Revolution. It is the main anthropogenic-influenced greenhouse gas affecting climate change.
Chenier	Beach ridge usually composed of sand or shells.
CO_2^e	Carbon dioxide equivalent concentration is used to compare the effect from various greenhouse gases.
Climate	Climate in a narrow sense is usually defined as the “average weather”. The classical period is of 30 years.
Climate model	A numerical representation (typically a set of equations programmed into a computer) of the climate system. The most complex and complete climate models are known as General Circulation Models.
Climate projection	A projection of future climate based upon simulations by climate models.
Climate scenario	A plausible and often simplified representation of the future climate, based on an internally consistent set of climatologically relationships.
Coastal geomorphology	The physical structures, processes and patterns associated with the coast, including landforms, soils, geology and the factors that influence them.
Coral bleaching	The paling of corals and other animals with zooxanthellae caused by the expelling of these symbiotic algae under stress. Bleaching occurs in response to physiological shock due primarily to periods of increased water temperature coincident with high levels of light. Bleaching can also be caused by changes in salinity or turbidity.
Demersal	Being or living on or near the bottom of the ocean.
East coast lows	Intense low-pressure systems which occur on average several times each year off the eastern coast of Australia.

Ecosystem services	Ecological processes or functions having monetary or non-monetary value to individual or society at large.
El Niño	See El Niño Southern Oscillation.
Endemic	Belonging or native to a particular geography, group, field, area, or environment.
El Niño Southern Oscillation	El Niño Southern Oscillation (ENSO) refers to widespread 2–7 year oscillations in atmospheric pressure, ocean temperatures and rainfall associated with El Niño (the warming of the oceans in the equatorial eastern and central Pacific) and its opposite, La Niña. Over much of Australia, La Niña brings above average rain, and El Niño brings drought. A common measure of ENSO is the Southern Oscillation Index (SOI) which is the normalised mean sea level pressure difference between Tahiti and Darwin. The SOI is positive during La Niña events and negative during El Niño events.
Exposure	Refers to the elements of risk which are subject to the impact of a hazard.
Geomorphology	The study of landforms, their origin, and evolution.
Glacier	A mass of land ice flowing downhill (by internal deformation and sliding at the base) and constrained by the surrounding topography (e.g. the sides of a valley or surrounding peaks). A glacier is maintained by accumulation of snow at high altitudes, balanced by melting at low altitudes or discharge into the sea.
Greenfield subdivisions	Subdivision on land that was previously rural land.
Greenhouse effect	An increase in the temperature of the earth's surface caused by the trapping of heat by greenhouse gases.
Greenhouse gases	Gases in the earth's atmosphere that absorb and re-emit infrared (heat) radiation.
Hazard	Is a source of potential harm or a situation with a potential to cause loss. It may also be referred to as a potential or existing condition that may cause harm to people or damage to property or the environment.
Holocene Period	The Holocene interglacial period is a geological epoch that began approximately 12–10,000 years ago and within which nearly all human civilisation developed.
Ice cap	A dome-shaped ice mass covering a highland area that is considerably smaller in extent than an ice sheet.
Ice sheet	A mass of land ice that is sufficiently deep to cover most of the underlying bedrock, so that its shape is mainly determined by the flow of the ice as it deforms internally and/or slides at its base.
Ice shelf	A floating ice sheet of considerable thickness attached to a coast (usually of great horizontal extent with a level or gently undulating surface); often a seaward extension of ice sheets. Nearly all ice shelves are in Antarctica.
Interglacial period	The warm periods between ice age glaciations. The "Last Interglacial" (before the current one), dated approximately 130,000 to 115,000 years ago.
Inundate	To cover with water.
La Niña	See El Niño Southern Oscillation.
Leachate	A product or solution often containing contaminants formed by leaching.
Littoral	In coastal environments the littoral zone extends from the high water mark, to areas permanently submerged.
Marine carbonates	Carbonates are rocks composed mainly of calcium carbonate $CaCO_3$, such as limestones and chalk. They may be formed by shells or skeletons of organisms.
Mitigation	Refers to those response strategies that reduce the sources of greenhouse gases or enhance their sinks.
Non-linearity	A process is called 'non-linear' when there is no simple proportional relation between cause and effect.
Palaeontology	The study of prehistoric life.
Pelagic	Relating to, or living in open oceans or seas rather than waters adjacent to land or inland waters.
Phenology	The study of the timing of recurring natural phenomena such as; leaves and flowers emerging, migratory birds appearing or eggs hatching.
Phytoplankton	Minute, usually single celled, free floating aquatic algae. Important source of organic material and energy in marine food webs.
Ramsar	The Convention on Wetlands, signed in Ramsar, Iran in 1971 is an international intergovernmental treaty dedicated to the conservation and "wise use" of wetlands.
Relative sea level	Sea level measured by tide gauge with respect to the land upon which it is situated.
Resilience	The ability of a social or ecological system to absorb disturbances while retaining the same basic infrastructure and ways of functioning, the capacity for self organisation and the capacity to adapt to stress and change.

