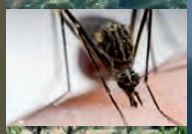
NCCARF
National
Climate Change Adaptation
Research Facility

National Climate Change Adaptation Research Plan

Settlements and Infrastructure





Writing team
Bruce Thom (University of Sydney)
Jennifer Cane (Department of Sustainability and Environment, Victoria)
Ron Cox (University of New South Wales)
Catherine Farrell (Department of Climate Change and Energy Efficiency)
Peter Hayes (RMIT University)
Robert Kay (Coastal Zone Management Pty Ltd)
Allen Kearns (CSIRO)
Darryl Low Choy (Griffith University)
John McAneney (Macquarie University)
Jan McDonald (Griffith University)
Michael Nolan (Maunsell AECOM)
Barbara Norman (University of Canberra)
Jonathan Nott (James Cook University)
Tim Smith (University of the Sunshine Coast)

Florence Crick (NCCARF Secretariat)
Daniel Stock (NCCARF Secretariat)

Published by the National Climate Change Adaptation Research Facility
Email nccarf@griffith.edu.au
Website www.nccarf.edu.au

The National Climate Change Adaptation Research Facility hosted by Griffith University is an initiative of, and funded by, the Australian Government, with additional funding from the Queensland Government, Griffith University, Macquarie University, Queensland University of Technology, James Cook University, The University of Newcastle, Murdoch University, University of Southern Queensland, and University of the Sunshine Coast.

The role of the National Climate Change Adaptation Research Facility is to lead the research community in a national interdisciplinary effort to generate the information needed by decision-makers in government and in vulnerable sectors and communities to manage the risks of climate change impacts.

This publication should be cited as:

Thom B, Cane J, Cox R, Farrell C, Hayes P, Kay R, Kearns A, Low Choy D, McAneney J, McDonald J, Nolan M, Norman B, Nott J, Smith T, 2010: *National Climate Change Adaptation Research Plan for Settlements and Infrastructure*, National Climate Change Adaptation Research Facility, Gold Coast, 60pp.

ISBN 978-1-921609-07-7

NCCARF Publication 05/10

National Climate Change Adaptation Research Plan

Settlements and Infrastructure

Contents

Image: Wally Irwin.

Executive Summary

Climate change poses significant threats to the social fabric of our towns and cities and to our urban and strategic infrastructure. Climate change is likely to result in increased damage to buildings, energy, telecommunications, transport and water infrastructure and the services they provide. Coastal settlements and infrastructure will be especially vulnerable to the combined effects of climate change including sea-level rise, increased air and sea surface temperature, increased storm intensity and frequency, ocean acidification, and changes to rainfall and runoff. Sea-level rise will cause greater coastal inundation, erosion, loss of wetlands and saltwater intrusion into freshwater sources, with impacts on infrastructure, coastal resources and existing coastal management programs.

Developing effective adaptation responses will be critical in reducing the impacts of climate change on settlements and infrastructure and, carefully designed and implemented, these responses could generate significant benefits such as increased energy or water efficiency. A variety of adaptations have already been identified, including revising building codes to take account of changing climatic conditions, introducing climate-responsive planning measures (e.g., planned retreat, dune management, building design, and regulation of new structures), and managing urban development in climate-sensitive areas through zoning and regulation. However, many more adaptation responses need to be developed and implemented, including shifts in the behaviour and expectations of urban, regional and remote area populations.

The National Climate Change Adaptation Research Plan for Settlements and Infrastructure identifies critical gaps in the information needed to address the full range of issues arising from the potential impacts of climate change on settlements and infrastructure. The primary purpose of this Research Plan is to set out the priority research agenda for the next 5–7 years to inform a better understanding of climate change risks and impacts on settlements and infrastructure and how

The National Climate Change Adaptation Research Plan for Settlements and Infrastructure identifies critical gaps in the information needed to address the full range of issues arising from the potential impacts of climate change on settlements and infrastructure.

Image: Alexander Rist

these risks can be managed and impacts reduced through planned adaptation interventions. This Research Plan will support adaptation efforts by identifying research priorities that are most relevant to the needs of stakeholders. Involving stakeholders in research programs will help ensure the relevance and uptake of research findings and contribute to building knowledge and commitment from key stakeholders and the broader community.

This Research Plan is structured around four themes which relate to the issues around and management of settlements and infrastructure that are under threat from the impacts of climate change. While there are overlaps in the research questions for each of the four themes, they individually enable the development of research priorities across different sectoral interests, time-scales and, especially, different spatial scales.

The themes are:

- Urban and regional planning and management
- Built environment
- Vulnerable coastal communities
- Infrastructure.

Image: Mauro Bertolini

A number of critical information needs and research gaps are identified under each theme. Ranking research areas into higher and lower priorities is difficult, given that many aspects of research are not directly comparable and time-frames for research vary, but questions were prioritised using six criteria that have also been applied in the other sectoral National Climate Change Adaptation Research Plans.

Essential

- Severity of potential impact to be avoided or degree of potential benefit to be derived
- Immediacy of required intervention or response
- Need to change current intervention and practicality of alternative intervention.

Desirable

- Potential for co-benefit
- Cross-sectoral relevance
- Equity considerations.

Applying these criteria, the research questions on the following page were identified as high priority.

A fundamental input to achieving the research activities described in this Research Plan is the availability of sound climate projections pertaining to parameters and scales that are relevant to the risks and vulnerabilities of the sectors and interests on which this plan is focused. This input will require ongoing research to better understand climate change and its impacts at a regional level. In particular, better information is required about what extreme events are likely to be experienced at regional and local levels, and what their frequency, intensity and scale are likely to be. The research to develop this information will be undertaken as part of the Australian Climate Change Science Program.

Implementation Plan

An Implementation Plan is being prepared in parallel to the development of this Research Plan and will include consideration of existing projects, of research capacity and resource issues, and of funding opportunities. The Adaptation Research Network for Settlements and Infrastructure will play an essential role in implementing the Research Plan, and will contribute greatly to building collaboration, information-sharing and research capacity across the Australian research community.

Levee wall, Charleville, Qld
Image: Michael Jefferies

Priority research questions for climate change adaptation and settlements and infrastructure

1. Urban and regional planning and management

- How can existing urban planning principles and practices accommodate climate change and the uncertainty of climate change impacts? How should these principles and practices differ, based on the location and spatial scale of the settlement? What can we learn about the adaptive capacity of settlements from responses to stresses in the past?
- How can the governance of urban planning in Australia, including formal and informal rules, nationally consistent approaches and guidelines, and locally driven standards and outcomes, and the institutions responsible for decision-making, be improved to facilitate planning processes and outcomes which incorporate adaptation to climate change?
- What are the particular planning needs of remote and Indigenous settlements under a changing climate?

2. Built environment

- What are the design options and principles for adapting new buildings to climate change in different locations, and how can these be implemented?
- What are the design options and principles for adapting existing buildings to climate change in different locations, and how can these be implemented?
- What are the full life-cycle costs and benefits of adapting the built environment and how can they be reliably estimated? Who will bear these costs and who will benefit? What financial and other policy instruments can be used to address the equity impacts of these costs?

3. Vulnerable coastal communities

- How will demographic pressures and changes in different Australian coastal settlement types affect (i) potential impacts of extreme and gradual climate change, and (ii) current policy and regulatory settings which govern decision-making by government agencies, businesses and individuals? How will planning for coastal climate change impacts respond to local circumstances?
- How well do we understand the relationship between climate and coastal processes? How can methods currently used to determine the physical risk on a regional basis of extreme inundation and coastal erosion from climatic and oceanic processes, either singly or in combination, be improved and new methods developed and applied?

4. Infrastructure

- What is the vulnerability of infrastructure (individual and interlinked critical sectors) to existing and predicted climate change conditions at various spatial scales, considering average and extreme weather conditions? How can climate-induced service or structural failure thresholds for infrastructure and services be identified in light of the inherent uncertainty in climate projections?
- What impacts on key infrastructure might have downstream or cascading impacts during extreme climate events, and how might these impacts be avoided?
- What design standards for the average recurrence interval (ARI) and/or average exceedance probability (AEI), and planning periods for the various infrastructure components, should be adopted for particular locations and over what time-frames?

5. Cross–cutting issues

- What would a climate-adapted Australian settlement look like?
- What sectors of society are most vulnerable and least able to adapt to climate change in urban, regional and remote settlements? What is the nature of those vulnerabilities and the barriers to adaptation? How can physical, social, economic and institutional factors reduce their vulnerability and increase their adaptive capacity? At what spatial and temporal scales should adaptation responses for vulnerable communities be developed?
- To what extent can geological/geomorphic/historical/traditional/local knowledge be best applied to assessing vulnerability of existing settlements under different climate change scenarios?

1. Context and objectives

1.1 Background

There is now widespread acceptance that human activities are contributing significantly to climate change and that this change is producing significant physical effects. Since 1950 Australia has experienced a warming between 0.4 and 0.7°C, with more heatwaves, more rain in the north-west and less rain in the southern and eastern regions and an increase in the intensity of droughts. It is generally acknowledged that some of the effects from climate change are now either present or inevitable and that they will become more severe if we do not modify our behaviour. Australia is already experiencing impacts from recent climate change, with increasing stresses on water supply and agriculture, and is expected to face more severe extreme events with more intense and frequent heatwaves, fires, droughts, floods and storm surges (Hennessy et al., 2007).

Human responses to climate change generally fall into two broad categories: mitigation and adaptation. Both mitigation and adaptation help to reduce the risks of climate change. Mitigation requires the implementation of policies to reduce emissions and enhance sinks (IPCC, 2007). Adaptation consists of adjustment in natural or human systems in response to actual or expected climate changes or their effects, which moderates harm or exploits beneficial opportunities (IPCC, 2007). Adaptation actions aim to reduce the impacts of climate stresses on human and natural systems.

Our focus in this National Climate Change Adaptation Research Plan (NARP) for Settlements and Infrastructure is on adaptation. Specifically, this NARP identifies research required to help Australian governments, organisations and communities prepare and respond to likely or inevitable effects of climate change on settlements and infrastructure. It provides a framework to guide research funding decisions and key directions for the country's settlements and infrastructure research community. It is recognised that climate change will be only one of several drivers of change for settlements and infrastructure. Nevertheless, this NARP focuses on identifying research that is likely to inform adaptation to climate change and guide funding priorities within that broader context.

The aims of this NARP are to:

- identify important gaps in the information needed by decision-makers to reduce the vulnerability of settlements and infrastructure to climate change impacts;
- set adaptation research priorities based on these information gaps.

1.2 National policy context for this National Climate Change Adaptation Research Plan

The National Climate Change Adaptation Framework (the Framework) was endorsed by the Council of Australian Governments (COAG) in April 2007 as the basis for government action on adaptation over 5–7 years. The Framework identifies possible actions to assist vulnerable sectors and regions, such as water resources, human health, settlements and infrastructure, and coasts, to adapt to the impacts of climate change. It also identifies actions to enhance the knowledge base underpinning climate change adaptation and to improve national coordination of climate change adaptation research. In 2007 the Australian government provided $126 million over 5 years towards implementing the Framework.

In addition to work at the national level, state and territory governments as well as local government authorities are beginning to consider the impacts of climate change on settlements and infrastructure and the communities they support. Increasingly, professional and industry groups, such as the Institution of Engineers Australia, Infrastructure Partnerships Australia, and the Planning Institute of Australia, are also taking into account climate change impacts in their ongoing activities.

The Australian government established the National Climate Change Adaptation Research Facility (NCCARF), hosted by Griffith University, to coordinate and lead the Australian research community in generating the biophysical, social and economic information and tools needed to facilitate adaptation to climate change. Research outputs will be focused on the needs of decision-makers in government, vulnerable industries and communities as they respond to the range of

Image: Jana Stiller

The primary purpose of this NARP is to set out the priority research agenda for the next 5–7 years to inform a better understanding of climate change risks and impacts on settlements and infrastructure and how these risks can be managed and the impacts reduced through planned adaptation interventions.

potential climate change impacts. A key role of the Facility is to coordinate development of National Climate Change Adaptation Research Plans (NARPs) across NCCARF's eight priority areas:

- Water resources and freshwater biodiversity
- Marine biodiversity and resources
- Terrestrial biodiversity
- Primary industries
- Human health
- Settlements and infrastructure
- Emergency management
- Social, economic and institutional dimensions of adaptation.

NARPs identify critical gaps in the information needed by sectoral decision-makers and set national priorities for research to assist adaptation to expected impacts of climate change. Up to $30 million will be invested in priority research for key sectors as identified in these NARPs. These Research Plans are being developed in partnership with governments, stakeholders and researchers.

1.3 Development of this National Climate Change Adaptation Research Plan

The development of the NARP for Settlements and Infrastructure was led by the following drafting team: Professor Bruce Thom (Chair), Ms. Jennifer Cane (DSE, Victoria), Associate Professor Ron Cox (UNSW), Ms. Catherine Farrell (DCCEE), Professor Peter Hayes (RMIT), Dr. Robert Kay (Coastal Zone Management Pty Ltd), Mr. Allen Kearns (CSIRO), Associate Professor Darryl Low Choy (Griffith University), Professor John McAneney (Macquarie University), Professor Jan McDonald (Griffith University), Mr. Michael Nolan (Maunsell AECOM), Professor Barbara Norman (University of Canberra), Professor Jonathan Nott (JCU) and Professor Tim Smith (USC).

The drafting team has developed this Plan following three national 1.5-day workshops for key stakeholders and researchers with an interest in settlements and infrastructure held in April–May 2009 in Cairns, Adelaide and Sydney. These workshops addressed the core issues of built environment, urban and regional planning and management, vulnerable coastal communities and infrastructure. An Issues Paper was prepared and distributed to the participants to form the basis for discussion and elicit comments from the stakeholders on their adaptation issues and information needs.

More than 100 participants from a wide range of stakeholder groups attended these workshops, including: representatives from state and territory governments' planning, infrastructure, transport and environment agencies; local government agencies; water authorities; coastal management and port authorities; natural resource managers; researchers from universities and national research agencies/centres; engineers (e.g., water, civil, electrical); insurers/re-insurers; architects; property developers; representatives from the construction and transport industries; and associations working on sustainability, livelihood and Indigenous issues.

