Towards a Resilient Sydney
Urban Adaptation Research Synthesis

December 2014

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1 Introduction

This report was prepared as part of the *Towards a Resilient Sydney* project: a cross-government initiative to assess Sydney's climate change vulnerability and impacts on key government service sectors, and make recommendations for a coordinated approach to increase Sydney's resilience. It was led by the Office of Environment and Heritage (OEH) in partnership with the NSW Department of Planning and Environment (DP&E), the NSW Environment Protection Authority (EPA), the Sydney Coastal Councils Group (SCCG) and the Western Sydney Regional Organisation of Councils (WSROC).

Urban centres are complex systems that require comprehensive analysis to inform and support workable adaptive responses. In May 2012, OEH commissioned a series of research reviews across eight key themes in order to better understand emerging and existing Australian and international research in relation to urban adaptation in relation to each theme, and to identify where research gaps or opportunities may exist which could support adaptation planning in Sydney.

Table 1: Urban adaptation research sectors

Sector	Research review leader
Economy and industry	Bill Pritchard, University of Sydney
Natural assets	Jennifer Hearn, Office of Environment and Heritage
Human health	Hilary Bambrick, University of Western Sydney
Cultural assets	Susan McIntyre-Tamwoy, James Cook University
Settlements and communities	Michael Neuman, University of New South Wales
Buildings and neighbourhoods	Michael Neuman, University of New South Wales
Emergency management	Neil Dufty, Molino Stewart
Infrastructure	Ron Cox, University of New South Wales

Each research review leader approached their topic with different methodologies, reflecting the nature of the respective sector. For example, the infrastructure review drew heavily from interviews with infrastructure operators while the cultural assets review conducted a comprehensive literature review from both Australian and international sources. However, all reviews provided relevant and comparable insights for Sydney in terms of geography, population, current climate and culture. Each review also outlined a comprehensive reference list, a selection of which has been included here as Appendix A.

This synthesis report summarises each urban adaptation research review, lists potential areas for further investigation in each sector and finds a number of cross-disciplinary knowledge themes relevant to urban adaptation across multiple sectors in Sydney. These include:

- fostering adaptive urban design
- using land-use planning mechanisms to minimise climate risks
- finding opportunities for data sharing and downscaling
- improving cross-government coordination

- identifying vulnerable communities, populations and infrastructure
- securing water quality and supply
- understanding infrastructure interdependencies
- promoting best practice adaptation in local government
- exploring the role of the private sector in urban adaptation and
- improving community connectedness.

2 Economy and industry

This review sets out a climate change research agenda for Sydney's economy and industry sector. The research team reviewed emerging international research on urban economy and industry adaptation and conducted interviews with key sector informants. The findings were used to inform a holistic adaptation model for analysing sectoral issues specific to Sydney. In applying this framework to the Sydney context, this review has identified research opportunities for five key sectors of Sydney's economy (agriculture, manufacturing, wholesale and retail trade, tourism, business and financial services) and for local governments.

2.1 Understanding city-scale economic impacts of adaptation

Metropolitan areas are the places where much of the vulnerability and many of the adaptive responses relating to climate change will play out. Large numbers of people are moving into cities (OECD 2010) and many cities are located in areas near coasts or rivers that are becoming increasingly vulnerable to the impacts of climate change (Wheeler 2011).

Cities provide more than half of global gross domestic product (GDP) (Dobbs et al. 2011), have higher energy intensity than rural areas – cities contribute 60–80 per cent of world energy demand (Hallegate & Corfee-Morlot 2011) – and are major emitters of greenhouse gases contributing approximately 40 per cent of global emissions (Rosenzweig et al. 2011).

Parry et al. (2007) argue that those industries which have longer-lived capital assets (e.g. energy), fixed or weather-dependent resources (e.g. agriculture, food) and extended supply chains (e.g. retail) are more likely to be vulnerable to climate change.

Global-scale climate reporting tends to be devoid of detail about local, city-scale trends, and therefore provides little basis for decision-making at the urban scale. Understanding the exact nature of climate risks at the city scale presents great challenges, but is necessary to allow authorities and other stakeholders to make informed decisions about cost-effective responses and capture potential economic opportunities. Key policy recommendations relating to urban economy and industry adaptation identified through a review of international literature include:

- Energy consumption management is critical.
- Appropriate socio-economic planning and development can reduce risks.
- 'No regrets' is an important strategy for framing options (that will be beneficial in the absence of expected climate change).
- It is important to appreciate the socio-economic and spatial diversity of vulnerability exposures and adaptation requirements (UN Habitat 2010).
- Urban economic vulnerability is closely linked to urban asset maintenance and preservation (UN Habitat 2010).
- Governance considerations are crucial (Hunt & Watkiss 2011).
- Defining different scales of risk is crucial (Hunt & Watkiss 2011).

2.2 Developing a city-scale assessment framework

Due to the difficulties of applying a range of climate change factors to industry experience, there is no commonly accepted model to assess the impacts of climate change upon different economic sectors at any scale.

To date very few studies conducted have managed to produce an economic assessment which places a monetary value on the cost of adaptation. Economic assessments have tended to focus on impacts to markets, rather than impacts at the city-scale. However, general principles for undertaking a broad quantitative approach have been developed:

- City-scale assessment should be framed so as not to exclude inter-dependencies with surrounding and wider geographical regions.
- Scoping of city-scale climate change risk assessment should be designed to consider all potential climate risks and ensure that city-based stakeholders are well-represented.
- Quantitative climate risk analysis is best focused on a small number of risks that can be prioritised through a ranking process.
- The evaluation of adaptation responses to climate risks should be mainstreamed into current practices at the city scale (from Hunt & Watkiss 2011).

There are currently no commonly accepted frameworks or approaches for assessing the effects of climate change impacts on urban economies. Only a handful of (mainly OECD) countries have assessed the costs of vulnerability and adaptation for a city's economy, but there are inconsistencies of scale and issues with data that result in uncertainties and large margins of error.

A framework developed by Hallegatte & Corfee-Morlot (2011) provides a comprehensive guide to assessing the economic issues associated with climate change adaptation at a city scale. This framework suggests a four-stage process for undertaking adaptation planning:

1 The first stage is a stocktake of the city's economic structure, in order to set out the nature of its vulnerability and adaptation challenge.

2 The second stage is then to apply ('downscale') the stocktake to economic and social scenarios, in particular districts of the city.

3 The third stage is then to build estimates of industry-specific adaptation benefits and costs, based on information from stages 1 and 2.

4 Finally, once industry estimates are generated, these should be inserted within a model of the city's economy, so the overall impacts of climate change adaptation can be gauged (Hallegatte & Corfee-Morlot 2011).

2.3 Applying the assessment framework to Sydney

Sydney continues to be Australia's largest urban economy and leading hub for the higher order services industries associated with international trade and investment. Financial and insurance services dominate the Sydney economy (21.4%), followed by professional, scientific and services (11.2%), wholesale and retail trade (10.6%) and manufacturing (10.3%).

Shifts in economic conditions, exchange rates, trade rules and migration policies can all have profound implications for the shape and performance of the Sydney economy. Understanding how these processes will affect Sydney's economy in future is a major challenge. It is

essentially impossible to completely separate the economic and industry implications of climate change from the broader set of climate issues facing cities. Changes in the climatic conditions of the Sydney basin are only one aspect of the economic and industrial impacts of climate change – more relevant is the way in which global climate change will encourage shifts in the factors of production and prices of goods and services relevant to the city's economy.

Applying Hallegatte's framework for adaptation planning, a number of key adaptation challenges and opportunities can be identified. Table 2 outlines key challenges expected for the Sydney region across five industry sectors.

Table 2: Expected impacts in the Sydney region across five industry sectors

Industry	Impacts identified for the Sydney region
Agriculture	• Increase in flood risk is a potential vulnerability, however given the lower opportunity cost of agriculture on flood-prone land, planning decisions may favour agriculture over other infrastructure-based land uses. • Agriculture generally has high greenhouse gas emissions intensity due to its consumption of fertilisers, fuels, energy and livestock production. This may expose it to impacts relating to changing global markets and altered demand.
Manufacturing	• Key vulnerability relates to changing energy costs, including those related to carbon pricing policies. • Manufacturing is concentrated in Western Sydney which is projected to face higher temperatures, which may not have direct impacts but could affect workforce health and infrastructure.
Wholesale and retail trade	• Location attributes of wholesale and retail trade sectors tend to be anchored to long-term infrastructure investments. As costs associated with the use of these infrastructures change (costs of freight, private transportation) impacts may be felt by the sector.
Tourism and accommodation	• Climate change impacts and shifting seasonality on Sydney's natural environment may affect its appeal as a destination for visitors. • Changes in costs e.g. carbon pricing and fuel cost increases may affect this industry because it is highly energy-intensive.
Business and financial services	• Potential opportunities exist for new businesses to emerge if a carbon pricing scheme continues.
Local government	• Local councils play a vital role in adaptation planning. They can often bear costs associated with economic and industrial change, however they have limited scope to exert influence over local economies. • Local governments at present may not have the resources or the institutional capacity to deal with adaptation challenges in all their complexity (Measham et al. 2011).

2.4 Potential areas for further investigation

- Identify potential opportunities for Sydney agricultural industry in the context of rising fuel costs. This study should examine the sensitivity of high-value horticulture to increases in fossil fuel prices, given its apparently high level of energy inputs, including fertiliser.
- Improve understanding of the energy intensity of different types of manufacturing in Sydney, the scope for adaptation and the adaptive capacities of different manufacturing sectors, and the spatial and intra-industry reverberations from shifts in energy prices, usage and behaviour by manufacturers.
- Assess the scope of Sydney's capacity to evolve as a financial centre for carbon trading.
- Prepare industry-specific input–output modelling for Sydney which takes into account potential shifts in factor prices (in particular, energy) as a result of policy responses to climate change.
- Conduct an overarching research project that brings together previous studies of local government and climate change to identify an optimal approach to ensure local government has the capabilities to incorporate climate change adaptation frameworks.