Return period	A measure of risk used by engineers and insurers describing the average time between events of a given magnitude. For example, a one-in-100-year event has a 1% probability of occurring in any given year. See also Average Recurrence Interval and Annual Exceedance Probability.
Sea-level rise	An increase in the mean level of the ocean. Eustatic sea level rise is a change in global average sea level brought about by an increase in the volume of the world ocean. Relative sea level rise occurs where there is a local increase in the level of the ocean relative to the land, which might be due to ocean rise and/or land level subsidence. In areas subject to rapid land-level uplift, relative sea level can fall.
Slumping	When loosely consolidated materials or rock layers move a short distance down a slope.
Southern Oscillation Index	See El Niño Southern Oscillation.
Special Report on Emissions Scenarios	Scenarios described in the IPCC Special Report on Emissions Scenarios (SRES), published in 2000 and used as a basis for climate projections shown in the IPCC assessment reports. SRES scenarios are grouped into four families – A1, A2, B1 and B2, that explore alternative development pathways covering a range of demographic, economic and technological driving forces and resulting greenhouse gas emissions.
SRES A1FI	The most fossil fuel intensive scenario in the SRES, commonly viewed as one of the worst case scenarios.
Storm surge	Elevated sea level at the coast caused by the combined influence of low pressure and high winds associated with a severe storm such as a tropical cyclone. Includes wave run up and wave set up.
Storm tide	The total elevated sea height at the coast above a datum during a storm, combining storm surge and the predicted tide height.
Sustainability	Development that meets the needs of the present without compromising the ability of future generations to meet their own needs.
Symbiosis	Interactions between different biological species. Symbiotic relationships may be mutuality, parasitic, or commensal.
Tectonics	Geological study of the earth's Lithosphere (crust and mantle). The Lithosphere consists of tectonic plates. There are currently eight major and many minor plates.
Thermal expansion	Refers to the increase in volume that results from warming water.
Threshold or tipping point	The point in a system at which sudden or rapid change occurs, which may be irreversible.
Uncertainty	An expression of the degree to which a value (e.g. the future state of the *climate system*) is unknown. Uncertainty can result from a lack of information or from disagreement about what is known or even knowable.
Vulnerability	Degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity.
Wave run up	The ultimate height reached by waves (storm or tsunami) after running up the beach and coastal barrier.
Wave set up	The super-elevation in water level across the surf zone caused by energy expended by breaking waves.

Acronyms

AEP	Annual Exceedance Probability
AHD	Australian Height Datum
ARI	Average Recurrence Interval
AR4	IPCC Fourth Assessment report 2007
DEM	Digital Elevation Model
COAG	Council of Australian Governments
CSIRO	Commonwealth Scientific and Industrial Research Organisation
GIS	Geographic Information Systems
IPCC	Intergovernmental Panel on Climate Change
LGA	Local Government Area
NEXIS	(Geoscience Australia's) National Exposure Information System
TAR	IPCC's Third Assessment Report 2001.