Discussions during these workshops and feedback on the Issues Paper provided valuable insights into decision-makers' and stakeholders' information needs and research priorities, and are reflected in this Research Plan.

1.4 The scope of this National Climate Change Adaptation Research Plan

The NARP for Settlements and Infrastructure identifies critical gaps in the information needed to address the full range of issues arising from potential impacts of climate change on settlements and infrastructure. The primary purpose of this NARP is to set out the priority research agenda for the next 5–7 years to inform a better understanding of climate change risks and impacts on settlements and infrastructure and how these risks can be managed and the impacts reduced through planned adaptation interventions.

Implementation of the Research Plan will help inform a range of strategic activities including:

- understanding and responding to community expectations concerning the built environment and its amenity;
- assessing the vulnerabilities of human settlements, taking into account differences in size, location, demography, and socio-economic and environmental circumstances;
- assessing the vulnerability of infrastructure at various spatial scales under both average and extreme weather conditions;
- informing the revision of building codes and other standards as well as retrofitting measures to reduce vulnerability of infrastructure and buildings to climate change impacts;
- promoting a more coordinated approach to urban and regional planning policy across jurisdictions and between all levels of government;
- embedding climate change consideration into ongoing urban and regional planning, including planning for coastal settlements, and decision-making processes;
- assigning priorities in the choice of adaptive strategies;
- developing appropriate government policy responses to inequities that arise as a result of the differential impacts of climate change on vulnerable communities.

This NARP will provide further stimulus to future thinking about how best to study the risks to settlements and infrastructure, approaches to developing effective adaptation responses and consideration of how to include these issues into policy developments and adaptive strategies within other related sectors.

There are many stakeholders who have a need for improved knowledge on precisely how, where and when the various components of climate change, acting singly or in combination, will require the introduction of adaptation strategies that will remove or reduce adverse impacts on property, industry, services and infrastructure, and their related communities.

This Research Plan recognises that climate change adaptation issues are important to Indigenous communities around Australia. We recognise that these issues are critical. They will be considered more fully through a NARP on Indigenous Communities.

This NARP will support adaptation efforts by identifying research priorities that are most relevant to the needs of stakeholders.

This NARP will provide further stimulus to future thinking about how best to study the risks to settlements and infrastructure, approaches to developing effective adaptation responses and consideration of how to include these issues into policy developments and adaptive strategies within other related sectors.

These priorities form a basis for improved decision-making and adaptive capacity across all levels of government, the private sector, community groups, property owners and developers and the professions engaged in urban and regional planning, design and infrastructure provision.
The Research Plan will reference past and current research into the impacts of climate change, including research on coastal settlements; public and private infrastructure including building and facility design and construction; urban water security; flooding and stormwater overflow; the social, economic and institutional implications of these impacts; and implications for urban and regional planning, design, and management of settlements and infrastructure.

Many research questions related to settlements and infrastructure show close affinities between measures intended to reduce emissions and measures introduced to adapt to the impacts of climate change. While there has been no explicit attempt in this NARP to exclude mitigation issues, the emphasis of this NARP is clearly on adaptation strategies.

This NARP is structured around four themes, which relate to both the issues and structures that are vulnerable to the impacts of climate change. While there are overlaps between some research questions in each of the themes, they individually offer scope for development of research priorities across different sectoral interests, time-scales and, especially, different spatial scales.

The themes are:

- Urban and regional planning and management
- Built environment
- Vulnerable coastal communities
- Infrastructure.

An analysis of research priorities that have emerged from consideration of these four themes reveals a set of cross-cutting research questions. These questions, which are listed after the discussion of the individual themes, have overlapping elements with each of the themes and provide an additional set of research priorities to those developed for each theme.

Overlaps and synergies between the scope of issues addressed in this NARP and those addressed in other NARPs are considered below. Section 2 outlines the projected impacts of climate change and the need for adaptation to these impacts for settlements and infrastructure. Section 3 discusses stakeholder information

Image: Donald Y Tong

needs and formulates research questions for the four themes described above. Section 4 outlines the process and criteria used to prioritise those research questions and lists the research priorities ranked as high priority. The full prioritisation matrix for all research questions is in Appendix 2. Section 5 concludes this NARP by discussing implementation issues.

A fundamental input to achieving the research activities described in this NARP is sound climate projections pertaining to parameters and scales that are relevant to the risks and vulnerabilities of the sectors and interests on which this Research Plan is focused. This input will require ongoing research to better understand climate change and its impacts at a regional level. In particular, better information is required about what extreme events are likely to be experienced at regional and local levels, and what their frequency, intensity and scale are likely to be. The research to develop this information will be undertaken as part of the Australian Climate Change Science Program.

The discussion throughout this NARP is drawn from and supported by a range of sources. To improve readability, references in the text have been minimised. A broader list of references is included in the Suggested Reading section of this NARP (Section 7).

1.5 Links to and synergies with other National Climate Change Adaptation Research Plans

Adaptation policies and strategies for settlements and infrastructure will necessarily affect and be affected by parallel strategies addressing the impacts of climate change on human health, biodiversity, primary industries, emergency management, water, and social, economic and institutional issues. Some of the relationships and linkages between this NARP for Settlements and Infrastructure and other NARPs, either completed or in preparation, are set out in Table 1. The implementation plans for these NARPs will ensure that the research priorities identified in these Research Plans are complementary and mutually supportive and will seek to avoid duplication of research effort.

Table 1. Links between NARP for Settlements and Infrastructure and other NARPs

Theme	Cross-cutting issues to be addressed in the Settlements and Infrastructure NARP
Human Health (completed December 2008)	▪ The adequacy of current health infrastructure and work force to cope with extreme weather events ▪ The need for building design and urban form to reduce risks of heat stress and minimise urban heat islands ▪ Building standards to accommodate impacts of climate change through increased wind resistance, flood-proofing, insulation etc ▪ Water security systems for human settlements (supply and water quality) ▪ Capacity and resilience of key infrastructure
Emergency Management (completed September 2009)	▪ Urban and post-disaster planning and construction to reduce vulnerability to extreme weather events ▪ Balancing urban development and private interests against community risk ▪ Rationalisation of planning thresholds for various natural perils; e.g., the 1-in-100 year event annual exceedance probability (AEP) enshrined in floodplain management policy and legislation versus the 1-in-500 year seismic ground shaking threshold for life safety in buildings ▪ Learning from disasters rather than planning for their repetition ▪ Capacity and resilience of key infrastructure
Marine Biodiversity and Resources (completed August 2009)	▪ Coastal storm/tide protection/fortification ▪ Ecosystem resilience and its impacts on biodiversity ▪ Planning of coastal zone for conservation and urban development ▪ Protection of urban beaches – sand replenishment ▪ The need for coastal planning to integrate potential shifts in fishing and aquaculture operations and the associated needs for available coastal land and infrastructure
Terrestrial Biodiversity (completed January 2010)	▪ The special adaptation needs of intra-urban and peri-urban conservation areas ▪ Fire risk and management ▪ Demographic shifts in response to climate change and resulting conversion of habitat to housing and infrastructure
Freshwater biodiversity (Consultation draft in preparation; DEWHA's Water Knowledge Strategy will focus on non-biodiversity-related climate change and water issues)	▪ The Water NARP is mainly concerned with freshwater biodiversity: river and wetland health, environmental flow and biodiversity issues
Primary Industries (completed May 2010)	▪ Planning and management of peri-urban areas ▪ Protection of good-quality agricultural land ▪ Management of city-dependent peri-urban agricultural activities (e.g., horticulture) ▪ Planning and management for rural-based industries
Social, Economic and Institutional Dimensions (completed May 2010)	▪ Social justice and institutional issues relating specifically to adaptation needs for human settlements ▪ Social and economic aspects of community vulnerability, resilience and adaptation, equity aspects of climate change impacts ▪ Psychological impact of increased risk of drought, cyclones, bushfires etc. on communities
Indigenous Communities (Consultation draft 2010)	▪ Cross-cutting issues to be identified during the writing of the NARP for Indigenous Communities

2. The impacts of climate change on settlements and infrastructure and the need for adaptation

Climate change poses significant threats to the social fabric of our towns and cities and to urban and strategic infrastructure. Figure 1 illustrates how, for any given region, there can be a shift in averages and extremes of climate variables. Settlements and infrastructure will experience stress from the transition to new climate conditions as well as from the new conditions themselves. Moreover, settlements and infrastructure will need to adapt to ongoing changing conditions as well as to the projected future climate at any particular time. Settlements and infrastructure will also be affected by a range of social, institutional, political and economic factors, which may facilitate or impede progress towards adapting to the changes induced by global warming.

Climate change is likely to result in increased damage to buildings (e.g., concrete joints, steel and asphalt), energy services, telecommunications, transport structures (e.g., roads, railways, ports and bridges) and water services (IPCC, 2007; PMSEIC Independent Working Group, 2007; ATSE, 2008). Higher summer temperatures, for example, are expected to affect energy services by reducing transmission line conductivity and thus energy transmission efficiency. More frequent and intense extreme weather events are likely to damage transport and electricity transmission infrastructure and services. More frequent extreme daily rainfall events are expected to affect the capacity and maintenance of stormwater, drainage

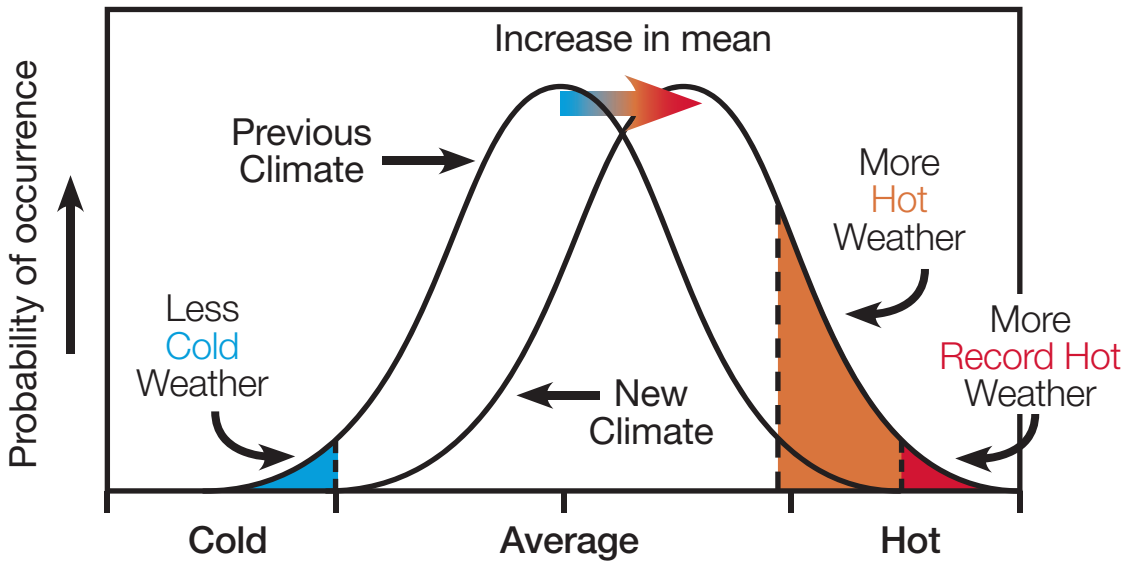


Figure 1. Effect of an increase in average temperature on extreme temperatures (Solomon et al., 2007)

Climate change poses significant threats to the social fabric of our towns and cities and to urban and strategic infrastructure.

Image: Robert Myers

and sewerage infrastructure. Higher ambient temperatures will increase warm season energy demand by individual households, businesses and public facilities in many areas but may reduce cold-season energy demand, affecting utilities and construction requirements that must be incorporated into future management and planning of the nation's settlements. Tipping points[1] are likely to be reached when the capacity of a given infrastructure or service provision is exceeded, requiring major investments in protective infrastructure needed to prevent catastrophic failure of essential physical assets and services. All of these impacts are likely to affect the quality of life and safety of the residents of affected communities. Property owners or major infrastructure managers such as port authorities need to make decisions in advance of a tipping point being reached. By 2030, design criteria for extreme events are very likely to be exceeded more frequently (Hennessy et al., 2007). Many decisions relating to settlements and infrastructure are being made now, including statutory land-use plans, building codes, design standards, and infrastructure development, maintenance, replacement or refurbishment. They come with long-term commitments and can have consequences for periods of 30–200 years or more (Hallegatte, 2009). These decisions and associated investments will therefore need to take into account future climate conditions.

Coastal settlements and infrastructure will be especially vulnerable to the effects of climate change such as sea-level rise, increased air and sea surface temperature, increased storm intensity and frequency, ocean acidification, and changes to rainfall and runoff. Sea-level rise will cause greater coastal inundation, erosion, loss of wetlands and saltwater intrusion into freshwater sources, with impacts on infrastructure, coastal resources and existing coastal management programs (IPCC, 2007). The concentration of urban development along our coast intensifies these exposures (Chen and McAneney, 2006). Over 80% of the population in Australia lives in the coastal zone (Hennessy et al., 2007; see also Garnaut, 2008). By 2050, current trends of population growth and ongoing coastal development, especially in areas such as Cairns, south-east Queensland and south-west Western Australia are likely to exacerbate risks from sea-level rise and from increases in the severity and frequency of storms and coastal flooding (Hennessy et al., 2007; Gurran et al., 2008). Remote communities, including Indigenous communities, may be severely impacted by climate change, especially sea-level rise. Cultural links of Indigenous communities to sea country create some highly sensitive issues when examining potential adaptation strategies to climate change.

The vulnerability of Australian settlements will vary depending on a range of factors, including their form and size, location, geography and economy. Vulnerability is a function of the extent to which a system is exposed to climatic effects, the sensitivity or responsiveness of the system to climatic influences, and the degree to which a system can adapt to change, i.e., its adaptive capacity (IPCC, 2001). This concept of vulnerability can be used in the assessment of risk that any community may face under specified or projected conditions of climate change. Changing conditions for a given place can be studied as scenarios through mechanisms of visualisation and other means of communicating risk and developing adaptive strategies including trade-offs. Individuals, communities, professions and decision-makers may then see the potential damage of climate change in vulnerable areas and, most important, assess how different adaptation options in terms of costs, benefits, liabilities and political trade-offs can be developed and implemented.