3 Natural assets

This review comprised a technical review of climate change and natural assets in Sydney – namely, biodiversity, soils and landscapes. The review draws on a range of sources, including academic literature, government reports and strategy documents, and interviews with key stakeholders. It covers the general impacts of climate change in the region, and the approaches taken to address the impacts of climate change on biodiversity and soils.

3.1 Biodiversity

Climate change is expected to be one of the main causes of biodiversity loss over the coming century and will affect terrestrial, aquatic and marine biodiversity (DECCW 2010b, Steffen et al. 2009). In New South Wales, climate change has been listed as a key threatening process under the *Threatened Species Conservation Act 1995.* The threats to biodiversity from climate change are the changes in the physical and chemical environment such as changes in rainfall, atmospheric carbon dioxide (CO_2) concentrations, temperature, acidity, and soil structure and function (Steffen et al. 2009).

Each species will respond to stressors through a variety of strategies, including acclimation, behavioral change, phenotypic plasticity, genetic adaptation and dispersal responses, or alteration of their physiological processes or their distribution. The reactions of individual species will also combine to result in changes at a community level, in terms of both structure and function, and then at an ecosystem level. Any direct change a species makes in response to climate change will affect its interactions with the surrounding environment and other species.

It is very difficult to describe the specific responses that will occur, especially because ecological responses are complicated by issues of non-linearity, time lags between pressure and response, the existence of thresholds or 'tipping points' and the existence of feedback mechanisms within ecosystems.

Observed changes which have already taken place in Sydney include changes in the arrival and departure of 12 species of migrating birds (OEH 2012) and changes in the numbers of aquatic invertebrates, with those favouring warmer waters increasing in number (Chessman 2009).

Likely climate change impacts upon different ecosystem types in the Sydney region include:

- **Bushfire intensity and frequency** are expected to increase. Changes to the frequency and intensity of fires in the landscape will affect both the types of communities which exist, and the distribution of those communities. It will impact the ability of fauna to find food and seek shelter from predators. High-intensity fires also result in longer periods of time for ecosystems to recover.
- **Invasive species** have a large impact on biodiversity in New South Wales, however, there is a lack of research into the interactions of invasive species and climate change. More research is needed to examine the impacts of invasive species under climate change (Brook 2008).
- Climate change is likely to exacerbate pressures on Sydney's **land-use patterns**. Increased proximity to development – which is likely to be exacerbated as coastal development is limited and peri-urban development expands – exposes ecosystems to

'edge effects', such as increased incursion of invasive species and weeds, increased predation and reductions in dispersal and habitat availability.

A key consideration when assessing the conservation and protection of biodiversity is the issue of limited resources –leading to the need to prioritise conservation actions (Botrill et al. 2008). A range of strategies can be employed to support prioritization, such as a landscape approach/connectivity, a focus on significant sites, prioritisation of threatened species, preservation of refugia, limitation of non-climate stressors and direct intervention.

3.2 Soils and climate change

Climate change is expected to change soils in two key ways: potential changes in the capability and degradation of the land, and potential changes in the productivity of the land (OEH 2011).

Degradation of the land can affect the capability of soils. Impacts include increased erosion by water and wind, decline in soil structure, soil acidification, acid sulfate soils, loss of soil carbon, salinisation, coastal saline incursions, mass movement and nutrient decline (OEH 2011).

Due to the many factors affecting soil condition and structure, and the varied impacts of climate change, it is difficult to estimate overall trends in impacts for a region. Climate impacts might have opposing effects on soils simultaneously, making it difficult to predict which impact, if either, will be dominant in a given landscape. There are a number of likely climate change impacts upon soils in the Sydney region, which include:

- **Sheet and rill erosion** will be directly affected by changes in rainfall intensity and increased frequency of extreme precipitation events, with larger amounts of topsoil being removed due to increased water moving through the landscape (OEH 2011, Rosenzweig & Hillel 2000).
- Increased rainfall intensity is likely to increase rates of **gully erosion** from overland flow (OEH 2011b), and, coupled with increased frequency of extreme precipitation events, will possibly result in higher amounts of **streambank erosion**.
- There is an expected increase in **beach and dune erosion** by both wind and water due to increase in intensity of summer and spring storms, sea level rise and changes to wind and wave direction (OEH 2011b).
- An increase in **saline incursions** will likely occur due to sea level rise and higher rainfall in spring and summer (OEH 2011b).
- Warmer average temperatures in New South Wales may increase the production of potential **acid sulfate soils** (OEH 2011). Seasonal changes in soil hydrology as a result of changes to rainfall patterns increase in acid sulfate soils. Acid sulfate soils occur when sediments and soils that contain iron sulfides are exposed to oxygen, resulting in the formation of sulfuric acid.
- **Soil acidification** may be caused by rising water tables (OEH 2011b).
- **Soil structure**, the prime physical determinant of soil condition, is likely to be affected by higher rainfall patterns (OEH 2011b).
- **Soil carbon** will be affected by both temperature and soil moisture, through altered rainfall patterns (OEH 2011b).

- There is likely to be increased risk of **mass movement** on all currently vulnerable slopes in the coastal hinterland due to increases in spring and summer rainfall (OEH 2011b).
- **Changes in nutrient retention** are likely to be the result of sea level rise (due to saline incursion), increased rainfall leading to increased leaching and temperature and rainfall effects on vegetation (Rosenzweig & Hillel 2000).

Changes to vegetation types, abundance and distribution; biomass availability; changes to fire intensity; and land-use patterns are likely to trigger potential feedback loops that will have complex interactions with soil erosion, nutrient availability, soil temperature, soil carbon and rainfall erosion (Ravi et al. 2010).

Long-term monitoring programs at local and regional scales can assist resource managers to:

- understand changes to soil condition
- makesoil management decisions
- build an evidence base for the response of soil systems to various management techniques
- incorporate rehabilitation techniques to address historical degradation
- improve understanding of urban soils, which have received less attention than agricultural soils.

3.3 Potential areas for further investigation

- Identify how impacts of climate change will affect existing soil conservation approaches in Sydney.
- Review the suite of land-management models in use in Sydney, and assess their utility for projecting future land condition.
- Identify and map areas in Sydney that will be more vulnerable to soil degradation hazards under climate change.
- Map existing contaminated sites in Sydney, and identify how changing hydrology due to climate change and soil structure might affect the containment of contamination.
- Identify soil degradation hazards which are likely to have an increased adverse impact on the built environment under climate change; understand where these hazards are likely to occur in urban areas, or around key infrastructure.
- Map the areas of Sydney that will experience a changed risk of landslide under climate change and explore the emergency management and land-use planning implications of these changes.
- Assess the likely impacts of changed fire regimes on soil erosion in Sydney.
- Assess the likely impacts of changed rainfall regimes on soil erosion in Sydney, and the likely impacts of extreme weather events on streambank, estuarine and coastal erosion in Sydney.
- Identify how considering impacts of climate change would affect existing approaches to biodiversity conservation in Sydney, and assess whether conservation program goals and evaluation processes need to be reconsidered.

- Develop a methodology for identifying and prioritising species and/or communities for conservation in Sydney under climate change scenarios.
- Research the key characteristics of resilience and adaptive capacity for key species and communities in Sydney, and identify ways of increasing resilience and adaptive capacity.
- Use historical studies to identify past thresholds or tipping points in populations or communities that have declined, and develop an understanding of whether these tipping points or thresholds hold relevance for existing species/communities.
- Assess the key impacts of climate change on sites of international significance within Sydney, and identify potential management options to reduce the vulnerability of these sites.
- Explore how land-use planning processes in Sydney can help conserve areas which are likely to be of high biodiversity value under climate change.
- Explore how existing planning regulations for green space and vegetation can be used to improve biodiversity outcomes.
- Identify quick connectivity gains that can be made in Sydney, and explore how existing programs aimed at increasing connectivity in Sydney can be enhanced or expanded.

4 Human health

This review explores current and emerging research in health adaptation planning for climate change, and identifies priorities and needs for further research. A literature review and a series of interviews with academics and stakeholders were conducted in order to understand the likely adaptation challenges for Sydney.

The likely adverse health impacts from climate change are many and include heat-related illness or death, injury and death from natural hazards such as flooding and bushfires, and increase the potential transmission of vector-borne diseases.

The adverse health impacts on Sydney will not be evenly distributed geographically or throughout the population. Health and other services will need to be able to respond to the changing health needs of the population. Gradual changes over time are likely in the incidence or prevalence of some health outcomes. Other climate-related population health events may be relatively sudden, such as an extreme heat wave or disease outbreak.

4.1 Heat

Increasing temperatures associated with climate change are an important health concern for Sydney. The frequency of extreme heat events in Sydney is expected to more than triple over the next 40 years as temperature variability increases (Gosling et al. 2009).

Ambient temperature is associated with mortality and hospitalisations. The threshold temperatures for population health effects differ by location, presumably due to a level of acclimatisation within a local population, but health effects generally become apparent when the temperature reaches the mid to high 20s (Bambrick et al. 2008).

While a single day of hot weather can increase emergency department visits, ambulance call-outs and hospital admissions, sustained periods of heat over a few days are particularly relevant (Kjellstrom & Weaver 2009). During Adelaide's 13-day heat wave in 2009, hospital admissions directly related to heat increased 14-fold, ambulance call-outs increase by 16 per cent and there was a 9.5 per cent increase in mortality (Nitchske et al. 2011).

Much of the ill-health and mortality associated with high ambient temperatures is preventable with appropriate health promotion information and emergency management (Williams et al. 2011). However, it is older people and people with underlying chronic respiratory or cardiovascular health conditions who are most at risk in hot weather. An important avenue of (longer term) prevention will be to reduce the burden of chronic disease in a population.

4.2 Extreme weather events

Extreme weather events (storms, floods, drought) are expected to increase in frequency and intensity with climate change. Extreme events can cause disruption to transport, interrupt power supply and damage water and sewerage infrastructure (Steffen et al. 2012). In addition to injury from accidents and direct exposure, severe events can have additional health impacts.