While the vulnerabilities of human settlements are acknowledged and understood in general terms, quantification on a local scale will better assist with planning and management for adaptation. Research efforts into effective and equitable adaptation responses will reduce the current levels of knowledge deficit and uncertainty. However, decision-makers face many uncertainties in meeting the challenges of climate change, and some uncertainty will not be reducible. The vulnerability of Australia's highly urbanised society requires close investigation

1 A tipping point refers to the critical point at which a small perturbation leads to or initiates a transition from one state to another or a change in the characteristics of a system.

across the hierarchy of settlements, including capital cities, new greenfield peri-urban settlements, inland towns, and remote, rural and Indigenous settlements, across Australia's diverse geographical and climatic contexts from the tropics to cool temperate zones.

Research in this area will require a systematic application of knowledge from a range of disciplines – including climate change science; geomorphology and hydrology; urban planning, design and management; material science and engineering; and human behaviour and other social sciences – to analyse how climate change is likely to affect our settlements and infrastructure. Economics and actuarial studies, psychology, cultural studies, public policy, communication theory and other social sciences will also be implicated in the development of adaptation strategies to respond to those effects. Most adaptation planning and implementation activities will require information from a variety of disciplines.

Developing appropriate adaptation responses will be critical in reducing the impacts of climate change on settlements and infrastructure. A variety of adaptations have already been identified, including revising, renewing and enforcing building codes to take account of changing climatic conditions, introducing consistent planning measures (e.g., planned retreat, dune management, building design, and regulation of new structures), and managing urban sprawl in climate-sensitive areas through zoning and regulation (PMSEIC Independent Working Group, 2007). Recent parliamentary inquiries are disclosing many of the issues confronting coastal and other settlements in relation to the potential impacts of climate change (see House of Representatives Standing Committee, 2009; NSW Legislative Assembly, 2009). However, much still remains to be done, especially in implementing adaptation responses and in promoting shifts in the behaviour and expectations of urban, regional and remote area populations. There are many barriers to adaptation for settlements and infrastructure, including lack of appropriate information and data as well as access to such information and data, institutional inertia and resistance to change, uncertainty in climate change impacts, and the existing urban envelope and infrastructural legacies which limit the response options. Recognition of such barriers as well as potential limits to adaptation is a necessary part of any attempt to develop and implement adaptation strategies.

Taking climate change into account in decisions relating to settlements and infrastructure remains a challenge for three reasons. First, changing climatic conditions will impact in different ways on various types and locations of settlements and infrastructure in Australia. Second, because future climate conditions remain inherently uncertain it will be critical to communicate risk scenarios based on probabilities to property owners, developers, investors in infrastructure, insurers and service providers and to develop further frameworks and tools that explicitly communicate residual uncertainties. Finally, these decisions will be made in the context of many other interrelated and to some extent competing issues, which require attention in both the short and long term and involve priorities and attitudes that may not see climate change impacts as relevant or important. Yet the magnitude of impacts that are likely to affect Australians as a result of climate change necessitates a program of detailed research into adaptation issues that, unless undertaken, could lead to local, regional and national crises affecting the sustainability of Australian society. Both research and adaptation responses will remain ongoing iterative processes as the specific impacts of climate change become better understood and more evident.

3. Information needs and key research questions

3.1 Urban and regional planning and management

Urban and regional planning is a process developed to manage, guide and direct change in urban and regional systems to protect social and environmental values, gain economic, social and environmental benefits, and achieve efficiency in both the system and the change process. Planning activities determine the arrangement of uses over a region and landscape, how land can be used, the resulting traffic and transport and other infrastructure locations and corridors, how and where waste is collected and disposed of, where cultural or sports activities will be focused, and every other locational aspect of the human-built environment.

The magnitude and rate of climate change will significantly test the statutory planning system that has underpinned urban management in Australia over the last 100 years. Sea-level rise and increased storm surge and temperatures will all introduce new uncertainties. Some will, potentially, bring non-linear variable or unpredictable changes which will require a highly adaptive and responsive approach to urban planning. Urban planning and emergency management systems will need to be more closely connected and may lead to new approaches to how we plan and manage future settlements and infrastructure. However, the systems basis, information and evidence-based analytical approach and participatory nature of Australia's planning process are inherent qualities that support adaptation capacities.

3.1.1 Stakeholders and key impacts of climate change

Virtually every Australian citizen resides and every business operates in a community or rural area which is subject to and benefits from urban and regional planning processes and the decisions resulting from them made at the local, regional or state/territory level. Governments at all levels avoid risk to citizens and their property and well-being, and to community infrastructure and services.

Stakeholders in planning decisions thus include communities, residential and business property owners and occupiers, the construction industry (architects, developers and builders), insurers, transport and other infrastructure and service owners, operators and users, and local, state and territory and Australian government decision-makers and advisors. The specific group of stakeholders concerned with any particular risk, impact, location or decision depends on perceptions of the potential implications of decisions affecting the location and stakeholder groups. Thus determining the relevant stakeholders for any particular circumstance can be challenging.

Sea-level rise, rising temperatures and potentially more extreme weather events point to some of the future climate change impacts on Australian cities and infrastructure. The way in which large urban centres both generate and trap heat and thereby create 'heat banks' or 'heat islands', the bushfire risks of the urban fringe and the flooding of coastal and low-lying settlements are all expected to challenge the quality of life in our urban centres. Urban and regional planning can make a critical contribution to increasing the resilience of existing and new settlements and infrastructure.

The impacts of climate change will not fall equally throughout Australia, and the size and location of settlements could affect impacts and responses in major cities, regional townships, and remote and rural settlements. The density of population, complexity of the built environment and scale of infrastructure in capital cities will bring particular challenges. The location of urban settlements will also lead to different impacts. For example, in northern Australia, increased extreme weather events including cyclones will impact cities such as Cairns and Darwin, and a southward movement of cyclones would result in other urban centres being affected. Rising temperatures and lower rainfall in southern Australia will bring prolonged drought and increasing risks of heat stress and bushfires to major urban centres, such as Melbourne, Adelaide and Perth and many smaller cities and towns. Regional townships may have their own shared set of issues such as distance from essential services and limited alternative options, such as temporary housing or shelters in an emergency situation. The costs of gathering

Image: Dean Kennedy

evidence-based research on these types of localised climate change impacts may be prohibitive to individual local councils in regional areas. Remote and Indigenous settlements will have specific climate change vulnerabilities, some derived from cultural values and others resulting from their economic and environmental circumstances.

3.1.2 Adaptation options and adaptive capacity

Planning is concerned with the management of natural and human-induced change, which can be positive or negative and which can at times be rapid.

The spatial impact of urban and regional planning is critical for climate change adaptation and requires an understanding of what climate change adaptation means for 'place', the process of planning and the possible consequences for urban governance. Additionally, cities, urban settlements and rural communities do not exist in isolation but are inextricably linked into a wider region on which they rely for a broad range of services and functions. For example, the city region provides essential physical infrastructure for the city, outdoor recreation opportunities for urban dwellers and is a source of food, ecosystem services and open space. The protection of good-quality agricultural land and the proper management of rural-based activities and industry, peri-urban agriculture and peri-urban areas in response to climate change are consistent research themes across this NARP and others such as the Primary Industries NARP. Mutual dependence between urban and rural regions and overlapping jurisdictional responsibility both complicate and facilitate integrated responses, but also increase adaptation options.

Urban and regional planning responses will require a suite of adaptive measures. These will range in policy objective from defending existing infrastructure to modifying the built environment and urban form, to retreating and, in some cases, to abandoning existing areas. Significant retrofitting of existing built form may be required in the large cities, although rebuilding or alteration in high-risk zones may be economically unfeasible and the relocation of whole coastal townships may be required.

Most forms of urban planning offer opportunities for communities to reduce risk and adapt to changing climatic regimes. Urban planning and management occurs across a wide range of spatial scales and landscapes from local scale through regional and state/territory to national, and including urban, peri-urban, regional and rural landscapes. Planning also occurs across temporal scales, e.g., short- and medium-term (structure plans) to long-term (strategic plans). In addition, it occurs across a number of legal contexts involving statutory and non-

Image: Matthew Godfrey

statutory planning. Urban planners face the combined challenges of how to modify existing urban landscapes to deal with projected climate change impacts and how to minimise future impacts by avoiding or modifying new development in areas of high vulnerability.

Urban and regional planning in Australia is predominantly governed at the state/territory and local levels, where a range of tools is applied to manage urban growth and regional development. These include dedicated planning legislation in each state and territory, supported by a variety of regulatory mechanisms at local level, regional and metropolitan plans for major cities, and regional planning in some non-metropolitan areas. All these spatial planning processes and instruments involve a wide range of stakeholders across government, non-government, industry and communities.

Urban and regional planning which is directed towards or includes the impacts of climate change will add to these already complex arrangements and may bring new alliances of stakeholders, such as government, urban planners, the insurance industry and social scientists, to plan for 'urban climate change risk'. For example, to minimise impacts on existing communities, urban planning for existing settlements and infrastructure will require closer connections between the 'built form' professions, climate change scientists, natural resource managers, insurance providers, and emergency management officials. Engagement of the communities in this process will be essential in order to gain understanding for local knowledge and acceptance of and legitimacy for possible adaptive strategies. The Local Government and Planning Minister's Council (LGPMC) has a potential role in assisting the integration of climate change adaptation principles into existing guidelines and in consolidating existing guidelines across local government areas.

Planning is exercised through deliberately designed interventions into the natural and human processes of change affecting, or expected to affect, our landscapes. Essentially, urban planning achieves this through two principal foci; namely (1) a development control focus (the day-to-day matters of managing the development in urban settlements) and (2) a strategic focus (forward planning that sets directions and pathways for the future location and form of settlement and land use). Adaptation options for climate change through planning will need to address both foci. Incorporating climate change considerations into the development control process will help minimise the impacts of climate change on settlements and infrastructure through modifying zonings and regulations in statutory planning schemes.

Contemporary approaches to planning increasingly adopt performance-based approaches in order to encourage innovative designs that are unconstrained by regulations or prohibitions associated with the prescribed land-use zones of traditional statutory planning. Performance-based planning relies on being informed by reliable and robust science. However, we do not yet have the necessary science to support these approaches across the full spectrum of statutory urban and regional planning activity. Nor are the science requirements of the different forms of planning fully understood. Caution will need to be exercised against an over-reliance on modelling and a desire for 'accurate' predictions of future climate change, especially as we are dealing with a highly uncertain climate future. Specifically, we will need to explore ways to embed climate change science into planning, particularly the planning instruments and tools of statutory plans, if we are to take full advantage of the opportunities for climate change adaptation that urban planning offers.

Strategic planning will need to address adaptation measures in respect of issues such as:

- managing urban sprawl in climate-sensitive areas and to protect ecosystem services;
- minimising the heat island effects of high density urban areas;
- retrofitting existing urban areas, including the modification of urban form to accommodate the adaptability of older communities to the adverse effects of climate change (e.g., thermal or heat stress);
- incorporating climate change into risk assessments;

- managing inundation, flooding and stormwater;
- in some instances, a planned strategic retreat from highly exposed areas.

Historically, the design of most planning systems has limited their ability to incorporate new understanding of environmental change. A cyclic (continuous) planning process could incorporate an adaptive management framework that can account for short- and long-term change and uncertainty: two key dimensions of climate change. In this manner, decision-makers in government, vulnerable industries and communities can develop and progress policies and plans through a process of adaptive response which acknowledges 'imperfect knowledge' with a high degree of confidence that policies can be adapted in the light of subsequent new learning.

A priority challenge is therefore to ensure that both statutory and non-statutory planning is informed by climate change science, while taking an adaptive management approach. To a large extent this will rely on the relatively unknown adaptive capacities of planning and natural resource management agencies at all levels of government and the non-government sector, industry and communities. These may include innovative approaches that can deliver multiple adaptation benefits across sectors. For example, recent research points to the considerable potential for co-benefits of biodiversity-led adaptation initiatives. This includes the use of mangrove and coastal revegetation to protect vulnerable shorelines from sea-level rise and storm surge, and the promotion of urban green spaces as a means of offsetting 'heat island' effects while also creating wildlife refuges.

The implementation of adaptation responses will need to understand the process of promoting shifts in the behaviour and expectations of urban populations and institutions and other key stakeholders in the planning process. Achieving resilient urban settlements and communities adapted to climate change will require a new renegotiated collaborative planning approach, to bridge multiple landscape managers and to align the various plans and policies from the complex layers of governance in which planning occurs.

3.1.3 Information needs

There are four main information needs for adaptive response in urban planning and management:

1. **to assess the vulnerability of particular communities and locations;**
2. **to provide historical and current information that informs and supports future adaptation;**
3. **to fill information gaps that hinder or obstruct adaptation;**
4. **to provide information management, strategies, and decision tools to guide information producers and consumers towards useful information with which to adapt to climate change.**

Community vulnerability

Reliable information for estimating future risk will help urban planners and policy-makers implement land-use strategies, map and reduce vulnerable populations and determine resilient spatial design, critical infrastructure, and density planning goals. It can also help communities and households to make informed decisions. While planners must also learn to operate under conditions of ongoing change and irreducible uncertainty, accurate digital elevation and climate-related natural hazard mapping using GIS and similar tools, geophysical accounting, downscaled climate change and impacts modelling, and social and economic analysis of impacts and adaptive responses are needed across all scales of the Australian settlements hierarchy. In particular, research is needed on the dimensions of adaptive capacity of various parts of the urban landscape and the community which are relevant to urban planners and managers. This will enable adaptation resources to be focused where most required and useful, from inner city to suburban and peri-urban areas, and between various community sectors. Understanding how locations or communities having low adaptive capacity increase the vulnerability of urban systems and vice versa will also be valuable. Maintaining flexible approaches to uncertain future conditions will be essential.

To respond to this vulnerability mapping, improved and integrated quantitative and

qualitative data on impacts and responses are needed in order to identify priorities for decision-makers and policy-makers to develop adaptive responses in urban planning and management. Some of these data exist already, but need to be compiled. For example, historical information exists on adaptive responses to past flooding and on the efficacy of various institutional and behavioural responses thereto. Similarly, data exist on the housing stock and householder investment in responding to thermal stress in buildings (insulation and air conditioning), on the one hand, and water management, on the other. These data need to be collected, analysed and integrated, so that adaptive responses are developed that integrate distributed water management strategies for climate adaptation with building design, materials choice, thermal efficiency, and heat management strategies. These choices will be affected by climatic zone and by institutional choices, and must therefore include social and economic analysis of the housing market, including barriers that arise from market failures as well as cultural studies of occupant behaviour and choices under different information conditions.

Historical information

Australian settlements have experienced many external pressures in the past. While climate change will present different and ongoing adaptation challenges, the way in which communities in these settlements adapted to these previous pressures is an important source of information on their potential adaptive capacity in respect of future climate impacts and the efficacy of existing adaptation response programs. Such information will also reveal the degree to which settlements have responded autonomously and how much they depended on government support or regulation to make transitions due to technological disruption, globalisation of markets, global conflict, large-scale immigration, etc. Research may also show what policy changes resulted in social and institutional learning, especially comparative case studies using a consistent framework that accounts explicitly for local and regional variation in climate, scale and socio-economic variables. Case studies may also be needed to establish baselines against which future studies can measure change and adaptive response. Such studies might also provide insight into the economic costs and benefits of different urban planning and management adaptive responses, and the impact of these on municipal assets and tax revenues.

Traditional knowledge (that is, tacit, artisanal and locale-specific information that is handed down over generations) may also be critically important to tailoring generic adaptive strategies to a particular settlement. Indigenous knowledge may also provide an important insight into the landscape and cultural values that are at risk, as well as management strategies in the face of climate impacts.

Overcoming barriers to adaptation

Research into strategic planning and policy and regulatory frameworks under conditions of increasing complexity, and the response of local governments to different land-use and resource management policies and institutions, is particularly important, given that much adaptation occurs on a local scale. Studies of community receptivity to change in matters such as building codes, planning zones and service availability after catastrophic events may be useful in the climate context, especially as risk data for coastal and other vulnerable settlements become available to financiers, insurers, real estate agents, and current and prospective purchasers. Information about the best techniques to promote integrated mitigation/adaptation solutions that support adaptation across more than one sector will enhance decision-making about future urban form and structure. Research into the future aspirations, goals and preferences of Australians as to what kind of settlements they want to live in, the educational and media influences on these orientations, and how to gain community engagement and support for climate change adaptation responses will cast light on cultural resilience versus rigidity, and on possible barriers to adaptive responses to climate impacts.

Information for effective adaptation is often costly to create and of high value to users. The extent to which such information should be available as a public good rather than a privately supplied service involves many trade-offs and

is a research topic in its own right. The impact of asymmetric information and of information disparities between different interests, both locally and across scales, will affect the equity and efficiency of outcomes in both market and non-market-based adaptive strategies. Research into analogous issues may cast light on how to manage critical information and impacts in the climate change adaptation context. Research is also needed urgently on appropriate protocols for ensuring equal access to critical information, the use of information created in the course of adaptive response, the rules for protection of proprietary but critically needed data disclosure, and the range of possible rules for sharing and ownership of data sets, tools, and information management techniques. Two important research questions are: (i) What mix of 'discovery' research into climate adaptation response, driven by which disciplinary and sector-based imperatives, will work best with research focused on practitioner knowledge based on multiple stakeholders? (ii) How can these two types of information be integrated effectively in the process of their creation and use, and how can this process be user-driven?

Knowledge uptake

Finally, research is needed on what type of information portals and networks will serve Australian settlements in their planning response and help them to manage the impacts of climate change. Such information systems could be integrated with existing sustainability schemes such as BASIX in New South Wales (green rating of buildings). On the other hand, it could be argued that climate change demands a distinct strategy aimed at embedding key issues into the mainstream information systems of all the major players in Australian urban planning and management, including officials, corporations, civil society entities such as professional associations, universities, etc. Moreover, providing the information necessary to enable communities to change their expectations and behaviours can play a major role in increasing the adaptive capacity of communities without incurring significant costs. If a discrete system is established, questions arise about its design, including whether it should match or traverse jurisdictional boundaries and whether it should be self-organising in response to complexity and rapid change. An open-source repository of essential data, standards, planning approaches, and tool 'wizards' (such as UKCIP[2] or integrated assessment tools) can facilitate rapid exploration and communication of the planning issues posed by climate change.

Providing the information necessary to enable communities to change their expectations and behaviours can play a major role in increasing the adaptive capacity of communities without incurring significant costs.

2 UK Climate Impacts Programme (see http://www.ukcip.org.uk/)

3.1.4 Research priorities

From the analysis of issues facing urban planning and the information needs identified above, the following research priorities emerge:

1. **How can existing urban planning principles and practices accommodate climate change and the uncertainty of climate change impacts? How should these principles and practices differ, based on the location and spatial scale of the settlement? What can we learn about the adaptive capacity of settlements from responses to stresses in the past?**
2. **How can planning approaches address the multiple objectives of urban adaptation to climate change impacts, mitigation of greenhouse gas emissions, and biodiversity conservation?**
3. **How can the governance of urban planning in Australia, including formal and informal rules, nationally consistent approaches and guidelines and locally driven standards and outcomes, and the institutions responsible for decision-making, be improved to facilitate planning processes and outcomes which incorporate adaptation to climate change?**
4. **What are the particular planning needs of remote and Indigenous settlements under a changing climate?**
5. **What information about urban and regional planning and climate change impacts, in what form and at what resolution, should be publicly available? How should climate change impacts and adaptation information be presented and made available to urban and regional planning decision-makers?**

3.2 Built environment

3.2.1 Stakeholders and key impacts of climate change

The built environment in this context refers to human-built structures from large-scale civic buildings to personal dwellings, the space in between such structures and their spatial arrangement on the landscape.

The impacts of climate change coupled with significant demographic changes and population increases in vulnerable areas greatly increases the need for society to develop effective means for adapting to a warmer climate. However, because most of Australia's 2025 built environment is already in place, we must find efficient and effective strategies for modifying or retrofitting this environment to enable

Image: Adam Zaborszczyk

it to adapt to changes imposed by climate and demographic pressures. The 2009 heatwave in southern Australia highlighted the need to design the built environment to be resilient and adaptable in the face of localised and large-scale extreme weather events.

Consideration of how climate variables affect the utility and sustainability of the built environment is an inherent part of the traditional urban design process. Integrated urban design and development now needs to recognise climate as a variable factor that has implications for how design, materials, structures, parks and other natural areas and human behaviours are adapted for future Australian communities and how they can help communities adapt to future climate conditions.

Government regulators, the construction industry and developers especially need to embrace climate change when designing new developments and renovating existing structures. However, as previously discussed, the biggest differences to raising the resilience of communities would come from improving the existing stock of buildings. The Australian Building Codes Board has representative participation from all states and territories and seeks national agreement and adoption of any changes it introduces. Thus the wind code regulations are national. However such regulations are not retrospective and finding mechanisms and incentives to encourage retrofitting of the existing building stock to be better adapted to both the current and future climate remains a significant challenge.

Another aspect of the built environment that complicates design for climate change is the resistance to change resulting from deep infrastructural legacies of historical decisions and incumbent sectoral and local interests in government, industries and communities. For example, the long-term dominant use of fossil fuels for energy generation for heating, ventilation and cooling and transport increases greenhouse gas emissions and constrains design innovation for dispersed energy sources. Least-cost alternatives need to be developed for ensuring human thermal comfort in a warmer climate, such as through the adoption of options such as passive ventilation and cooling systems which are adapted to climate change.

There is considerable uncertainty about the timing and intensity of future climate change, especially at regional and local scales. Nonetheless decisions about developments, many of them irreversible, will continue to be made, and these increasingly need to take into account an awareness of both climate change and uncertainty about its specific local implications. One sensible approach for large investments is to undertake staged developments that allow for future expansion or additional adaptive features to be implemented contingent on certain climatic thresholds being

Image: Nurbis

Many simple but effective adaptation options that increase local employment and participation in climate adaptation activities are possible at a local scale.

surpassed (such as the Thames Estuary 2100 plan, which anticipates ongoing modification). These so-called 'real options' allow for learning and flexibility in planning and design decisions prior to full commitment of scarce resources. This type of option development and maintenance can add value to projects in a way that can be priced with modern financial tools that avoid the pitfalls associated with the traditional Net Present Value calculations often used for cost–benefit analyses. This is also a significant issue for infrastructure financing (see Section 3.4).

Stakeholders concerned with the built environment include:

- individual groups and communities who use or are affected by buildings;
- Australian, state, territory and local governments, who regulate the construction industry, urban development and home additions and modifications;
- at-risk groups, including Indigenous communities, who seek guidance on how to adapt and prepare for the consequences of future extreme weather events;
- urban managers and elected representatives of local government faced with deciding upon development alternatives in the face of considerable uncertainty about the costs, consequences and time horizon of future climate change impacts;
- development design and production professions and industries such as architects, engineers, surveyors, landscape architects, planners and urban designers, building maintenance and construction industries, as individuals in companies, government departments and professional societies;
- social service planners and providers;
- financial institutions such as banks who are keen to avoid losses associated with climate impacts;
- the real estate and property management sectors who are the interface between the direct stakeholders;
- insurance companies who are developing long-term policy responses to insuring risks from extreme weather events;
- policy-makers faced with establishing long-term planning, legal and regulatory frameworks and investments in future built environments in areas anticipated to be exposed to weather extremes and population increase;
- property owners and leaseholders who will ultimately bear much of the risk;
- emergency management services, who seek to reduce risks from natural hazards through prevention preparedness and to respond to calls for assistance from owners and leaseholders of buildings damaged by extreme events and support recovery.

3.2.2 Adaptation options and adaptive capacity

Australia has the design and professional basis to support considerable adaptive capacity, with good universities and schools, skilled architects, engineers and tradespeople, and a well-developed national regulatory mechanism via the Australian Building Codes Board (ABCB). These professions are very capable of responding to the challenge and need to be encouraged to embrace global climate change in their activities through appropriate regulatory change. One of the best examples worldwide of adaptation to the physical environment is the influence of building regulations that stipulate more wind-resistant construction in tropical cyclone-prone areas of Australia. These enhancements were introduced in the wake of devastating losses caused by Tropical Cyclones Althea in 1971 and Tracy, which in 1974 almost completely destroyed Darwin. As a result of these construction changes, newer buildings are now generally much less vulnerable to wind damage. The ABCB is reviewing the Buildings Code of Australia for climate changes.

Many simple but effective adaptation options that increase local employment and participation in climate adaptation activities are possible at a local scale. Examples could include designing and constructing local transport facilities above peak flood levels, provided that their construction does not impede the flow of floodwaters, making these more dangerous. Similar local-scale adaptations include increasing the numbers of well-designed bus shelters, park benches

and tree plantings in high heat-stress areas, and the identification and potential relocation of coastal and riverside infrastructure that is likely to fail during future storm events. There are also many opportunities for well-designed heating/ventilation/cooling systems at residential, commercial and institutional building scales that adapt built environments with minimal investment in increased energy efficiency, reducing greenhouse gas emissions and improving quality of life and well-being. Community engagement concerning expectations can also extend urban adaptive capacity.

In particular, the standards adopted for public safety for floodplain management are quite different from those for other hazards such as earthquake and bushfire and, even for a given hazard, different states and territories interpret these standards differently.

Some existing elements of the built environment, including materials, processes and equipment, are particularly vulnerable to failure during extreme events, as demonstrated by the heatwave in southern Australia in 2009. These failure points need systematic identification and rectification in order for the built environment to become better adapted to extreme climatic conditions. Similarly, there needs to be greater awareness about who bears the costs of disasters caused by extreme weather events.

Because a focus on climate adaptation may not be enough to influence policy change, an alignment with other social and design agendas is required. There may not be sufficient local and regional design capacity to respond to innovative design requirements. In some local and regional jurisdictions designers may require the ability to set design within an integrated overarching urban planning and design strategy that is currently missing from state/territory and national policy development.

3.2.3 Information needs

Stakeholders are seeking information for developing improved options for adapting to more severe sea level extremes and are generally calling for consistent guidelines in relation to the planning and design of the built environment in relation to climate change. Better climate and sea-level rise projections are necessary at the regional and subregional scales, and they need to be integrated with improved understanding of possible storm surge and river flooding impacts. For example, comprehensive analyses of combinations of storm surge and coastal flooding, including inundation associated with sea-level rise, could be improved with better digital elevation models (DEMs). Scenario planning for a range of coastal flood and storm surge levels could then be used to set heights for designing and constructing reliable infrastructure

Darwin post Cyclone Tracy, December 1974
Image: National Archives Australia

such as critical evacuation routes that are above peak flood levels.

Better information is needed on the full social and environmental consequences of the costs and benefits of all adaptation options, including increased costs or lower service standards. Decision-makers would also benefit from information about the economic costs of 'doing nothing' as opposed to taking innovative action. Cost–benefit analyses must take into account the uncertainty about the timing and intensity of likely impacts. Many designers also lack access to science and engineering journals and the latest professional information. Consequently, there is a need for better built-environment networks, including means of incorporating practical knowledge from local tradesmen, and improved remote broadband access to knowledge and experience about adapting to climate change. Information on case histories and testable scenarios can help local governments make decisions and develop more effective designs for the built environment.

Planning for effective adaptation responses requires access to reliable, consistent and relevant data and modelling results, including baseline data, relating to design, planning, vulnerability assessment, risk assessment, decision-making and investment.

Analysis of relevant information is also required. While sector-specific decision support tools such as the National Emergency Risk Assessment Guidelines are useful, there is a need for tools that go beyond hazard assessment to integrated risk assessment, including the assessment of adaptive capacity.