Damage to infrastructure from climate change-related extreme weather events could have widespread and severe consequences for population health, and the resulting mortality and morbidity has the potential to overwhelm the health system.

4.3 Vector-borne disease

Climate change is expected to alter the geographic distribution of vectors and increase transmission potential of vector-borne diseases already present in New South Wales such as Barmah Forest virus, dengue fever, Japanese encephalitis, malaria and Ross River virus (National Notifiable Diseases Surveillance System 2012). This may result in increased population at risk, longer transmission seasons and higher seasonal peaks (Bambrick et al. 2008).

Rainfall and coastal flooding is a significant driver of vector populations through providing suitable breeding habitats, and high humidity enhances vector survival. Areas where rainfall and humidity increase alongside temperature are those where risk of vector-borne disease will increase the most (Woodruff & Bambrick 2008). Coastal dwellers and those living in urban fringe areas may be at increased risk.

The installation of domestic rainwater tanks to accommodate periods of low rainfall may assist the distribution and increase the abundance of vectors in Sydney, creating unintended feedback loops within adaptation strategies.

4.4 Food safety and quality

Climate change may affect food sufficiency through the effects of seasonal conditions and extreme events on food production. Nearly all food produced in Australia is considered vulnerable to some extent (Stadler et al. 2011). Extreme weather events associated with climate change may reduce the long-term viability of agriculture in some areas, as well as diminish supply and raise prices. Further, access to nutritionally healthy foods may be reduced with climate change.

In addition to affecting the quality and sufficiency of fresh food, the safety of food may also be affected by climate change as increased ambient temperatures enhance growth of harmful bacteria. Salmonellosis and other bacterial gastrointestinal infections are predicted to increase in Australia overall by 3 per cent by 2020 and 14 per cent by 2050 (compared to 2000 rates) due to climate change, with usual summer peaks in case numbers becoming higher and more prolonged (Bambrick et al. 2008). Climate change impacts on food-borne disease may be a particular concern for already vulnerable residents in aged-care facilities and hospitals (Bambrick et al.2008). Food-handling guidelines may need to be revised to address increasing risks to food safety.

4.5 Air quality

Levels of air pollutants in Sydney are associated with hospitalisations and mortality (Morgan et al. 1998). Exposure to air pollutants may increase with climate change (IPCC 2007). In Sydney, these air quality concerns are compounded by potential for increasing urban pollution with population growth and urban expansion, and increasing ambient temperatures. Sydney's air quality may also be affected by increased frequency and intensity of bushfire smoke and dust storms under climate change (CSIRO & BoM 2007).

It is hypothesised that climate change could increase ill health due to asthma and hay fever and findings from overseas studies support this; however, very little is known about the impacts of climate change on outdoor or indoor allergens relevant to Sydney, such as important allergenic weeds, house dust mites and indoor mould spores (Beggs & Bambrick 2005). More research is needed to understand this fully.

4.6 Water quality

Rainfall patterns across New South Wales are expected to continue to change over coming decades as the climate changes. Population growth, especially in Sydney and other urban areas, could increase pressure on an already stressed resource. Water security is recognised as a growing concern, with the adoption of permanent water restrictions in recent years. Future climate in the Sydney region is expected to be marked by more intense rainfall variability so that droughts and rainy periods become more frequent and more severe (IPCC 2007).

Water quality will be affected by the changing patterns of rainfall. Flooding associated with an intense rainfall event can overload stormwater infrastructure and sewers and cause heavy runoff from farms, contaminating water supplies with protozoa, bacteria, viruses and agricultural chemicals, and lead to toxic algal blooms from high nutrient levels (McMichael et al. 2009; McCarthy et al. 2012). Drought can reduce water quality by increasing the concentration of pathogens, heavy metals and major ions and by depleting oxygen levels.

Changing temperature may also affect future water quality. A recent New Zealand study found a positive association between giardiasis notifications and both temperature and rainfall. Higher ambient temperatures also promote the growth of algae (Britton et al. 2010).

4.7 Mental health

The mental health impact of climate change is a relatively new area of research. Previous research has linked an increase in suicide with periods of low rainfall, and also during hot weather with low humidity. Rates are expected to increase in Australia in places where rainfall is reduced by climate change. Hospitalisations for mental health-related diagnoses increase significantly in hot weather (Hansen et al. 2008).

Other mental health effects may occur in response to acute events such as extreme heat or other extreme weather events associated with climate change. A further consideration is the potential increase in risk to hospital staff from patients presenting with mental health conditions in response to an extreme event (Cusack et al. 2011).

Significant research gaps exist relating to the likely effects of climate change on mental health in Sydney.

4.8 Community and indigenous health

There are approximately 55,000 Indigenous (Aboriginal and Torres Strait Islander) people living in the Greater Sydney region. In New South Wales, life expectancy for Aboriginal people remains nine years lower than non-Aboriginal life expectancy, at 74.6 years for females and 70.5 years for males.

Climate change is widely expected to have a disproportionately adverse effect on the health and wellbeing of Australia's Indigenous people, largely due to high rates of pre-existing chronic disease and social disadvantage. Indigenous communities in Sydney are likely to be affected disproportionately because of the existing health and socio-economic inequalities that, coupled with a distrust of mainstream health services, may manifest in lower quality housing and poorer access to health services.

There are currently no quantitative estimates of the health impacts of climate change on Indigenous communities in Australia. However, research is currently underway to model the

likely cause-specific health impacts on Australian Indigenous communities from climate change.

4.9 Health services and infrastructure

To be prepared for the impacts of climate change, the health system needs to be flexible (in regard to location, response and types of services), strategic in resource allocation (building on existing services, prioritising vulnerable populations and ensuring equity), and robust (resilient infrastructure, consistent and with a sustainable workforce) (Blashki et al. 2011). Health services and infrastructure is an area of current research into adaptation planning for Sydney and elsewhere in Australia.

The nation's major demographic change (the ageing population) was predicted to dominate health service planning over the next few decades, however, the impact of climate change on human health is now likely to exacerbate the associated health concerns related to ageing.

Surveillance and monitoring systems will be critical to enable early detection and management of infectious disease, as will health professionals being able to recognise symptoms of heat stress (Blashki et al. 2011). As the magnitude of climate impacts increases, so will the need for doctors and other health professionals to know and understand much more about the links between climate/weather and health and disease, and to apply this in their daily practice. An integrated approach, between health services and other industry sectors, is recommended to improve adaptive capacity (Horton et al. 2010).

A continued focus on high-end and expensive tertiary services and lack of investment in primary care could, potentially, leave the community more vulnerable to climate change. A greater focus on providing and supporting primary care and allied health services may improve population resilience to extreme events by reducing levels of obesity-related chronic disease and improving overall population health.

Finally, the impact of climate change, and extreme weather events on the physical characteristics of services, including the location of new health care facilities, should be taken into consideration.

4.10 Potential areas for further investigation

Heat

- Improve understanding of heat-related vulnerability, impacts and adaptation for specific population groups (elderly, Indigenous, workers) including how to best to reach these groups for prevention.
- Develop locally meaningful temperature/heat index thresholds at which to trigger a heat warning.
- Evaluate heat wave warning systems and response plans.
- Improve understanding of how the built environment ameliorates or exacerbates exposure and health impacts from high ambient temperatures, at scales from individual buildings to urban design, and modelling of health impacts under alternative built environments.

Extreme weather events

Improve understanding of the urban system, including points of vulnerability and resilience. This includes the need to:

- model possible extremes and potentially catastrophic events rather than climate averages to estimate both the immediate health impacts as well as systemic vulnerability
- develop and evaluate more integrated emergency response planning
- identify groups that are most vulnerable to extreme events
- improve understanding of mental health responses (in the short and long term) to extreme events
- identify ways to improve community self-reliance, especially in the context of multiple events.

Vector-borne disease

- Improve understanding of how urban ecosystems (microclimates, built structures, human behaviours) drive mosquito ecology, taking a broad systems-based approach to vector control.
- Development of ‘vector-safe’ communities as a pre-emptive strategy.

Food safety and quality

- Improve the evidence base around food provisioning systems, including quantitative assessments of the environmental footprints of different systems and their capacity to adapt with climate change, and the relative contributions of different systems to Sydney’s food supply.

Air quality

- Improve monitoring of aeroallergens, in particular providing better spatial coverage of the Sydney region.
- Conduct a spatial inventory of allergenic species across the region, and associations with respiratory outcomes. This relates to balancing the need for vegetation planting as an adaptive cooling strategy with the need to avoid adverse health impacts through exposure to allergenic species.
- Improve understanding of climate change impacts on indoor air quality (e.g. moulds, indoor pollution from heating sources) and related health outcomes.

Water quality

- Model climate change impacts on water sufficiency and quality, including the effects of extreme events.
- Improve understanding of how policy, regulation and surveillance can be proactive and effective to ensure water provisioning systems are robust.

Mental health

- Improve understanding of the mental health impacts of climate change on specific, vulnerable populations.
- Improve understanding of adaptation needs in different categories of places (e.g. urban/rural), including the characteristics of these that make them more or less resilient.
- Quantify the likely mental health impacts under different climate scenarios.

Community and Indigenous health

- Expand current research taking place in smaller urban and remote Indigenous communities to include impacts and adaptation in the Sydney region.
- Expand research to include development and evaluation of adaptation strategies that are specific to Indigenous communities.
- Investigate and evaluate local community ‘grass roots’ adaptation actions that are taking place and may have value for the Sydney region.

Health services and infrastructure

- Develop and model realistic scenarios that consider impacts on health services and infrastructure, including the impacts on staff and service buildings.
- Include climate change as a factor in health service planning and infrastructure design.

5 Cultural assets

This review collates available information relevant to the understanding of climate change impacts on cultural assets and draws out the themes and issues relevant to the broader Sydney area. A literature review, a survey of practitioners, agencies and local governments, and six targeted interviews were conducted to inform this review.

'Cultural assets' refers to the legacy of physical artifacts (cultural property) and intangible attributes of a group or society that are inherited from past generations, maintained in the present and bestowed for the benefit of future generations. Cultural assets include tangible culture (such as buildings, monuments, landscapes, books, works of art and artifacts), intangible culture (such as folklore, traditions, language, and knowledge), and natural heritage, including culturally significant landscapes and biodiversity.

Climate change poses threats to many cultural assets through impacts such as increased floods, increasing extreme weather events, and the decay of cultural landscapes and assets through changes in humidity, precipitation, temperature, and related consequences such as altered salt regimes, and invasive flora and fauna. Cultural assets across Sydney will have more or less vulnerability or adaptive capacity depending on a number of factors such as location, condition and age.

5.1 Predicted impacts on cultural assets

There are two key impacts on cultural heritage assets: direct impacts from changes to our current climate regime, and indirect impacts that arise from cultural reactions, and changes to natural habitats and landscapes.

The direct impacts of climate change on cultural heritage are generally within the same range of impacts that occur over time, but with a change in the intensity or rapidity with which these impacts may escalate. There is a consistency in the nature of the potential impacts that sites will experience, which means that we can learn from international colleagues at least in terms of impacts on tangible heritage.

Gradual and long-term decline in resources to manage cultural assets means that many have not been well maintained. This leaves them particularly vulnerable to any increase in intensity or frequency of climate-induced impacts. Key specific impacts include the loss of coastal Aboriginal sites and coastal built heritage assets, saltwater intrusion to historic engineering features, increased storm damage risk to heritage structures, increasing bushfires and potential depopulation of rural areas and abandonment of rural structures (Pearson 2007).

As well as the loss of physical sites and places, the intangible heritage of Indigenous people – which is directly linked to cultural landscapes, ecosystems and biodiversity – is at risk. Many people are likely to experience a loss of cultural identity from predicted climate change impacts, although these losses are difficult to quantify (Burgess et al. 2009; English & Brown 2001). The Sydney–Hawkesbury sandstone country is also particularly vulnerable to the impacts of bushfires, and some rock art sites have experienced significant damage from fires in the recent past – a risk that is likely to increase in future (Gunn 2011; Lambert & Welsh 2011).

5.2 Involving community

There is a noticeable lack of work being done on the theme of 'loss' – that is, what it will mean for communities to lose aspects of their heritage to climate change impacts. It is not going to be possible to adapt every cultural asset in such a way that it is protected from all of the possible effects of climate change, therefore there needs to be a process to prioritise heritage places and direct available funding to the most appropriate places and projects.

A sense of place contributes to our understanding of who we are as a community. It is important to identify heritage places in terms of their significance for past, present and future generations, yet there is a noticeable lack of community input into prioritising the issues and protecting cultural places from climate events. Understanding which cultural assets are important to current populations either broadly or to sections of Sydney's community is essential if governments are to meet the expectations of the community in maintaining and protecting cultural assets.

Community is central to the concept of cultural heritage value; however, some argue the increasing professionalisation of heritage has alienated the community by developing mechanisms that centralise control with 'experts' rather than engaging with the wider community. Professionals need to find new ways to engage the community with management of cultural assets.

5.3 Adapting cultural assets

A primary focus of climate change adaptation with regard to cultural assets appears to be related to sea level rise and disaster management. In particular, the impacts on Aboriginal heritage places of changes in rainfall, temperature, pests and salinity are important.

Maintaining heritage places is a key component of reducing vulnerability of heritage assets to the potential impacts of climate change. This is well demonstrated through the example of the maintenance of Innisfail's art deco buildings after Cyclone Larry in 2006. Places that had been repaired and maintained after damage from the 2006 cyclone withstood destructive winds from Cyclone Yasi in 2011 – a storm of much greater intensity.

Another key element for preservation of cultural assets from predicted impacts of climate change is preparation prior to a specific event. Where the predicted impacts are well understood, individual preparations for heritage assets can be made.

It is essential that all levels of government recognisetheir responsibilities relating to cultural heritage and climate change. If the cultural value of assets is not considered and does not trigger specialised treatment and/or exemption, standard adaptation responses such as disaster risk assessment of key infrastructure and replacement of canopy trees with more appropriate species, could potentially result in an indirect impact of climate change on cultural assets.

5.4 Monitoring and management

Monitoring impacts, adaptations and climate science and updating management plans is a sensible step towards the continuous assessment of vulnerability of cultural assets to climate change. While monitoring impacts to heritage assets is generally an important management step, it is especially important for climate change, where the science that informs predictive impacts is constantly being updated. There is also a need to include cultural assets in vulnerability mapping, to work towards understanding the potential impacts of climate change

and identify relevant adaptation strategies. There are good examples from Eurobodalla (Glatz 2010) and Narrabeen Lagoon (AECOM 2010) of where this has been done effectively.

Online databases sharing information about climate change and heritage issues have been used elsewhere in the world. For example, the California Climate Change Research Database (http://californiaccresearch.org/index.php) and the European Union Heritage Portal *(*http://www.heritageportal.eu/*)* allow the exchange of information relating to climate change and cultural assets, which could be useful in the Sydney context.

5.5 Potential areas for further investigation

- Conduct detailed long-term monitoring to better understand the impacts of climate change on cultural assets.
- Develop vulnerability maps for areas rich in cultural assets. Sea level rise data is not at a fine-enough level to allow prediction of impacts on specific sites except at a very crude level. There is an urgent need for this finer-scale vulnerability mapping.
- Develop adaptation strategies and treatments based on quantifiable data or detailed modelling.
- Research how the cultural landscape could be enhanced while taking positive steps towards climate change mitigation. There is also an opportunity for using predicted changes to cultural assets as a catalyst for understanding the values and priorities existing communities place on cultural assets.
- Research what loss will mean to the communities who value cultural heritage assets.

6 Settlements and communities

This review assesses Sydney's vulnerability to climate change with respect to planning and design of settlements and communities. Communities are defined as groups of people who live and work within the various settlements of Sydney. Communities' characteristics affected by climate change include their livability (quality of life, health and wellbeing). Settlements comprise buildings, transport and infrastructure networks that connect people to jobs, goods and services, making up the economy and society of a city.

The review focuses on several key areas including urban form, land use, temperature and the urban heat island effect, bushfires, riverine flooding, coastal flooding, social impacts, adaptive capacity and emerging policy and governance.

6.1 Urban form, land use and sustainability

To date, most urban sprawl and compact city planning and design strategies that have considered climate change have focused on mitigation and not adaptation. However, urban form has a significant impact on extreme heat events.

To a certain degree, urban compactness causes a reduction in greenhouse gas emissions, and is found to be 2–2.5 times more energy efficient due to a range of factors. However, urban compactness may decrease green spaces if not properly designed (Dodman 2009). A reduction in green spaces and an increase in hard surfaces from paving and roofing cause inner cities to experience an increase in temperature (heat island effect), due to low rates of evapotranspiration, heat retention and light (sun) reflection, with an average increase in temperature of 5–11 degrees Celsius (˚C) compared to surrounding areas (Dodman 2009, Stone & Rodgers 2001). There is much work to be done to more fully understand these affects for Sydney and to apply climate modelling and understanding of thermal mass to practical applications of building design and planning.

For suburban settlement patterns, some climate change impacts are similar to urban areas. For example rising temperatures increase the use of air conditioning and impact vulnerable groups such as the elderly, young and the infirm. Other climate change impacts differ, such as increased heat affecting gardens and increased exposure and vulnerability to bushfires (Williams et al. 2010).

Infrastructure and structures are increasingly vulnerable to the growing frequency and severity of storms and bushfires. Impacts include buckling and cracking in roads and rails, flooding of roads and metro systems, downing of power and utility wires and cables, fire damage, and levees and seawalls being topped by floodwaters (Wald & Schwartz 2012).

6.2 Temperature and urban heat island effect

Urban form has a significant impact on extreme heat events. Between 1956 and 2005, compact cities experienced an average increase of 5.6 extreme heat event days whereas sprawling cities had an average increase of 14.8 days (Stone et al. 2010). Heat waves have a significant effect on human health and mortality. Exaggerated effects of heat waves are felt in cities due to the urban heat island effect.

People most vulnerable to death during a heat wave are people who are elderly, young or infirm as well as those that are less mobile or unable to take care of themselves, or are

socially isolated (Stone et al. 2010). Social inequity will likely occur for those who cannot afford or lack air conditioning.

Adaptation strategies include preserving and incorporating more green spaces, creating more reflective surfaces on roads and buildings, and making cities more compact. Green infrastructure (parks, open lands and waterways) can be used as a key climate change adaptation strategy to improve air quality, reduce hard, impermeable surfaces, and create natural cooling and heat absorption.

Innovative adaptation strategies from around the world were reviewed, and principles applicable for Sydney were identified, including:

- modify heat alert systems and hot weather response plans
- enhance weather monitoring networks
- analyse how heat waves may increase anti-social behaviour in the city
- institute programs to reduce peak electricity demand during heat waves
- provide locally specific design guidance
- improve the care given to urban trees to extend their lives and health
- mandate that new developments contribute to offsetting the urban heat island effect
- facilitate public access to cool buildings, swimming pools and misting stations during heat waves
- encourage passive ventilation
- encourage ‘cultural’ adaptations (e.g. Schenk et al. 2010).

6.3 Bushfires

Recent bushfire history has highlighted the vulnerability of urban life in Sydney. Adaptation options include the modification of the urban form to allow for a greater distance between bushland and developments; continuous use of hazard reduction measures; and the use of community education, networks and engagement to increase the preparedness hence lowering the impact of fire events.

Community education and engagement increases physical and mental preparedness and lowers the impact of fire events. Community actions include improving housing stock to be more fire retardant, volunteering in community programs, assisting neighbours, providing support for vulnerable residents, and building communication networks.

Hazard reduction burns are the single-most widely used tool for managing bushfire risk (Fernandes & Botelho 2003). However, this method is a high-risk, resource-intensive operation with relatively short-term benefits and a heavy dependence on favourable weather conditions. It may also have a large impact on the structure and function of local ecosystems.