Valid peer-reviewed scientific information is needed to support evidence-based standards and building codes for extreme events such as cyclones and associated high windspeeds, storm surge, floods and fire. This information may need to draw on a broader base of data – ecological, geomorphologic, historical and traditional local knowledge might contribute to understanding the frequency and severity of extreme events, such as cyclones and storm surge, and supplement current reliance on point-source anemometer and tide gauge measurements.

Information is needed on the implications of climate change for materials and structures to inform standards development and revision. Practitioners also require regular updated research to underpin key tools such as the Australian Rainfall and Runoff Handbook and the skills development and support to use them.

3.2.4 Research priorities

1. What are the biophysical pathways (material failure, coastal erosion, etc) by which climate change is likely to damage buildings and infrastructure? What climate and other information is needed to understand likely damages and how can this information be presented in a clear, useable form to decision-makers?

2. What are the design options and principles for adapting new buildings to climate change in different locations and how can these be implemented?

3. What are the design options and principles for adapting existing buildings to climate change in different locations, and how can these be implemented?

4. What are the full life-cycle costs and benefits of adapting the built environment and how can they be reliably estimated? Who will bear these costs and who will benefit? What financial and other policy instruments can be used to address the equity impacts of these costs?

5. What additional information is needed concerning materials and loading to inform the development of design standards that take appropriate account of future climate scenarios? At what intervals should standards and tools (such as the Australian Rainfall and Runoff Handbook) be reviewed in order to ensure that they provide effective guidance to decision-makers?

3.3 Vulnerable coastal communities

3.3.1 Stakeholders and key impacts of climate change

Australian coastal settlements are variously exposed to climate events that can cause loss of life and significant damage to private and public assets. Geological and historical records reveal how extreme events under natural patterns of climate variability have impacted on coastal geomorphology, ecosystems and human structures. Long periods of relative quiescence in storm frequency, leading to coastal system recovery, are interrupted by clusters of destructive storm events.

Climate change projections by the IPCC (2007), reinforced by more recent studies in Australia by CSIRO and others, indicate that a new set of climatic, hydrological and oceanographic conditions will be imposed upon, or will modify, the natural forces of variability that impact on coastal environments. Coastal settlements can expect, over this century and beyond, higher sea levels, more intense tropical cyclones, longer dry spells, higher land and sea temperatures, changed groundwater regimes and generally more severe weather events. These changes will be manifested in two forms on human settlements: (i) more intense and damaging extreme events such as those involving storm surges, urban flooding and foreshore erosion; and (ii) the 'creeping' impact of climate change such as progressively higher sea levels resulting in more extensive and more frequent flooding during high spring tides. Drier conditions in the future may also affect coastal communities through the evaporation of blocked coastal lakes and lagoons, bushfires and water shortages. Rising sea levels will affect groundwater resources, aquatic wetlands and soil stability. Uncertainty remains as to exactly how frequent, severe and extensive these changes will be. Continued modelling and observations should progressively refine our understanding of the probability of impacts under climate change that settlements must plan for in different coastal regions.

Climate change exacerbates the risks associated with other changes in the coastal zone. For example, the sea-change phenomenon has resulted in rapid rates of population growth in high-amenity non-metropolitan coastal towns (see, for example, Salt, 2001, 2003; ABS, 2004; Burnley and Murphy, 2002; Smith and Doherty, 2006). As Smith and Thomsen (2008) highlight, 'The issue for sea change communities is the rate of change in low population areas, where the effects of high percentages of growth on relative small communities may not be as easily absorbed as in the cities'. These rates of change also create potential indirect impacts, such as reduced social capital, which may translate into challenges for effective response to natural disasters such as those emanating from climate change (Smith and Thomsen, 2008).

The nature and extent of impacts induced by climate change on coastal settlements will vary with location, settlement type and settlement history (Chen and McAneney, 2006). Cities with embedded infrastructure designed to cope with a certain frequency of extreme flooding events will be more limited in response by the very scale of the problem than many coastal villages. Old canal estates built to a particular water level will be less able to manage higher tides than those designed more recently to meet higher storm surge and tidal heights under climate change. Therefore it will be necessary to examine various degrees of vulnerability, including exposure, sensitivity and adaptive capacity not only of different settlement types, but also of their particular history, demography and governance structures that may or may not limit effective adaptation.

Consideration needs to be given to the methods used to determine the physical risks to coastal communities from both gradual and extreme events across the range of coastal settlement types. Some of the approaches that have been developed for more temperate coastal regions might not be so appropriate in tropical areas. The methods currently in use need to be subjected to wider scientific scrutiny, for instance in relation to historical and geological recorded events, in order to ascertain their robustness for

Currumbin Surf Club
Image: Michael Mitchell

estimating these risks to coastal communities that are vulnerable to the impacts of climate change. Such scrutiny should include the effectiveness of statutory and policy measures used in a particular area.

There is inconsistency in approaches to regional hydrodynamic modelling which, in turn, gives rise to differences in the interpretation of coastal inundation and riverine flooding data. There are gaps in the network of gauges used to measure tides. This information is fundamental to developing more accurate assessments of future risks.

Responsibility for developing and implementing adaptation strategies in coastal settlements in Australia rests with a range of stakeholders. The bulk of assets in the coastal zone are owned, built and managed by private individuals or firms. State and territory governments have primary constitutional responsibility for land management in the coastal zone, and local councils operating under state laws perform key roles, although precise powers will vary from state to state/territory. The Australian government also has interests in the coastal zone including, for example, Australian government assets and a range of natural resource management issues. Within local areas, the role of community groups in supporting coastal actions aimed at meeting the challenges of climate change is becoming more and more evident, often with individual property owners, their insurers and banks, and developers in the front line of decision-making. Understanding local impacts is one of the main challenges facing all stakeholders in coastal settlements.

Indigenous communities will require suitable, and possibly culturally specific, communication about climate change impacts, consequences and means of adaptation where exposure to climatic and oceanic forces threatens cultural links to sea country and physical structures. Torres Strait Island communities are highly vulnerable to sea-level rise, coastal erosion and storm surges.

3.3.2 Adaptation options and adaptive capacity

There is a wide range of options to adapt to climate change impacts on vulnerable Australian coastal communities. These options can be described or categorised in many ways, but generally fall within the following three generic categories: (i) retreat (e.g., property relocation); (ii) accommodate (e.g., natural disaster management); and (iii) protect (e.g., hard and soft engineering options) (Klein et al., 2000).

While these categories provide a useful starting point for considering coastal adaptation options, there has been increasing awareness of the need to consider these within the context of Australia's coastal management system(s) and the decision-making options available. The various case studies that have begun to explore coastal adaptation options commissioned at an Australian government, state and territory or local level have tended to use a risk management framework to describe adaptation options (see Table 2).

Table 2. Generic adaptation categories based on a risk management framework (based on IPCC, 2001; AGO, 2006; Travers et al., 2009).

1 Spread Risks

- Insurance and diversification strategies; e.g., geographical diversification by relocating property in highly vulnerable areas

2 Prevent effects: structural and technological

- Prevent effects through engineering solutions and changed practices; e.g., scale-up coastal protection works

3 Prevent effects: regulatory and institutional

- Prevent or mitigate effects through revised regulations and planning; e.g., increase resources for coastal planning, amend building design standards

4 Avoidance

- Avoid or exploit changes in risk; e.g., change location of new urban developments

5 Research

- Improve understanding of relationship between climate change and risk; e.g., improved understanding of relationships between changes to frequency and magnitude of extreme events and critical thresholds for individual risks

6 Encourage behavioural change through education and information

- Educate and inform stakeholders about the risks of climate change

Although there appears to be an increasing awareness of these options, driven by various coastal risk assessments nationwide, the mechanisms for effectively choosing between them is in its infancy. Decision support methods for coastal adaptation, such as risk–benefit and cost–benefit, have begun to be explored through case studies and strategic-level assessments; however, many practical and methodological issues need to be effectively addressed before these approaches can be applied with rigour and consistency. This is a significant research challenge.

The adaptive capacity of coastal communities is highly variable. Large urban communities and some others have access to considerable financial resources, information bases, skilled personnel and leadership. In contrast, other communities may have extremely limited access to such resources and attributes. Factors that influence the adaptive capacity of coastal communities include the following (see Travers et al., 2009):

- Information access: there is information readily accessible to organisational staff and relevant stakeholders, i.e., effective monitoring or other programs are in place to detect changes to the coastal environment.
- Flexibility and resources: changes can be made easily and there are appropriate resources (personnel and financial) in place.
- Susceptibility to non-climate risks: susceptibility to non-climate-related risks can influence the ability to respond to climate-related risks.

While the factors which contribute to the adaptive capacity of coastal communities are

being identified through site-specific coastal risk assessments, there remain challenges in scaling these findings to both a national and regional level in order to support coordinated national adaptive capacity building efforts.

The capacity for coastal communities to adapt to climate change will be determined to some extent by the degree to which statutory and regulatory provisions constrain or prohibit building in exposed locations. States and territories and local councils in Australia have a variety of provisions and policies that guide decisions on land use. Effectiveness of these provisions in preparing coastal communities for the impacts of climate change is a matter of debate, including being the subject of an active House of Representatives enquiry. The Federal government has no constitutional power to ensure nationally consistent management and planning practices that will potentially minimise adaptation costs on future budgets and community interests (Thom, 2008).

Climate change impacts around the Australian coast constitute a national problem, not just a state/territory problem. The level of technical advice available to local councils is variable; a potential difficulty when priorities for investment in adaptation measures should be based on the best available information and consideration of adaptive capacity.

3.3.3 Information needs

Coastal settlements are variously exposed to the impacts of climate change. While a range of basic information can assist decision-makers to plan for the future, information requirements to support long-term decision-making will not be the same for each settlement. For instance, greenfield developments will have different needs compared with those of long-established population centres.

There is a need to better understand past and present extreme climate events and how these events interact with hydrological and geomorphic processes and impacts. Specifically, consideration should be directed towards obtaining information on the extent and nature of landform modification under extreme wave and wind conditions. There is also the need to improve the capacity of hydrodynamic models linking riverine floods with wave-induced storm surges. Coupled models of fluvial–estuarine–oceanic phenomena are required in order to improve assessment of low-lying coastal lands at risk of inundation under extreme events. Such models should be tested against historical flood events in coastal settlements. Risk assessment methods and decision support tools can be made more robust when they incorporate knowledge of past and present-day extreme events and are then tested against scenarios of the impacts of these hydrodynamic processes as envisaged under local and regional climate change conditions.

Effective risk assessment involves a continued commitment to the collection and dissemination of information on risk. New techniques such as LIDAR can now offer high-resolution data on elevations which, when combined with scenario modelling, offer land owners and public asset managers vital information required to assess the impacts of extreme and creeping events (NSW Department of Planning, 2008). Most critically, it is important that property owners and occupiers are notified of the risks and are regularly updated as new information becomes available.

Building codes and standards may need to be modified to take into account new information on exposure and risk. Much has already been done in tropical regions faced with cyclone impacts. However, housing affordability, location of low-cost services, and the availability of flat land may tempt developers and councils to accept lower standards than are required to protect communities from surges and floods. Design and retrofitting of buildings and services for the impacts of creeping flood tide events may also need to be revised to accommodate climate change. The extent to which insurance can be provided or maintained under these conditions, both for property owners and councils, must also be looked at in relation to standards, locations and approvals processes.

Decision-makers need to understand the benefits of developing adaptation strategies and communicate those benefits regularly to communities. Avoiding the loss of public assets such as beaches is an example.

Sea-level rise by itself might not destroy a beach until a threshold is reached. Conditions need to be assessed when augmenting the sand on a beach is required, otherwise a city or tourist-dependant town may lose one of its prime assets. Community attitudes to loss or change of environmental assets or facilities, what can be done to ensure they are protected, and who will pay, are issues that vulnerable coastal settlements must address.

Coastal communities may be faced with trade-offs between environmental, amenity, health and property protection. Resources for maintaining or improving natural resources and public access to wetlands, beaches, littoral forests, dunes, sea grasses and reefs may locally compete with demands for protective works such as sea walls, revetments, levees and associated pumping stations in order to limit inundation.

3.3.4 Research priorities

1. How will demographic pressures and changes in different Australian coastal settlement types affect (i) the potential impacts of extreme and gradual climate change, and (ii) current policy and regulatory settings which govern decision-making by government agencies, businesses and individuals? How will planning for coastal climate change impacts respond to local circumstances?

2. How do coastal communities perceive coastal vulnerability in different settlements, and to what extent is that influencing adaptive capacity now and will be likely to influence it in the future under scenarios of climate change?

3. How well do we understand the relationship between climate and coastal processes? How can methods currently used to determine the physical risk on a regional basis of extreme inundation and coastal erosion from climatic and oceanic processes, either singly or in combination, be improved and new methods developed and applied?

4. Better information is needed about hydrodynamic processes and their interrelationship with sediment supply over time, including thresholds and tipping points that could result in fundamental landform changes. What is the switchover point from accretion to erosion? How soon is this phenomenon likely to happen? What are the locations at greatest risk?

Community attitudes to loss or change of environmental assets or facilities, what can be done to ensure they are protected, and who will pay, are issues that vulnerable coastal settlements must address.

3.4 Infrastructure

3.4.1 Stakeholders and key impacts of climate change

Infrastructure in this context includes the traditional areas of energy, water security, stormwater and flooding, transport, and communications. In discussing the adaptation of infrastructure to climate change, social, economic, environmental and health issues are also relevant – these will not be directly included here; however, their relevance and importance should not be overlooked.

Virtually every member of the community is a primary stakeholder in the sustainability of effective infrastructure, as a user of the services provided by the infrastructure. Moreover, the continued effectiveness of infrastructure under changed climate conditions is important for overall community adaptive and emergency responses to climate change. Many people are also stakeholders as owners, operators or employees of private or public infrastructure.

Representing community interests are the three levels of government, a range of authorities, service providers and industry groups employing managers, professionals (engineers, architects, planners, scientists) and support staff who make or implement decisions relating to design, maintenance, operation, replacement and overall management of infrastructure. Within major cities, infrastructure is generally managed by state/territory government, corporatised authorities or private industry. In non-urban regions, local government plays a greater role in the design, maintenance, operation, replacement and management of infrastructure across all sectors. Even within energy generation the role of local government is already growing with the establishment of local/regional carbon reduction targets and the development of distributed renewable sustainable energy (e.g., methane gas from landfills, wind turbines).