A strategic review and research initiative by Ku-ring-gai Council indicated that initial climate change adaptation models were not adequately addressing risks and did little to assist in determining feasible actions. The assessment and communication of bushfire vulnerability is an important element of a future adaptation strategy. California provides another good example of adapting to bushfire risk by bringing together multiple agencies and policies for an integrated approach (California Climate Change Adaptation Policy Guide 2012).

6.4 Riverine flooding, including flash flooding

Exposure and vulnerability to riverine flooding is expected to increase due to denser developments and an increase in exposure to storm events. The catchments of the Hawkesbury–Nepean and Georges rivers are likely to be exposed to inundation.

The most effective way of reducing flood risk is locating property outside the floodplain or placing new buildings within the lowest risk areas. Decentralisation of green infrastructure is also an environmentally and cost-effective way of reducing excessive stormwater runoff (Keeley 2011).

Selling development credit which allows for rezoning is a strategy used internationally to allow for the conversion of flood-prone land to prevent future development. Such strategies prevent future development from occurring within the floodplain – relocating it to other low-risk areas, thus allowing the restoration of the natural riverine ecosystem within an area (Mandarano 2010).

There are many international examples of flood adaptation measures that may be applicable to Sydney, for example:

- Raise public awareness of flood risk.
- Review flood response plans to identify and protect critical infrastructure.
- Require new developments to take account of climate change-related vulnerabilities, and to contribute to improved risk management.
- Implement or improve flood warning systems and emergency response plans, update flood maps.
- Conduct risk assessments of major road culverts and bridges
- Identify ways to house the displaced, and assist them with insurance claims, post-traumatic stress, unemployment and other fallout from hazards
- Consider the costs of and logistical issues surrounding post-storm clean-up.
- Move or abandon infrastructure in hazardous areas.
- Increase the capacity of stormwater collection systems.
- ‘Green’ the urban environment; design green spaces to absorb and retain rainwater.
- Identify sites, such as industrial land, that can be used for flood storage.
- Subsidise the installation of back-water valves and sump pumps on residential sewer connections.
- Introduce city-wide mandatory downspout disconnection.
- Prohibit construction of new reverse-slope driveways.

6.5 Coastal flooding

Property and infrastructure are at increasing risk from sea level rise and resulting coastal inundation and erosion. About 50,000 beachfront or waterfront properties in New South Wales (statewide) are likely to be affected by coastline erosion and sea level rise (DECCW 2010a).

Protection, accommodation and retreat are the broad adaptive strategies for sea level rise (Alexander et al. 2012). Highly developed coastal cities facing sea level rise and extreme events tend to favour 'protective' approaches (as in Cape Town and Singapore). In areas such as Sydney, where there are highly valued and immovable assets, sea level rise risks will likely be mitigated through protection and accommodation. A recent report indicates that the consequences in coastal parts of Sydney from climate change will be driven as much by socio-economic factors and decision-making as by climate hazards (Preston et al. 2008).

Prevention of new developments within risk areas is of great importance. The California Climate Council uses setback requirements from the water's edge to prevent development in vulnerable areas (California Climate Change Adaptation Policy Guide 2012). These setbacks have been strengthened over time to allow new structures a longer planned life (initially 35–50 years, now generally 75–100 years).

Key strategies that have been used internationally to minimise risk that may be applicable to Sydney include:

- Assess the impacts of sea level rise on public investments and identify vulnerabilities.
- Encourage spatial planning in the longer term that takes account of sea level rise.
- Identify where and how flooding and coastal lines may be redrawn in future.
- Conduct analysis and start to plan for priorities for protection.
- Plan the siting of infrastructure and development away from hazard-prone areas.
- Describe a transitional zone between the hazard area and the built area.
- Establish a comprehensive planning and zoning policy.
- Support the phasing out of insurance for developments in vulnerable areas.
- Ensure that public access to the shoreline is not lost with sea level rise.
- Secure strategic open lands to provide transition zones to accommodate retreat.
- Investigate the various forms of shoreline protection, evaluating inherent trade-offs and associated costs for each option.

6.6 Social impacts and adaptive capacity

Activities in urban areas have both positive and negative impacts on social equity and its spatial distribution, and this is true for adaptation to climate change. Existing vulnerable social groups, such as those with low income, may suffer dramatically from climate change and adaptation, especially where inadequate infrastructure and facilities exist. Increased risk from existing hazards, such as frequent floods and hotter climates, can impact poorer groups disproportionately by lowering their access to goods such as food and clean water (Dodman 2009).

There are significant gaps in understanding the capacity for social or institutional change, the extent of communities' adaptive behaviours, and how people and institutions behave based on changes in climate conditions.

The *California Climate Change Adaptation Policy Guide* (2012) encompasses a range of strategies with regard to equity, health and socio-economic impacts, including assessing community-wide health vulnerability, refining emergency preparedness, and developing an outreach program.

6.7 Potential areas for further investigation

- Quantify the impact of adaptation options such as green infrastructure and greening urban spaces on reducing anthropogenic warming. There is much work to be done to more fully understand these affects for Sydney and to apply climate modelling and understanding of thermal mass to practical applications of building design and planning. This should include an investigation into building materials and designs which can withstand extreme heat events.
- Assess opportunities to link bushfire and other hazard planning needs more closely to community-based development of local environmental plans.
- Explore the economic, environmental and social costs and benefits of zoning flood-prone areas in Sydney versus adapting existing buildings in flood-prone areas.
- Develop a set of criteria specific to Sydney to achieve a ‘disaster resistant community’ in the Sydney metropolitan area, including urban planning and design guidelines, policies, and strategies.
- Develop a life-cycle-based cost and impact assessment model for climate change in the Sydney metro area.
- Develop GIS-based tools that display and help visualise the projected impacts and effects of climate change in the Sydney metro area.
- Model disaggregated behaviours (at the individual human level) of individuals in the face of climate change, such as residential and business location choices, and transport options.

7 Buildings and neighbourhoods

This review assesses and synthesises the academic and practice literature relating to adaptation of neighbourhoods and built components of the urban environment to inform adaptation in Sydney. It presents tested strategies and emerging innovations employed around the globe in adapting neighbourhoods and buildings for climate change, focusing on exposures to which Sydney is most vulnerable.

Buildings are the fixed, permanent structures within the landscape. Buildings play a significant role in moderating and providing a living environment that is both safe and comfortable.

A **neighbourhood** is assumed to be of a spatial size capable of generating communal relationships that can 'induce rewarding human association' (Kallus & Law-Yone 2000). Planning is paying increasing attention to the neighbourhood scale due to it being critical for comfort and convenience and for generating links with supporting infrastructure and services.

7.1 Temperature increases

In Sydney, there is a growing need to study the impact of temperature increases, especially given the significant impact of the urban form upon maintaining higher heat levels. The main causes of the urban heat island effect are:

- low albedo (reflectivity) of surfaces
- low biomass (vegetation) coverage
- thermal mass of built form
- high waste heat production (CCAP 2007).

Strategies to reduce the urban heat island effect include increasing biomass (planting street trees, increasing green space), installing white roofs, de-paving driveways and encouraging passive design.

Seven key steps for effective urban heat island policy have been proposed by CCAP (2007), which will become essential as an adaptation strategy. They are:

1 Recognise high-risk areas.

2 Assess likely causes.

3 Identify adaptation measures suitable to each area.

4 Prioritise these measures with greatest effectiveness.

5 Conduct cost-benefit analysis of measures.

6 Engage residents and other stakeholders.

7 Include clear performance measures, and monitor results.

7.2 Drought and water

Climate change projections for New South Wales suggest significant increases in drought frequency. Intense floods and droughts will affect water quality, exacerbate water pollution and also cause thermal pollution, with possible damage to ecosystems, human health and water system reliability and operating costs (ECE 2009). In urban areas, the main impacts of drought will include building damage (due to soil shrinkage), changing soil mechanics (relating to road design), hydrologic effects (impact on water quality) and loss of vegetation.

Adaptation measures can be grouped into two main categories – prevention and preparation. Prevention involves actions such as reducing demand on existing water resources, lessening the impacts on infrastructure, changing building codes for greater resilience, and landscaping using drought-tolerant species, water-sensitive urban design and stormwater management. Preparation involves management of water reservoirs by regulating demand and water levels in dams.

7.3 Bushfires

The threat of bushfires is predicted to escalate within the Sydney region as a result of climate change. Bushfires constitute a direct threat to property and people, and therefore are important to include as a factor in climate change adaptation for buildings and neighbourhoods within Sydney. Adaptation strategies can be divided into three basic themes: preventing or combating ignition, reducing fuel loads, and enhancing firefighting capabilities.

Key ignition-reduction strategies recommended for Sydney at the neighbourhood scale include replacing and upgrading aged electricity infrastructure, constructing fire breaks and designating emergency access zones, upgrading construction codes, creating greenbelt barriers, disclosing bushfire hazards, and installing self-cleaning gutters and external water spray systems. The Australian Building Code prescribes minimum performance standards for buildings constructed in bushfire prone areas, however, there is an absence of any requirement for ongoing maintenance, as well as no requirement to retrofit non-complying older buildings.

Measures to improve firefighting capacity could include enhanced bushfire modelling and prediction, the introduction of electronic detection systems, emergency services levies, teams dedicated to vulnerable areas, private bushfire shelters and/or community fire refuges, and strategies for reduction of fuel loads, controlled burning and fuel-clearance abatement schemes (as used in California).

7.4 Severe storms and flash flooding

Severe thunderstorms and storms present two distinct threats: structural and other damage caused by wind gusts (direct or as a result of debris impact and tree fall), lightning strikes and hail damage, and flash flooding caused by intense rainfall accompanying these events. Seasonal runoff volumes in the Sydney region are projected to increase by as much as 26 per cent during the summer storm season (DECC 2008).

Adaptation strategies to reduce the risk of flash flooding aim to reduce water runoff from urban areas to avoid overwhelming the capacity of stormwater systems. Many of these adaptation strategies will offer ancillary benefits, such as the runoff retention benefits of green roofs. Strategies suitable for Sydney include green and blue roofs, water harvesting,

permeable surfaces, bio-swales, detention basins, assimilated wetlands and storm drain maintenance.