Another group of stakeholders are the researchers and funding bodies that undertake or fund research. Some of these researchers are located within the above-listed stakeholder organisations, while many are based in universities and government research agencies, such as CSIRO.

In order of confidence of prediction, the climate changes that are likely to impact operating infrastructure are:

- increasing temperature – widespread – all persons and infrastructure impacted to some degree

Image: NSW State Emergency Service

- sea-level rise – widespread and very significant for all coastal cities and settlements as well as estuarine systems – large populations, major infrastructure and high-value assets directly impacted
- more variable rainfall – spatial and temporal changes across different regions – shifts in seasonality, reduced rainfall occurrence (fewer rain days and more time between rain events) in some regions, while intensity of rainfall (when it occurs) may increase with higher flood risk in other regions – large populations, major infrastructure and high-value assets may be impacted on a regional basis
- reduced catchment runoff in many regions – resulting from increased temperatures, reduced and seasonal shifts in rainfall combined with increased evapotranspiration – indicate significant reductions in catchment runoff and water resources, direct impacts on water security that will require increased water storage, alternative sources or demand management for major cities and regional towns
- increased storminess and more extreme weather – this area of climate change science is the least reliable, because the climate models operate at much larger temporal and spatial scales than is necessary to accurately resolve the forcing mechanisms of cyclones/hurricanes/typhoons or tornados – large populations, major infrastructure and high-value assets may be impacted on a regional basis.

As noted by ATSE (2008) in the Assessment of Impacts of Climate Change on Australia's Physical Infrastructure, the major potential impacts arise from combinations of predicted climate change scenarios. Adopting standard risk assessment techniques, ATSE identified the most vulnerable infrastructure to be:

- energy generation and distribution – due to extreme temperatures, bushfires and drought (reduced cooling water)
- low-lying coastal developments – due to sea-level rise, storm surge and/or extreme rainfall
- drainage, stormwater and sewerage infrastructure, where significant rainfall intensity is projected.

The consequences of climate change on the transport and communications sectors will be minor to moderate relative to other sectors, with adaptation measures requiring only minor to moderate investment. That said, where this infrastructure is located in a vulnerable area, such as a low-lying or flood-prone area, it will obviously require attention, especially where it

Image: Michael Jefferies

concerns key assets such as major transport routes and nodes, hospitals and communications transmitters.

A major review of the impacts of climate change on Australia's infrastructure is currently under way, supported by the Australian Government Department of Climate Change and Energy Efficiency.

3.4.2 Adaptation options and adaptive capacity

Throughout Australia all sectors of infrastructure operate at or beyond design capacity at various locations and times. There is a recognised need (without the additional impacts of climate change) for significant infrastructure investment to raise capacity. However, very little infrastructure is designed to meet peak demand, with some demand management measures being applied. The likely impacts of climate change need to be recognised and an adaptive management approach to designing and managing investment is essential. It will similarly be essential that infrastructure users have a sound understanding of the capacity of infrastructure to deliver services under projected climate conditions, and particularly during and after extreme climate events, when demand may be greatest.

Climate conditions will change considerably over the life of long-lived infrastructure, such as bridges (100 years) and rail tracks (60+ years). The capacity for such assets to incorporate adaptation treatments or adjustments to their maintenance regime will in part determine their resilience to accelerated degradation of materials and fatigue of structures due to increased intensity and frequency of extreme events (storms, wind, rainfall, bushfire). Assets which are periodically renewed, such as communication infrastructure, which can be renewed within a decade, or roads having a life expectancy of less than 20 years, are likely to have a larger adaptive capacity than long-lived assets such as bridges. Although a road surface may be degraded more rapidly than a bridge from increases in temperature, solar radiation and flooding events, each periodic renewal of the road (four times in 100 years) can incorporate knowledge about then-current and anticipated climate conditions in its design, and new technologies and materials in its mix of materials. Integrating such renewal options in long-lived infrastructure would also help enable periodic improvements to these assets as knowledge improves.

The adaptive capacity of each of the infrastructure sectors as a whole is complex and relates to a range of drivers of adaptation and

Assets which are periodically renewed, such as communication infrastructure, which can be renewed within a decade, or roads having a life expectancy of less than 20 years, are likely to have a larger adaptive capacity than long-lived assets such as bridges.

barriers to adapting within each sector. Some of the key adaptation drivers include:

- the level of early climate change impact on a sector's key assets or service provision
- increase in capital and operational costs due to climate impacts
- regulatory, investment and liability pressures to increase the adaptive capacity of the network or new assets.

Some of the key adaptation barriers include:

- understanding the cost versus the benefit of incorporating adaptation capacity into new and existing assets
- knowledge gaps for infrastructure-specific climate information (such as extreme rainfall events) to inform decision-makers
- climate change adaptation not being specified in investment, design, operation and maintenance requirements.

For all infrastructure sectors, adaptive capacity is directly related to the present condition of the infrastructure, life expectancy, service level expectancy, maintenance regime, levels of investment and lead times for planning, design and construction of adaptation options such as protection, reinforcing and elevation adjustments. Information which enables users to avoid unwittingly damaging the infrastructure or rendering it ineffective during extreme events can also increase the adaptive capacity of the infrastructure system.

Energy

The combined effects of higher temperatures, increased wind, bushfire risk, and reduced water resources are of major concern to energy infrastructure, both generating plant and transmission lines. In a warmer environment, cooling water requirements for thermal power plants (be they oil, coal, gas, nuclear or solar) will need to compete for diminishing water resources. Air cooling and/or hybrid air–water cooling provides some adaptive capacity, albeit at a cost in efficiency. The environmental and ecological impacts of power station warm-water releases into warmer receiving rivers, lakes, estuaries or coasts require careful consideration.

Many existing power plants are located close to the coast, near to major cities and coal deposits. Sea-level rise will directly impact on these power stations, although it is likely that adjustment will be relatively inexpensive, where staged adaptation of the plant and flood levee protection is feasible.

Thermal power is expected to continue to provide the bulk of Australia's energy needs for some considerable time. The relative

For many locations the combined effects of higher temperatures and more variable rainfall are expected to result in lower annual rainfall but more intense precipitation events. Both drought and extreme rainfall will also affect the quality of drinking water supplies, as will fires in surface catchments.

effectiveness of renewable energy sources including current solar, photovoltaic, wind, geothermal wave and hydro technologies are individually known but can be expected to change in time with technological development, energy demand and pricing policy. The integration of distributed energy sources with the existing concentrated transmission grid offers an opportunity to improve resilience of the overall energy supply system. Energy demand reduction is clearly a most effective adaptation option for which the community has demonstrated capacity, and this could play an effective part in avoiding catastrophic system failure. Uncertainty in the transition path from centralised high carbon energy to dispersed low emission renewable sources is limiting adaptation progress with uncertain investment priorities and timing.

Water security

For many locations the combined effects of higher temperatures and more variable rainfall are expected to result in lower annual rainfall but more intense precipitation events. Both drought and extreme rainfall will also affect the quality of drinking water supplies, as will fires in surface catchments.

The options for adapting to water supply risks are to reduce demand (lowest cost adaptation strategy) and to increase storage and/or alternative sources (groundwater, rainwater tanks, reuse or desalination). Community capacity to reduce water demand is substantial and has been demonstrated in various drought-affected cities/regions.

Reuse includes various combinations of potable and non-potable with direct and indirect delivery. Potable reuse is presently not socially acceptable with the majority of Australia's population. Desalination and potable reuse options require high energy consumption. If this energy cannot be provided by renewable energy sources, those options may conflict with climate change mitigation objectives.

Reduced water flushing of sewerage systems reduces solid waste transport capacity as well as creating a changed biochemical environment with impacts on system longevity. Higher sea levels and higher groundwater tables will directly impact on the hydraulic performance of the extensive pipeline and pumping networks within coastal communities.

The present condition of the distribution pipe networks for both supply and waste disposal are of concern. Most water authorities are making major investments in this area to improve adaptive capacity into the future. Long lead times

Image: Matthew Godfrey

and major investment in new systems for the changing climate require adaptive investigation, design and planning.

Stormwater and flooding

Changed rainfall variability (both spatial and temporal) and changes in extreme weather events are expected to result in many regions experiencing longer periods of drying, with precipitation occurring in more intense events. We can reasonably expect more frequent and potentially more severe flooding events, with associated risks to human life and property. Increasing the areas of impervious surface will exacerbate this in urban regions. The economic costs of floods in Australia are likely to be far greater than official estimates, since the latter are largely based on reports of insurance industry payouts and/or government (Australian, state and territory, and/or local) costs. There are many affected properties and infrastructure at risk from flooding and coastal inundation (particularly resulting from projected sea-level rise) along the open coast and around bays and estuaries. Specific hydrological/hydraulic investigations are required on a regional basis to determine risk profiles for damage from increased stormwater flow and coastal flooding.

Engineers Australia is presently revising the guideline document (Australian Rainfall and Runoff) for assessment of rainfall, runoff, water resources and flooding to include issues related to climate change.

Many urban areas will be unable to significantly expand either the carrying capacity or storage components of regional stormwater or natural river/creek systems to handle increased flows from either minor (frequent events with an average return interval of less than 10 years) or major (infrequent damaging events with an average recurrence interval of more than 50 years) events. This is especially problematic in the coastal zone, where the effects of rainfall/runoff changes interact with coastal storm surges and sea-level rise. The costs of such solutions may well prove to be prohibitive or, at best, suboptimal. The community will need to consider accepting lower standards of nuisance stormwater flooding in minor events and should seek to avoid locating infrastructure in vulnerable locations.

Transport and communications

Although less vulnerable to climate change than the infrastructure sectors discussed above, recent fire and flood events in Victoria and Queensland/NSW have highlighted the importance and fragility of these infrastructure sectors during extreme events. Roads are vulnerable to very high temperatures, changes in moisture content and sloping land forms. Ports, bridges and many major airports are vulnerable to sea-level rise, storm surge and extreme rainfall events. Adaptive capacity shortcomings in the transport sector relate to the levels of investment required and the long lead times for planning, design and construction.

Even in normal operational environments, demand for our public transport systems frequently exceeds capacity. Rail services in most major cities cannot presently meet the increased peak demand arising from the recent community shift towards public transport which is likely to be further increased should energy prices rise. Rail assets are generally in a poorer condition than other transport assets and are more vulnerable to track buckling, as they are not designed for high temperatures. The maintenance and operation of rail services during heatwaves is a key current adaptation factor for this sector.

Integrated freight transport infrastructure can expand freight movement options and thus adaptability, especially in established major city environments, but this may require more effective integration of port, rail and road terminals.

Many of our major airports are located on reclaimed land established over the seabed and are thus directly vulnerable to sea-level rise and changes in coastal extreme weather; risks that can be addressed relatively easily with the raising of perimeter seawalls.

The communications sector has high adaptive capacity due to the rapid development and community adoption of new technology. Government support of major investment in high-speed internet connectivity is expected to overcome present deficiencies and raise Australia's system to a competitive international level. However, many small and remote communities, which have relatively limited adaptive capacity due to other factors, have

limited mobile telephone and high-speed internet communication, and providing better options is difficult. Communication systems are vulnerable to windstorm and other climate impacts.

Systemic, cascading and cumulative impacts

In addition to the discrete impacts of climate change on particular infrastructure assets, there are also significant risks of downstream or cascading network failures. These failures can affect multiple systems, with potentially unpredictable impacts on essential services. Downstream impacts include stormwater system failure, resulting in the release of pollutants that contaminate groundwater or receiving waters. Cascading effects are those with extended causal chains, for example a bushfire might destroy transmission lines, which in turn impacts on other critical infrastructure such as telecommunications, water purification, sewerage disposal and emergency services. More research is needed in order to understand the ways in which infrastructure systems interact and are likely to behave under particular future scenarios of climate change and extreme weather.

3.4.3 Information needs

Data and information

There is a large amount of data, reports and related information relevant to infrastructure, climate change and adaptation planning held by various agencies that is not known about and is not available to others to whom it could provide insights and guidance. There is a clear need for this data and information to be collated, publicised, quality controlled, data-based, archived and made accessible to all stakeholders in a managed and effective nationwide system. There is need for a national host gateway that should provide the pathways/links to the various host or collecting agencies where the data and information will continue to reside and be managed. There is a need by all stakeholders to access consistent and reliable information for the purposes of decision-making and for developing decision support tools to be used by all sectors.

Governance

There are barriers to adaptation resulting from the lack of clearly defined areas of responsibility and authority between the three levels of

Adelaide, January 2009
Image: Newspix/ Calum Robertson

government (Australian, state and territory, and local). This results in confused policy and reduces effective governmental planning and management. Research could inform future institutional arrangements that might best support effective adaptation by infrastructure regulators and providers. Some aspects of effective arrangements may reflect the particular circumstances relating to infrastructure, but other aspects may be common to other sectors and reflect the nature of climate change.

Vulnerability

There is a need for organisations at various levels to test the resilience of infrastructure, systems and operations that they manage in order to gain a sound understanding of their potential vulnerability to the additional conditions imposed by climate change. Such investigations should identify the features of particular infrastructure components that render them vulnerable to climate change, and whether there are design or operational solutions to those features. The interdependence of key infrastructure was recognised – highlighting the need for an understanding of how infrastructure systems interact and are likely to behave with possible serious downstream or cascading impacts under particular future scenarios of climate change and extreme weather.

Energy and water

Clearer information needs to be more broadly available to specific stakeholder agencies as well as the broader community. Information is needed about the sustainability and adaptive strengths of the various long-term options for water supply, waste management and water reuse options, including risk assessment, life-cycle analysis and social acceptance. Information is also needed about the options and sequencing for transitioning from the existing centralised thermal energy system to incorporation of distributed alternative renewable energy generation sources including solar, photovoltaic, wind, wave and hydro. For instance, both industry professionals and the community need to understand how this could be undertaken, what it would cost, and the extent to which it would improve energy system capacity and resilience for decision-makers to be able to make significant changes to existing arrangements.