Reducing the vulnerability of neighbourhoods and buildings to severe storms will require both increasing the resilience of built structures and reducing the risk of debris impact. Strategies may include selecting hail-resistant roofing materials, installing hail netting/canopies, encouraging use of hail blankets and strengthening building codes to address threats from high wind and lightning strikes.

7.5 Sea level rise and coastal flooding

The profile of Sydney's coastal system makes it particularly susceptible to impacts linked to sea level rise (SCCG 2010). The impact of this rise upon the Sydney coastline is anticipated to include an increase in permanent tidal inundation of land by seawater, the recession of beach and dune systems, modification of tidal behaviours in estuaries, an extension of saltwater intrusion, an elevation of saline water tables and an increase in coastal flooding (DECCW 2009).

Adaptation for sea level rise must deal with competing forces between public and private interests. Managing the types of actions that owners of coastal land may take to defend their land from loss to the sea is complex. This review identified four adaptation strategy types for sea level rise: retreat, defence, elevation and reclamation.

Retreat strategies – such as scheduled or planned abandonment, compulsory surrender or acquisition, transferrable development rights, conservation covenants, building setbacks, house relocation and lease-back schemes – are varied forms of managed retreat from the shore. They involve moving infrastructure and housing to safe ground and conceding some land to become inundated (ICE 2010). Some of these apply to new buildings while others such as building setbacks apply to existing buildings. Many such strategies involve significant government outlay or capital.

Defence strategies aim to 'hold back' the sea to prevent inundation and erosion. Engineered strategies such as sea walls are coming under increasing criticism due to their high environmental impact, ongoing maintenance costs and difficulties with increasing their height over time. Natural barriers are the more desirable option, requiring the preservation of barrier islands, reefs, dunes and wetlands, which provide a natural coastline defence.

Elevation strategies involve raising components of the built environment above the anticipated flood inundation, allowing natural processes to continue unimpeded. Such strategies have been used in places such as the Netherlands and New Orleans.

Reclamation consists of engineered solutions to create dry land from an area covered by water. Reclamation techniques such as beach replenishment can have positive benefits for coastal adaptation to sea level rise in the re-establishment of natural defences. Negative impacts typically result from reclamation, including loss of intertidal habitats and development of vulnerable locations. The long-term ecology functionality and economic viability of reclamation strategies is subject to debate (Birch et al. 2009).

7.6 Urban salinity

Urban salinity is the accumulation of salts in soil or water to levels that impact on human and natural assets. Increasing urban salinity is a climate-related exposure posing an environmental threat to Sydney that is predicted to worsen as the region's climate changes and sea levels rise (Hunter 2012), however, precise predictions of the anticipated increase are not available.

Urban salinity causes damage to concrete, masonry and steel structures, including roads and bridges, as well as water, stormwater and sewerage systems (DLWC 2002, DNR 2006). It can also kill vegetation, and can sterilise the landscape in areas with severe impacts.

Two key adaptation strategies are available relating to urban salinity: prevention or reduction of the impact of activities known to contribute to salinity; and direct treatment of saline groundwater or land already subject to salinity impacts. Prevention and reduction strategies might include monitoring, changes in building design codes, use of salt-tolerant plants in landscaping and salt disposal agreements. Direct treatment strategies for urban salinity available for Sydney might include engineered inception systems, evaporation basins or desalination technologies.

7.7 Energy efficiency

Energy efficiency, while generally considered a climate change mitigation strategy, also plays a role in adaptation, due to associated benefits such as reduced air, land and water pollution and habitat conservation. Adaptation of buildings to reduce energy use is a key strategy for reducing greenhouse gas emissions.

Producing energy from renewable sources is the first adaptation strategy to be employed in reducing the impact of the built environment. Following this, the use of energy-efficient systems and low-carbon innovations in the built environment will reduce the amount of energy consumed. Opportunities such as the retrofitting of municipal buildings, demand-side management and smart-metering have been used to reduce greenhouse gas emissions from the built environment both internationally and in Australia. Another strategy is to use greenery to absorb emitted carbon dioxide, using planting and tree management programs to increase green cover (CCAD 2007).

7.8 Social and institutional adaptations for climate change

A fuller understanding of the social and institutional context for climate adaptation in Sydney is recommended to support lasting change. Key issues include:

- Many environmental risk management strategies are aligned to historical climate conditions, not new or future risks, and assume that conditions are stable and predictable (DCC 2009). Static benchmarks continue to be used to identify and measure risk (for example the 1-in-100-year storm and flood events – now happening more frequently), and these continue to influence institutional practices such as land-use planning, urban development practice, land prices and insurance premiums. These static benchmarks will need to be revised to incorporate the rates of change of the conditions caused by future climate.
- Australia has a well-established early warning system to monitor and predict likely risks and hazards. However, some improvement may be needed regarding encouraging people to take protective action, the use of locally specific indicators and evaluating warning

performance and its impact on community preparedness, among other elements. Brisbane City Council has made innovations complementing the Bureau of Meteorology's monitoring and warning systems, including the Brisbane Early Warning Alert Service that allows residents to receive serve storm and creek flood alerts, and flood flag maps which provide information on flooding within the local government area.

- Promotion of self-reliance within the community is complementary to development of an effective early warning system. Response capacity can be built through community education programs and the use of local drills and exercises. Queensland has taken the lead in promoting self-reliance for climate change through its Harden Up: Protecting Queensland project, which aims to assess community vulnerability to natural hazards and encourage people to take action to become more self-reliant.
- Raising awareness among the community about climate change risks is essential for appropriate responses in adaptation. Public training such as the Ontario Regional Adaptation Collaborative program, which runs citizen forums and workshops to raise awareness of the impacts of climate change and the need for adaptation, can enhance preparedness.
- The insurance industry, too, has a core role to play in climate change adaptation in the built environment due to its risk management role for private property (Blazey & Govind 2007). The insurance industry shares similar motivations with adaptation policies, in that it has an interest in minimising long-term risk and loss. Attaching conditions to insurance policies that promote proactive adaptation can reduce long term risks for the industry, the individual and the community.
- Community participation in, and support of, adaptation is critical to the success of climate change adaptation initiatives.

7.9 Implementing adaptation

Six key factors should be used to measure the success of adaptation strategies (ECE 2009):

- coverage: the extent to which projects reach vulnerable stakeholders (e.g. individuals, households, businesses, government agencies, policymakers) and ecosystems
- impact: the extent to which projects reduce vulnerability or enhance adaptive capacity (e.g. through bringing about changes in adaptation processes: policymaking/planning, capacity-building / awareness-raising, information management)
- sustainability: the ability of stakeholders to continue the adaptation processes beyond project lifetimes, thereby sustaining development benefits
- replicability: the extent to which projects generate and disseminate results and lessons of value in other, comparable contexts
- effectiveness: the extent to which the objective has been achieved, or likelihood that it will be achieved
- efficiency: the outputs in relation to inputs, looking at costs, implementation time, and economic and financial results.

There is a need to ensure that roles and responsibilities are consistent and compatible across all scales of government, and that all levels have awareness of climate change impacts and response strategies.

Managing adaptation is not a concern only for the national level of government, but also multiple levels of international, national and sub-national levels of government as well as the private sector, research bodies, civil society and communities (Twigg 2004, Schipper 2009, Wisner 2011). Key among private sector interests in this context is the role the development industry plays in climate change adaptation and disaster risk management. Through corporate social responsibility, public-private partnerships, new business models and the intersection of the development industry with the insurance industry, the private sector can be engaged in adaptation.

Confidence among the diverse set of stakeholders involved in the built environment sector needs to be gained by collaboratively engaging them in the processes and structure of policy- and strategy-making. Key points for effective engagement of these stakeholders include

- the establishment of state and local guidelines and procedures, including a predictable engagement process
- interviews with stakeholders
- continuous and active engagement of stakeholders throughout both development and implementation
- third-party evaluation of the effectiveness of the engagement process (EERE 2008).

7.10 Potential areas for further investigation

- Review existing policies, programs and strategies that relate to neighbourhood and building-scale development to identify the degree of coordination and conflict among agencies; the development of performance measures and indicators that are used in managing climate change adaptation in the built environment; and dialogue between government and insurance companies relating to climate change adaptation.
- Study the linkages between climatic events and urban design issues to understand the benefits of urban-scale improvements; including research on zero energy buildings.
- Analyse and evaluate current salinity mapping and development controls; identify complementary building and neighbourhood scale adaptation, including approaches to subdivision and landscape management that reduce the impacts of salinity.
- Prepare case studies of coastal suburbs to identify the range of adaptation responses available to local governments; research how a range of retreat, defence, elevation and reclamation strategies can be integrated to support the development of a comprehensive coastal management strategy; identify and prioritise the city's vulnerability to loss of critical infrastructures; evaluate the effectiveness of recent sea level rise adaptation policies and mechanisms used by local governments in NSW and Australia.
- Identify neighbourhood-scale vulnerability to flash flooding in order to evaluate costs and benefits of various mechanisms; research the skills and training requirements associated with construction and maintenance of emerging forms of flood mitigation works; identify the cost-effectiveness and multiple benefits of flood management works; research the costs and benefits of insurance premium discounts for hail-resistant roofing.
- Identify best practice for bushfire evacuation at a neighbourhood scale; research the effectiveness of mandatory disclosure of bushfire hazard.

- Investigate areas in Sydney that are likely to be affected by drought in order to strategically plan adequate future water supply; analyse the implications of inconsistent policy settings in relation to drought; research best practice demand-side management for water, including its costs and benefits and the barriers to implementation in Sydney.
- Conduct behavioural studies to determine how quickly populations can adapt to highly variable summer temperatures; research adaptive capacity of the population, and barriers and incentives to adaptation; use high-resolution climate change projections to investigate the costs and human-comfort benefits of passive design for buildings and neighbourhoods in Sydney; map areas of current and future exposure to urban heat island effect within Sydney along with cost-benefit analyses of different building and neighbourhood-scale adaptation measures.

8 Emergency management

The increase in frequency and intensity of hazard events expected for the Sydney region is likely to have implications for emergency management sectors and potentially impacted communities. Emergency management consists of the organisation and management of resources for dealing with all aspects of emergencies.

This review examined emergency management in the Sydney region with regard to climate change impacts, analysing relevant Australian and international research relating to disaster risk reduction, emergency management and community development, relating to fire, flooding, coastal inundation, heat and storms. A governance map is included to outline linkages between State, district and local emergency management for planning, response and recovery.

8.1 Disaster risk reduction

The linkages between disaster risk reduction and climate change adaptation have been increasingly identified in the literature. Disaster risk reduction has been defined as 'the concept and practice of reducing disaster risks through systematic efforts to analyse and manage the causal factors of disasters' (UNISDR 2011).

Specific findings relating to disaster risk reduction in the Sydney context include:

- There has been considerable research into understanding the flood risk to infrastructure in the Sydney region, however, with increasing potential risk to infrastructure, it is imperative that emergency agencies have access to data from all infrastructure owners to enable future emergency planning particularly in flood-prone areas.
- Bushfire prone areas of the Sydney region are well-covered by risk management plans, however considerations of climate change projections have yet to be built into these plans.
- There is currently no national heat wave plan, nor a consistent national approach to data collection and comparison with regard to heat waves (PwC 2011). Of particular importance in future planning is an understanding of people's heat stress thresholds and the impacts of the urban heat island effect and air pollution on heat stress.
- The NSW Government is continually monitoring sea level rise observations and is reviewing coastal planning.

8.2 Emergency management

A full understanding of and preparation for the risks from climate change require more than a simple multiplying of existing emergency management capabilities. This is because the consequences of natural disasters are a function of the effectiveness of the disaster mitigation strategies that have been implemented, the activities of the emergency services and the resilience of the communities and economies affected.

Three key challenges emerge for the emergency service agencies. These include increased workload and strained capacity, declining volunteerism, and uncertainty as to the effects and community response to hazards.

Volunteer workforces tend to be in decline, and are generally comprised of older cohorts. The projected changes in the frequency and duration of hazard events will place added pressure on a potentially dwindling volunteer workforce.

Agencies are concerned with the future preparedness and response behaviours of Sydney communities, particularly in the light of projected changes in intensities, frequencies and durations of hazard events. Community disaster education is an evolving field in emergency management, recognising that individuals and businesses may be more exposed to the impacts of hazards (Elsworth et al. 2009).

The NSW State Disaster Plan details emergency preparedness, response and recovery arrangements for the State to ensure the coordinated response to emergencies by all agencies having responsibilities and functions in emergencies. Climate change impacts can be seen as an external factor that will drive organisational and cultural change in emergency agencies in Australia. Good relationships and goodwill between agencies will be required to meet these future climate change challenges.

Figure 1 shows relationships between various governance agencies involved in emergency management in New South Wales.

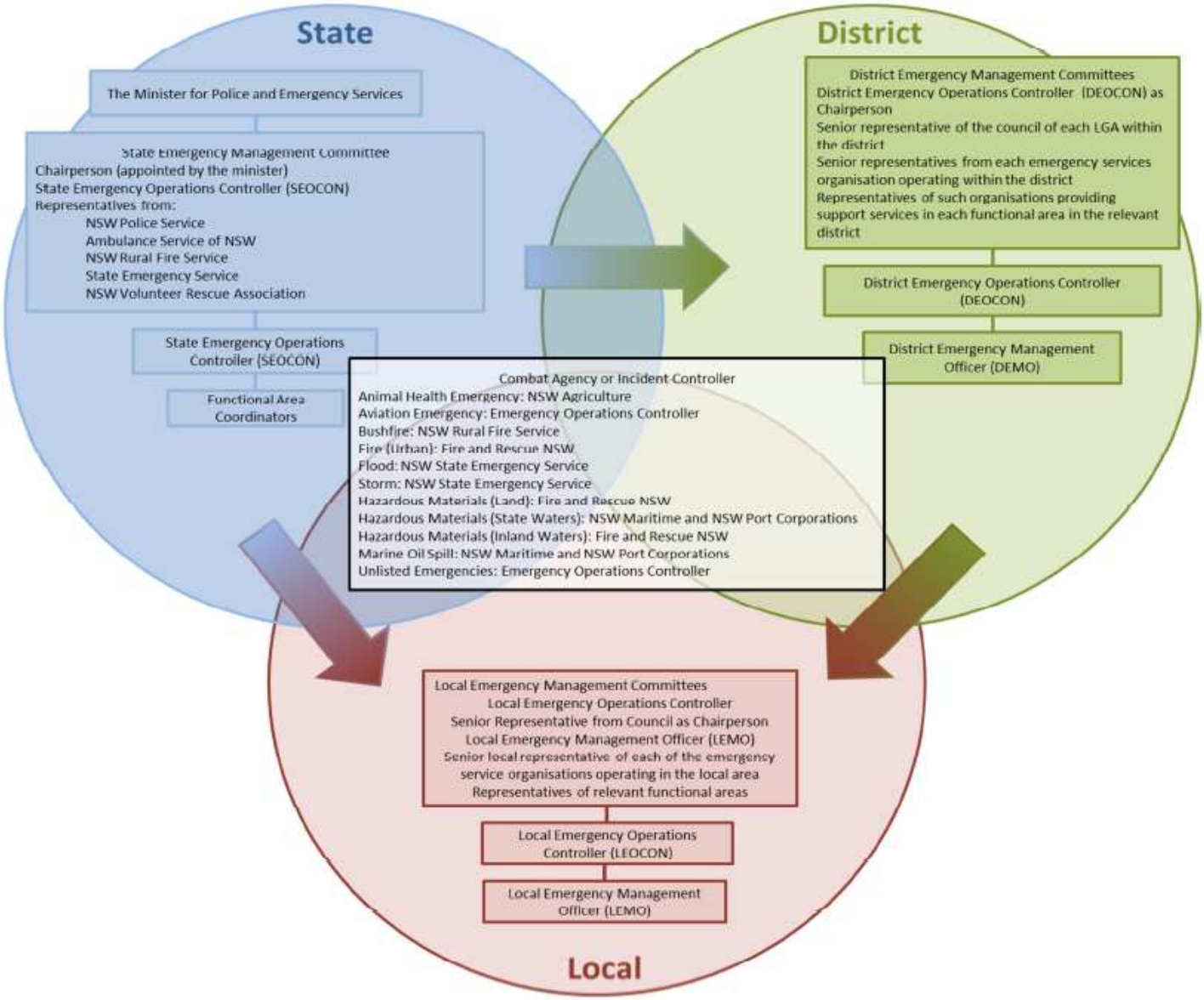

Figure 1: Governance map relating to emergency management in NSW

8.3 Community development

Extensive research into recent disasters around the world has shown that social capital is a critical factor in long-term community recovery and resilience building (Aldrich 2011). The level of connectedness and cohesion is now recognised as critical to disaster recovery, emphasising the importance of community development.

Community development has generally not been aligned with emergency management except in disaster recovery, however, there is increasing evidence that community development activities such as those conducted in communities by local and state governments should be integrated with disaster risk reduction and other emergency

management activities in the face of increasing risk (Dufty 2012). A recent study found that community education programs were particularly effective when delivered through community bushfire groups (Gilbert 2005).

An emerging body of research is concerned with psychological responses to disasters – how people prepare for, respond to and recover from disasters (Paton, 2006). These individual responses to disasters are particularly relevant in the context of a trend towards shared responsibility, which requires communities, individuals and households to take greater responsibility for their own safety. Several studies have been conducted to help understand the psychological profiles and potential behaviours of some Sydney communities in relation to flooding and bushfire.

8.4 Potential areas for further investigation

- Investigate the recovery stage of disasters experienced in Sydney.
- Understand the increased capacities required to respond to large-scale hazard events in Sydney.
- Understand the present risk perception, preparedness and potential response behaviours of individuals, communities and businesses in Sydney.
- Develop projections showing changing future demographics of potentially impacted parts of the region.
- Define the roles and responsibilities of Sydney local governments in emergency management.
- Understand community resilience levels in relation to potential disasters.
- Understand the linkages between community development and emergency management in the Sydney region.
- Understand the potential risks, preparedness, response and recovery required for heat waves in Sydney.
- Identify best practice in recovery across the key natural hazards impacted by climate change.
- Examine the role of the private sector in climate change adaptation.

9 Infrastructure

This review examines current and emerging research in infrastructure adaptation planning for climate change across five key sectors: energy, water, telecommunications, transport and community infrastructure. Information for this review was gathered from academic literature and from interviews with key infrastructure sector representatives.

Sydney's infrastructure underpins the city's economic strength, as well as supporting the standard of living of its citizens. Regional climate change projections indicate the three major concerns for Sydney's infrastructure are sea level rise, increased frequency and duration of heat waves and associated bushfires, and increased frequency and duration of extreme weather events leading to flooding. These projected changes in climate may place enormous pressure on Sydney's infrastructure. Nationally significant infrastructure including Port Botany and Sydney Airport are located in vulnerable coastal locations, and, as with other types of development in low lying coastal areas, may be impacted.

Significant current investment and the long life span of many types of infrastructure make it essential to consider the impacts of climate change now to avoid ineffective and inappropriate infrastructure decisions and policies. Major infrastructure must be designed to withstand infrequent extreme events during its lifetime, which may require changes to the current engineering standards for key infrastructure types. The implications of climate change for decision-making vary within and between sectors, depending on the life spans of different types of infrastructure.

Extreme events, in particular, highlight the interdependencies between infrastructure sectors and types because they are liable to lead to 'cascade failure' where the failure of one aspect of infrastructure, such as flood defences, can lead to other failures, e. g. flooded power stations leading to power cuts which thereby affect telecommunications networks.

9.1 Energy sector

The consequence of most concern in the electricity sector is interrupted supply (e.g. generator or substation outage due to a major storm). The severity of consequence of a major plant being disabled for an extended period, e.g. one to three months, would depend on which plant was affected and at what time of year. As the system is designed for peak loading and with reasonable contingencies, a reasonable buffer is built in. However, such an outage would be highly problematic if it coincided with a summer heat waves.