The strong interdependence of water supply with energy warrants an improved understanding of the linkage between energy and many water supply, waste management and water reuse options including 'water needs for energy generation' and the 'energy implications of adaptive water supply options'.

Coastal infrastructure

Better understanding is required of the best tools and mechanisms for adaptive planning of infrastructure in the coastal zone. Essential further research areas include flood hydrology, flood hydraulics, flood hazard, vulnerability, warning and evacuation, social and economic risk assessment, and the combined probability of flood peaks with ocean storm surges and sea-level rise.

Design standards and planning periods

The lack of national design standards and planning periods for infrastructure at all levels is a serious deficiency of existing planning and for adaptive management under climate change. Design standards specified as average recurrence interval (ARI, years) or annual exceedance probability (AEP, %) need to be developed and adopted nationwide for specific regions and infrastructure. Guidelines (in lieu of standards) for planning periods also need to be developed nationwide by region and infrastructure.

Financial analyses

Traditional Benefit/Cost analyses based on the Present Worth method with relatively high discount rates and short planning periods are not appropriate to the long planning periods inherent in adaptation to climate change over the next century (and longer). Financial analyses for assessing infrastructure projects need to be modified to incorporate and take account of risks that are likely to change with climate over an extended time-line. Alternative financial and business models need to be investigated for use by government and private sectors for adoption in options assessment and investment decision-making in the new climate era.

Tipping points

The climate system is changing incrementally as global temperature rises, but step changes in

the range, extremity and behaviour of regional and global conditions are also occurring. Anticipating the occurrence and effect of these step changes or tipping points would enable infrastructure managers to prepare for new local or global conditions. For instance, the rapid and ongoing reduction in Perth's rainfall was only recognised a decade later and characterised after two decades. Some rapid changes, such as rapid sea-level rise resulting from a significant mass of land ice entering the ocean, can be anticipated in general terms but not with respect to specific timing.

New infrastructure which involves long lead times for planning and decision-making will benefit from the early identification of relevant tipping points. Climate and other parameters that determine when tipping points will occur need to be identified and monitored.

3.4.4 Research priorities

1. **What is the vulnerability of infrastructure (individual and interlinked critical sectors) to existing and predicted climate change conditions at various spatial scales, considering average and extreme weather conditions? How can climate-induced service or structural failure thresholds for infrastructure and services be identified in light of the inherent uncertainty in climate projections?**
2. **What impacts on key infrastructure might have downstream or cascading impacts during extreme climate events, and how might these impacts be avoided?**
3. **What design standards (ARI and/or AEP) and planning periods for the various infrastructure components should be adopted for particular locations and over what time-frames?**
4. **What financial analysis tools will allow longer planning periods and climate change adaptation options to be realistically evaluated and ranked?**
5. **What are the best tools and mechanisms for adaptive planning of management regimes for infrastructure and assets?**

3.5 Cross-cutting research issues

The analysis of the four themes within this Research Plan and the development of associated research questions led to the recognition of the need for a set of cross-cutting research questions to achieve a more complete program of research on adaptation to climate change for settlements and infrastructure. These questions, which are listed below, have overlapping elements with each of the themes and provide an additional set of research priorities.

Research priorities

1. **What would a climate-adapted Australian settlement look like?**
2. **How can communities' (of place/interest) expectations, behaviour and capacity in relation to climate change be influenced and what measures need to be used?**
3. **What are the barriers to adaptation planning in urban areas and how can factors that contribute to maladaptive decision-making be minimised/removed?**
4. **What tools/methods for managing data and information are needed for identifying tipping points and for assisting decision-making in relation to climate change?**
5. **What sectors of society are most vulnerable and least able to adapt to climate change in urban, regional and remote settlements? What is the nature of those vulnerabilities and the barriers to adaptation? How can physical, social, economic and institutional factors reduce their vulnerability and increase their adaptive capacity? At what spatial and temporal scales should adaptation responses for vulnerable communities be developed?**
6. **To what extent can geological/geomorphic/historical/traditional/local knowledge be best applied to assessing the vulnerability of existing settlements under different climate change scenarios?**
7. **How can communication of climate change impacts and uncertainties be improved and can communities be engaged in adaptive responses for settlements and infrastructure?**

4. Research prioritisation

4.1 Criteria and considerations for prioritising research activities

Actions aimed at addressing the likely impacts of climate change span a wide spectrum of sectors. The COAG National Climate Change Adaptation Framework 2007 identifies eight sectoral areas, including settlements and infrastructure, for implementing adaptation actions. Since resources and capacity currently available in Australia for adaptation research are limited, the National Climate Change Adaptation Research Facility has developed a set of six criteria to be used for prioritising research topics within each theme area (see Appendix 1 for details). These criteria are being used in all the Research Plans being developed by NCCARF.

The criteria are:

1. **Severity of potential impact to be avoided or degree of potential benefit to be derived (essential)**
2. **Immediacy of required intervention or response (essential)**
3. **Need to change current intervention and practicality of alternative intervention (essential)**
4. **Potential for co-benefit (desirable)**
5. **Cross-sectoral relevance (desirable)**
6. **Equity considerations (desirable).**

A number of issues need to be considered when assessing priorities for climate change and adaptation research for settlements and infrastructure, in order to achieve the 'best' outcomes. An essential front-end need is for information about the (likely) magnitude of adverse impacts due to climate change, so as to guide decisions about the choice of adaptive interventions. It is relevant to seek evidence of actual impacts of climate change, particularly in vulnerable sectors or locations. However, other factors will affect the amount of evidence required to guide decision-making. For example, less evidence may be needed to justify a relatively low-cost undertaking that will be useful in both current and future situations in any event. Research into adaptation and adaptive strategies must also address both short- and long-term time horizons.

4.2 Prioritising research activities related to adaptation to climate change for settlements and infrastructure

Ranking areas for research into high and low priority is difficult, given that many aspects of research are not directly comparable and time-frames for research vary. Nonetheless, an attempt has been made to apply the six prioritisation criteria to the lists of research questions identified in Section 3.

Applying the prioritisation criteria, research priorities were ranked from low to high. The full assessment matrix is in Appendix 2. From this, a list of high-priority topics emerged (Table 3).

Image: Marcus Wong

Table 3. High priority research questions for settlements and infrastructure.

1. Urban planning and management

- How can existing urban planning principles and practices accommodate climate change and the uncertainty of climate change impacts? How should these principles and practices differ, based on the location and spatial scale of the settlement? What can we learn about the adaptive capacity of settlements from responses to stresses in the past?
- How can the governance of urban planning in Australia, including formal and informal rules, nationally consistent approaches and guidelines, and locally driven standards and outcomes, and the institutions responsible for decision-making, be improved to facilitate planning processes and outcomes which incorporate adaptation to climate change?
- What are the particular planning needs of remote and Indigenous settlements under a changing climate?

2. Built environment

- What are the design options and principles for adapting new buildings to climate change in different locations and how can these be implemented?
- What are design options and principles for adapting existing buildings to climate change in different locations and how can these be implemented?
- What are the full life-cycle costs and benefits of adapting the built environment and how can they be reliably estimated? Who will bear these costs and who will benefit? What financial and other policy instruments can be used to address the equity impacts of these costs?

3. Vulnerable coastal communities

- How will demographic pressures and changes in different Australian coastal settlement types affect (i) potential impacts of extreme and gradual climate change, and (ii) current policy and regulatory settings which govern the decision-making by government agencies, businesses and individuals? How will planning for coastal climate change impacts respond to local circumstances?
- How well do we understand the relationship between climate and coastal processes? How can methods currently used to determine the physical risk on a regional basis of extreme inundation and coastal erosion from climatic and oceanic processes, either singly or in combination, be improved and new methods developed and applied?

4. Infrastructure

- What is the vulnerability of infrastructure (individual and interlinked critical sectors) to existing and predicted climate change conditions at various spatial scales, considering average and extreme weather conditions? How can climate-induced service or structural failure thresholds for infrastructure and services be identified in light of the inherent uncertainty in climate projections?
- What impacts on key infrastructure may have downstream or cascading impacts during extreme climate events, and how might these impacts be avoided?
- What design standards (ARI and/or AEP) and planning periods for the various infrastructure components should be adopted for particular locations and over what time-frames?

5. Cross–cutting issues

- What would a climate-adapted Australian settlement look like?
- What sectors of society are most vulnerable and least able to adapt to climate change in urban, regional and remote settlements? What is the nature of those vulnerabilities and the barriers to adaptation? How can physical, social, economic and institutional factors reduce their vulnerability and increase their adaptive capacity? At what spatial and temporal scales should adaptation responses for vulnerable communities be developed?
- To what extent can geological/geomorphic/historical/traditional/local knowledge be best applied to assessing vulnerability of existing settlements under different climate change scenarios?

5. Implementation issues

A detailed Implementation Plan is being developed in parallel to the development of this National Climate Change Adaptation Research Plan for Settlements and Infrastructure. This section provides a broad overview of the resourcing issues that are likely to arise in the implementation of this Research Plan.

5.1 Research capacity

Across Australia there are a limited number of active professionals, academics and researchers who are well informed and already undertaking relevant and valuable research related to climate change adaptation. Many professional planners, engineers, managers and environmental scientists working for government, industry and infrastructure agencies would benefit from gaining greater access to information relating to climate change adaptation issues. There is clearly considerable scope and a need to develop capacity for practising professionals, academics and researchers in this area.

For several years, climate change has been recognised by various state and territory and local governments as requiring consideration in relation to the flooding and coastal erosion/inundation risks associated with infrastructure projects and development. There are numerous reports to government, and also independent publications by professional and learned associations, including: ATSE's 2008 Assessment of Impacts of Climate Change on Australia's Physical Infrastructure; SMEC's 2007 Climate Change Adaptation Actions for Local Government; and the Institution of Engineers Australia's 2004 Guidelines for Responding to the Effects of Climate Change in Coastal and Ocean Engineering.

Substantial debate and research is being reported in Australian planning, built environment and engineering conferences around climate change and settlements and infrastructure, incorporating themes of urban planning, the built environment, coastal environments and infrastructure (energy, water, flooding, transport and communications). However, refereed journal publications related to climate change adaptation are few, although their numbers have been increasing in recent years.

Research capacity in settlements and infrastructure adaptation is distributed sparsely across the nation in relatively small research groups (varying in number of members and amount of activity) housed within various University Departments/Centres in engineering, the built environment, planning, economics, geography, environmental and social sciences. Specific research groups are also to be found in Australian government agencies such as CSIRO, Geoscience Australia and the Bureau of Meteorology. In the main, these research groups are well engaged with stakeholders, including government, infrastructure authorities, industry and consultants. The research is at varying levels multidisciplinary.

There is a valuable role for NCCARF and the Adaptation Research Network for Settlements and Infrastructure to support and progress relevant research by raising awareness across the various research groups and by providing the opportunities for collaboration and access to prioritised funding.

5.2 Engagement

It is essential that the needs of research end-users be taken into account early in the design of research priorities, to ensure that research outputs are useful and of value to a variety of stakeholders. Much of this research involves issues where problem identification and research framing are substantial research issues in their own right: working out the right question is often more important than working out the answer. This frequently involves strong participatory engagement between researchers and end-users or research partners.

These participatory or 'action research' approaches seek to engage key stakeholders in helping to define the research questions to be addressed (such as through advisory groups or steering committees), rather than looking within the research community to define the research agenda. Such approaches have been shown to generate highly innovative research projects and outcomes, in part because they inject new ideas and encourage cross-fertilisation between disciplines in order to address these externally defined challenges.

Image: NSW State Emergency Service

Early genuine engagement and a continuing partnership ethic are seen as valuable central features of the research. This engagement also provides an important platform for identifying what insights are useful or of interest to different stakeholder groups, and assisting the communication of these ideas and tools to relevant constituencies.

Understanding the context and manner in which research will be used will help determine what modes of dissemination and uptake are most appropriate. Very few end-users will access primary research directly through traditional academic publications, instead preferring toolkits, presentations and workshops, interactive web-based material, CDs, DVDs and so on. The expected beneficiaries of adaptation research are, in general, secondary consumers of research outputs.

A critical starting point in deciding how best to disseminate information and promote uptake will be to identify relevant primary and secondary end-users for particular research priorities and to clarify the uses to which research outputs will be put. For example, will research results be used to assist individual responses to climate change 'from the bottom up', or primarily used to inform 'top-down' policy, legislative and regulatory responses? Some work, for example, may directly inform business decisions. Other research may speak directly to policy-makers, informing their choice of policy intervention.

There are already several key industry groups and peak bodies supporting the work of the stakeholders who will need to use the research outputs of this NARP. NCCARF will work with these groups as well as the Adaptation Research Network for Settlements and Infrastructure to ensure that existing mechanisms are used as much as possible but are supplemented where necessary to enhance the likelihood that research outputs will be applied.

Engagement with existing stakeholders groups which currently do not have a focus on climate change is also important. One example is the Trusted Information Sharing Network (TISN) for critical infrastructure protection, which is a forum where critical infrastructure owners and operators work together to share information on security issues. It is made up of a number of Infrastructure Assurance Advisory Groups (IAAG) for different business sectors and Expert Advisory Groups which provide advice on specific areas of interest. These groups are overseen by the Critical Infrastructure Advisory Council and the TISN is managed by the Federal Attorney-General's Department. Critical infrastructure owners and operators share information on threats and vulnerabilities and appropriate measures and strategies to mitigate risk. Nine groups have been formed, to cover Banking and Finance, Communications, Emergency Services, Energy, Food Chain, Health, Mass Gatherings, Transport, and Water Services. A TISN 'community of interest' on climate change was established in September 2009.

5.3 Additional funding sources

It will be necessary to identify funding sources additional to those made available through the Adaptation Research Grants Program to fully address the key research objectives outlined in this NARP and to undertake essential research programs.

The Australian Research Council grants program is likely to be the first port of call for many researchers and research institutions that seek additional support. Relevant grants offered by the ARC include

- *Discovery Projects.* A variety of fellowships are offered under the scheme to nurture the talents of Australia's most promising early-career researchers and to support established researchers.
- *Discovery Future Fellowships.* Future Fellowships are offered to promote research in areas of critical national importance by giving world-class researchers incentives to conduct their research in Australia.
- *Linkage Infrastructure, Equipment and Facilities.* The scheme fosters collaboration through its support of the cooperative use of national and international research facilities. Essentially, the scheme provides funding for large-scale cooperative initiatives so that expensive infrastructure, equipment and facilities can be shared by researchers in partnered organisations. However, the ARC

may fund single-organisation proposals in some circumstances.

- *Linkage Projects.* The scheme supports collaborative research and development projects between higher education organisations and other organisations, including within industry, to enable the application of advanced knowledge to problems. In recommending funding for proposals under Linkage Projects, the ARC may take into consideration the likely benefit of the research to Australian regional and rural communities.

Further potential funding sources particularly relevant to urban and regional planning include state and territory government agencies and local government collective organisations. This form of direct research funding would be outside of their possible involvement in ARC Linkage applications.

Image: NSW State Emergency Service

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Appendix 1

Criteria for setting research priorities

The criteria listed below will guide the research planning process to set research priorities.

Essential

1. Severity of potential impact or degree of potential benefit

What is the severity of the potential impact to be addressed or benefit to be gained by the research? Potentially irreversible impacts and those that have a greater severity (in social, economic or environmental terms) will be awarded higher priority.

2. Immediacy of required intervention or response

Research will be prioritised according to the timeliness of the response needed. How immediate is the intervention or response needed to address the potential impact or create the benefit? Research that must begin now in order to inform timely responses will receive a higher priority than research that could be conducted at a later date and still enable a timely response.

3. Need to change current intervention and practicality of intervention

Is there a need to change the intervention used currently to address the potential impact being considered. If yes, what are the alternatives and how practical are these alternative interventions? Research that will contribute to practicable interventions or responses will be prioritised. Does research into the potential impact of the intervention being considered contribute to the knowledge base required to support decisions about these interventions?

Desirable

4. Potential for co-benefits

Will the research being considered produce any benefits beyond informing climate adaptation strategies?

5. Potential to address multiple, including cross-sectoral, issues

Will the research being considered address more than one issue, including cross-sectoral issues?

6. Equity considerations

Will research priorities recognise the special needs of particular groups in Australia?

Appendix 2

Prioritising research needs

Research topics	Essential	
	Severity or benefit	**Immediacy**
1. Urban planning and management		
1.1 How can existing urban planning principles and practices accommodate climate change and the uncertainty of climate change impacts? How should these principles and practices differ, based on the location and spatial scale of the settlement? What can we learn about the adaptive capacity of settlements from responses to stresses in the past?	**High**	**High** Need to influence current planning practices, as planning decisions come with long-term commitments and can have consequences over many decades
1.2 How can planning approaches address the multiple objectives of urban adaptation to climate change impacts, mitigation of greenhouse gas emissions and biodiversity conservation?	**Medium**	**High**
1.3 How can the governance of urban planning in Australia, including formal and informal rules, nationally consistent approaches and guidelines and locally driven standards and outcomes, and the institutions responsible for decision-making, be improved to facilitate planning processes and outcomes which incorporate adaptation to climate change?	**High**	**High**
1.4 What are the particular planning needs of remote and Indigenous settlements under a changing climate?	**High**	**High**
1.5 What information about urban and regional planning and climate change impacts, in what form and at what resolution, should be publicly available? How should climate change impacts and adaptation information be presented and made available to urban and regional planning decision-makers?	**Medium**	**Medium**
2. Built environment		
2.1 What are the biophysical pathways (material failure, coastal erosion, etc) by which climate change is likely to damage buildings and infrastructure? What climate and other information is needed to understand likely damages and how can this information be presented in a clear, useable form to decision-makers?	**High**	**Medium**
2.2 What are the design options and principles for adapting new buildings to climate change in different locations and how can these be implemented?	**Medium**	**High**

	Desirable			Overall
Need to change intervention/ practicality	Potential co-benefits	Cross-sectoral relevance	Equity considerations	Priority ranking
High	**Yes**	**Yes** Enhance public health	**Yes**	**High**
Medium	**Very High** Planning actions can most effectively link multiple needs	**Yes**	**Yes**	**Medium**
High				**High**
High		**Medium**	**Very High** Little effort has been made to address long-term needs of these communities	**High**
Medium				**Medium**
Medium				**Medium**
High			**High**	**High**

Research topics	Essential	
	Severity or benefit	**Immediacy**
2.3 What are the design options and principles for adapting existing buildings to climate change in different locations and how can these be implemented?	**High**	**High** Vast numbers of existing buildings lack provision for the impacts of climate change
2.4 What are the full life-cycle costs/ benefits of adapting the built environment and how can they be reliably estimated? Who will bear these costs and who will benefit? What financial and other policy instruments can be used to address equity impacts of these costs?	**High**	**Medium**
2.5 What additional information is needed concerning materials and loading to inform the development of design standards that take appropriate account of future climate scenarios? At what intervals should standards and tools (such as the Australian Rainfall and Runoff Handbook) be reviewed to ensure that they provide effective guidance to decision-makers?	**High**	**Medium**
3. Vulnerable coastal communities		
3.1 How will demographic pressures and changes in different Australian coastal settlement types affect (1) potential impacts of extreme and gradual climate change, and (2) current policy and regulatory settings which govern decision-making by government agencies, businesses and individuals? How will planning for coastal climate change impacts respond to local circumstances?	**High** Population growth in vulnerable coastal areas is projected to increase dramatically over the next 20–30 years	**High** Planning reforms in many states provide opportunities to address issues of population pressure in areas potentially subject to impacts of climate change
3.2 How do coastal communities perceive coastal vulnerability in different settlements and to what extent is that influencing adaptive capacity now and likely to influence it in the future under scenarios of climate change?	**Medium**	**Medium** Generally of longer term significance
3.3 How well do we understand the relationship between climate and coastal processes? How can methods currently used to determine the physical risk on a regional basis of extreme inundation and coastal erosion from climatic and oceanic processes, either singularly or in combination, be improved and new methods developed and applied?	**High** Exposure to extreme events in the past and at present in coastal areas provides lessons for impact analysis; it reveals gaps in knowledge of processes requiring further research	**High**
3.4 Better information needed about hydro-dynamic processes and interrelationships with sediment supply over time, including thresholds and tipping points that could result in fundamental landform changes. What is the switchover point from accretion to erosion? How soon is it likely to happen? What are the locations at greatest risk?	**High**	**Medium**

	Desirable			Overall
Need to change intervention/ practicality	Potential co-benefits	Cross-sectoral relevance	Equity considerations	Priority ranking
High	**Yes**			**High**
High			**High**	**High**
Medium				**Medium**
High				**High**
High Better understanding of communities' perceptions of vulnerability aids understanding of how they respond to changes				**Medium**
Medium				**High**
Medium				**Medium**

Research topics	Essential	
	Severity or benefit	**Immediacy**
4. Infrastructure		
4.1 What is the vulnerability of infrastructure (individual and interlinked critical sectors) to existing and predicted climate change conditions at various spatial scales, considering average and extreme weather conditions? How can climate-induced service or structural failure thresholds for infrastructure and services be identified in light of the inherent uncertainty in climate projections?	**High**	**High** For existing infrastructure, need to understand which infrastructure is already vulnerable and needs to be retrofitted. As infrastructure decisions generally come with long-term commitments, new infrastructure needs to consider future climate change projections.
4.2 What impacts on key infrastructure might have downstream or cascading impacts during extreme climate events, and how might these impacts be avoided?	**High**	**High**
4.3 What design standards (ARI and/or AEP) and planning periods for the various infrastructure components should be adopted for particular locations and over what time-frames?	**High**	**High**
4.4 What financial analysis tools will allow longer planning periods and climate change adaptation options to be realistically evaluated and ranked?	**High**	**Medium** Generally of longer-term importance
4.5 What are the best tools and mechanisms for adaptive planning of management regimes for infrastructure and assets?	**Medium**	**Medium**
5. Cross-cutting issues		
5.1 What would a climate-adapted Australian settlement look like?	**High**	**High** Decisions relating to settlements come with long-term commitments, so any decision made today will have impacts over several decades
5.2 How can communities' (of place/interest) expectations, behaviour and capacity in relation to climate change be influenced and what measures need to be used?	**High** Many adaptation responses fail because they are not accepted by the community, so a better understanding of communities' expectations and behaviours will help develop appropriate adaptation responses	**Medium** Important over the long-term

	Desirable			Overall
Need to change intervention/ practicality	**Potential co-benefits**	**Cross-sectoral relevance**	**Equity considerations**	**Priority ranking**
High Consideration to be given to likely tipping points when major new structures or protective works will be required to lessen the impacts of climate change				**High**
High				**High**
High Current codes and standards do not consider uncertainty estimates of climate change impacts	**Yes**	**High**		**High**
Medium				**Medium**
Medium				**Medium**
Low Completely new visions of settlements may require significant changes to the way settlements are currently planned and may require time before they are accepted (both politically and by the public)	**Yes** Relevant to multiple fields of research, especially mitigation and sustainability issues	**Yes** Relevance for mitigation, health	**Yes**	**High**
Medium			**Yes**	**Medium**

Research topics	Essential	
	Severity or benefit	**Immediacy**
5.3 What are the barriers to adaptation planning in urban areas and how can factors that contribute to maladaptive decision-making be minimised or removed?	**Medium**	**Medium** Important over the long term
5.4 What tools/methods for managing data and information are needed for identifying tipping points and for assisting decision-making in relation to climate change?	**Medium**	**Medium** Tipping points unlikely to occur immediately, so more relevant for the longer term when climate change impacts more severe / pronounced
5.5 What sectors of society are most vulnerable and least able to adapt to climate change in urban, regional and remote settlements? What is the nature of those vulnerabilities and the barriers to adaptation? How can physical, social, economic and institutional factors reduce their vulnerability and increase their adaptive capacity? At what spatial and temporal scales should adaptation responses for vulnerable communities be developed?	**High** Not all sectors of society will be as equally vulnerable, so important to identify most vulnerable ones to address their specific vulnerabilities as early as possible	**High** Decreasing vulnerability of communities generally a medium-to long-term strategy so needs to commence as soon as possible, thus important to identify most vulnerable communities as early as possible
5.6 To what extent can geological/geomorphic/historical/traditional/local knowledge be best applied to assessing vulnerability of existing settlements under different climate change scenarios?	**High**	**High**
5.7 How can communication of climate change impacts and uncertainties be improved and communities be engaged in adaptive responses for settlements and infrastructure?	**High** Appropriate communication tools and methods for community engagement can lead to more effective adaptation responses	**Medium**

		Desirable			Overall
	Need to change intervention/ practicality	Potential co-benefits	Cross-sectoral relevance	Equity considerations	Priority ranking
	Medium Some barriers may be difficult to remove, for example if they are due to the way organisations or institutions are set up in our political / economic system				**Medium**
	Medium				**Medium**
	High			**High**	**High**
	High				**High**
	Medium				**Medium**

Appendix 3

List of key definitions and acronyms

Definitions

Adaptation

Actions taken to avoid actual or anticipated impacts from climate change, or to obtain potential benefits arising from climate change (see IPCC, 2007: 869).

Adaptive capacity

The ability to take action to adapt to climate change.

Resilience

The term 'resilience' is generally used to describe the capacity of a community or individual to resist the impacts of a disruption or adversity; the capacity to bounce back from the negative impacts of a disruption; or the capacity to adapt to those impacts.

Vulnerability

The degree to which a system is susceptible to, and 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 (IPCC, 2007: 883).

Acronyms

ABCB	Australian Building Codes Board
ARI	average recurrence interval
AEP	annual exceedance probability
ARC	Australian Research Council
ASBEC	Australian Sustainable Built Environment Council
ATSE	Australian Academy of Technological Sciences and Engineering
BASIX	Building Sustainability Index
COAG	Council of Australian Governments
CRC	Cooperative Research Centre
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DCCEE	Department of Climate Change and Energy Efficiency
DEM	digital elevation model
DPC	Department of Premier and Cabinet (Victoria)
DSE	Department of Sustainability and Environment (Victoria)
EU	European Union
GIS	geographic information system
JCU	James Cook University
IAAG	Infrastructure Assurance Advisory Groups
IPCC	Intergovernmental Panel on Climate Change
LGPMC	Local Government and Planning Minister's Council
LIDAR	Light Detection and Ranging
NARP	National Climate Change Adaptation Research Plan
NSW	New South Wales
NCCARF	National Climate Change Adaptation Research Facility
PMSEIC	Prime Minister's Science, Engineering and Innovation Council
RMIT	Royal Melbourne Institute of Technology (University)
SMEC	Snowy Mountains Engineering Corporation
TISN	Trusted Information Sharing Network
UKCIP	United Kingdom Climate Impacts Programme
UNSW	University of New South Wales
USC	University of the Sunshine Coast

Acknowledgements

The National Climate Change Adaptation Research Facility gratefully acknowledges the considerable time and effort invested by the writing team, and by many individuals and organisations in the development of this Plan.

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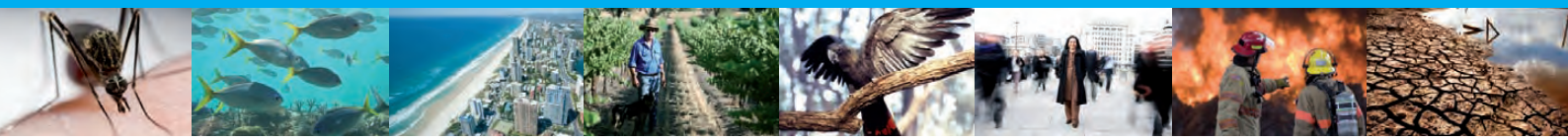
Climate Change Adaptation
Research Facility

Griffith University, Gold Coast Campus
Parklands Drive, Southport
QLD 4222, Australia
Telephone 07 5552 9333
Facsimile 07 5552 7333



Australian Government
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