From a weather perspective, the network is susceptible to storms, high winds, bushfire and floods. While the network is designed to cope with losing individual pieces of equipment, certain scenarios that can affect multiple pieces of equipment (e.g. a substation disabled by bushfire) can have widespread consequences.

One strategy already in place to manage interrupted supply is load shedding or power sharing. This involves instigating rolling interruptions to maintain overall supply. It can be done automatically or manually, depending on the affected infrastructure. Electricity distributors can also aim to reduce their vulnerability by reducing peak demand. Programs to reduce demand in the commercial and industrial sectors on critical peak days are being developed and trialled by electricity distributors in New South Wales, with the potential for wide-scale deployment in future.

Investment in low-carbon energy sources, such as a number of trigeneration projects proposed by the City of Sydney and those installed by Qantas at and near Sydney Airport, could improve resilience by reducing reliance on single energy sources and suppliers (Kinesis 2013).

The energy sector is critical for every other infrastructure sector's normal operation. Consideration of the flow-on consequences of supply disruptions, over extended durations and in emergency conditions, should therefore be a high priority for adaptation research.

9.2 Water

The range of water infrastructure assets in Sydney is extensive, from natural assets such as catchments, waterways and wetlands, through to long-lived constructed civil, mechanical and electrical assets such as pipelines, treatment plants, pumping stations, data acquisition systems and the desalination plant (WSAA 2012). Water infrastructure is recognised widely as being at risk from climate change. The implications for asset failure and reduction in asset life will cost water utilities and the paying community. The increased insurance costs associated with increasing climate change risks may also be of concern to Sydney Water and other water infrastructure providers (WSAA 2012).

Climate change impacts relevant to water infrastructure in Sydney include potential reduction in supply; changes to customer demand; increased risk of pipe corrosion; more extreme storms that test the capacity of plants and networks; increased sea levels and storm surges posing a flood risk to assets; more extreme hot days and intense bushfires that could pose a threat to worker safety; changes in soil conditions leading to greater risk of pipe failure; and disruption to electricity supplies.

The extensive and diverse supply chain for water supply, sewage collection and treatment, drainage and flood management also means that water utilities are highly vulnerable to power and telecommunications outages.

Efforts are currently underway to minimise Sydney's vulnerability to climate change impacts upon its water infrastructure, and general risk management frameworks already adopted by many utilities have the potential to account for many climate change risks (WSAA 2012). Adaptation strategies that are being investigated in Sydney include resilient infrastructure design, diversification of water sources and reduction of demand, better planning and management, incorporation of climate risks into decision-making, improved development planning and planning for the risks of service interruption (WSAA 2012). Utilities are also investing in back-up power generators to mitigate against power outages in extreme events.

9.3 Telecommunications

The telecommunications sector is naturally able to be more responsive and adaptable than other sectors, being accustomed to dealing with rapidly changing technologies and short asset life spans. The main impact to the telecommunications sector will be interruptions to continuity of service. The extreme-event scenarios with the highest potential to trigger this impact are bushfires and east coast low storm events. This sector also has a high level of interdependency with the electricity sector and emergency management under most extreme event scenarios (NSW Public Works 2011).

The most vulnerable part of the fibre network is the trunk cables because of the large number of affected services, with threats being caused by flood events, causing scouring/washouts. Mobile networks in Sydney are not particularly vulnerable because they are microwave

linked, and do not rely on cables. The biggest risk for this service is interrupted power supply, however there is up to eight hours back-up generation supply for these services.

Climate change adaptation in telecommunications infrastructure companies is framed in terms of energy efficiency and extreme event management. Key adaptation strategies include diversity (having multiple paths of service delivery) and redundancy (additional assets such as generators). Generators play an important role in managing dependency upon electricity infrastructure.

9.4 Transport

Rail

Key vulnerabilities for the transport infrastructure of New South Wales include heavy rain causing slippage and collapse; sea level rise affecting low-lying rail assets; bushfire and extreme temperatures causing service disruption; and extreme temperatures causing passenger discomfort. Adaptation strategies include slippage surveillance systems, measures to improve passenger comfort and consideration of adaptive capacity in design standards, but vulnerability to electricity supply remains a significant concern.

Road

In New South Wales, 26,000 and 33,000 kilometres of roads are potentially at risk from the combined impacts of inundation and shoreline recession due to sea level rise (DCCEE 2011). Extreme weather events also threaten roads due to road closures, congestion and physical degradation. Roads and Maritime Services has developed climate change mapping and modeling to identify vulnerabilities.

Ports

Given its location, Port Botany is likely to be vulnerable to the combined impacts of sea level rise, storm surge and increased storminess. Port activity is forecast to double over the next 25 years (TfNSW 2012). Port operations are most impacted by increased storminess affecting the sea supply chain, safe port navigability and piloting operations, and loading/unloading operations. The port is currently vulnerable to electricity service interruption, and to a limited extent, water supply disruption.

Airport

Sydney Airport is likely to experience increased disruption of services due to projected increases in the severity of extreme weather events. Flood modelling has determined that localised flooding due to combined storm surge and rainfall is likely to affect the northern end of the airport. Runways may be affected by sea level rise and increased storm activity. Climate change impacts are being considered in key planning documents.

9.5 Community infrastructure

Community infrastructure includes hospitals, places of education and worship, libraries and cultural facilities such as art galleries, childcare and preschool facilities, aged-care facilities, passive and active open space and police and fire stations.

The diversity of community infrastructure makes it difficult to pinpoint key vulnerabilities. Higher temperatures and increased number of heat wave days will most directly affect the operations of community infrastructure. The major vulnerability arises due to the valuable nature of the services such infrastructure provides to the community and the resulting potential for flow-on impacts to the community in the event of service interruption. Major impacts will also be a result of extreme weather events, which may disrupt services due to loss of power, water, transport or telecommunications services; or physical degradation of assets.

No research was found to explicitly indicate that climate change is being taken into account in community infrastructure planning in Australia or internationally. This may be because of the diverse nature of the assets and their disparate ownership and management.

9.6 Potential areas for further investigation

- Prepare high-resolution climate change projections to enable more accurate demand forecasting by the energy sector.
- Investigate the effect of different design standards used by the generators, transmission network service providers and distributors. It is unclear where the 'weak links' are (under normal and extreme events), and in turn what the resulting risk profile looks like across the Sydney basin.
- Investigate potential bushfire impacts on buried water infrastructure, and improve understanding of the exposure of water utilities to disruptions in supply chains.
- Understand the impacts of sewer overflows under climate change scenarios, and consider climate change scenarios in the design standards of sewer flows.
- Identify vulnerable assets, infrastructure and communities.
- Improve understanding of climate change impacts to water supply.
- Develop a central information hub so that existing data on assets can be used effectively in adaptation planning.
- Understand customer willingness to pay for the costs of climate change adaptation if and when they are passed on.
- Develop regionally downscaled climate change projections to support infrastructure services.
- Improve stormwater and floodplain mapping at the local government area scale.
- Better understand service disruptions due to loss of critical infrastructure in other sectors.
- Develop interactive modeling of the present and future Sydney-wide transport system in present and future climate scenarios.

10 Cross-cutting knowledge themes

Each chapter of this synthesis report has identified sector-specific areas where knowledge gaps exist or areas where further investigation may be warranted to support adaptation planning in Metropolitan Sydney. However, as adaptation is a multidisciplinary task, a number of cross-cutting themes have emerged which provide opportunities to inform and support adaptation across multiple sectors.

Figure 2 shows the key cross-sectoral knowledge themes, which have been extracted from the individual research reviews and specifically from the areas for potential investigation identified by the researchers, listed at the end of each chapter. The themes listed in the inner circle were identified from overlapping themes emerging in the sector reviews.

The cross-cutting urban adaptation knowledge themes are:

- fostering adaptive urban design
- using land-use planning mechanisms
- finding opportunities for data sharing and downscaling
- improving cross-government coordination
- identifying vulnerable communities, populations and infrastructure
- securing water quality and supply
- understanding infrastructure interdependencies
- promoting best practice in local government
- exploring the role of the private sector in urban adaptation
- improving community connectedness

Fostering adaptive urban design

Urban design has a significant role to play in the types of impacts that are felt, the populations they are felt by and the ability of the urban system to cope with impacts. There is an important need to understand how urban design can be adapted to minimise the risks to communities that are associated with urban heat island effects, extreme heat events, bushfires, floods, sea level rise and other impacts. Identification of urban design principles – as well as materials – that will minimise risks for Sydney's population is a key element of ensuring Sydney's built environment can adapt over time to climate change impacts.

Using land-use planning mechanisms

. Land-use decisions will have implications for biodiversity, soils, built environment risks from sea level rise and bushfires, managing flood-prone areas, urban heat island effects, urban agriculture and density. Understanding how land-use mechanisms can be used in Sydney to improve vulnerability and minimise risks from a range of climate change impacts is crucial to realising a strong adaptation response.

Finding opportunities for data sharing and downscaling

All sectors have a need to understand local impacts in order to accurately forecast and effectively manage the effects of climate change upon their activities. Fine-grained data is

essential for understanding the specific areas and assets affected by changes to sea level, bushfire regimes and flooding, among other changes.

Currently, data is available only at regional scale, and does not provide detail beyond the city-scale. Detailed data will help infrastructure service providers understand system vulnerabilities; allow local governments to improve strategic planning; identify vulnerable communities, species and ecosystems; and understand potentially-threatened assets and services.

Each sector identified a need for improved information sharing and data access, in order to adequately understand projections and impacts and to facilitate sector-wide responses.

Improving cross-government coordination

There was an identified need for improved clarity about how agencies can work together to deliver adaptation responses and manage emergencies. Further research is needed to understand how agencies can work cooperatively to deliver varied responsibilities.

Identifying vulnerable communities, populations and infrastructure

Mapping of assets, communities and infrastructure and their vulnerability to risks such as bushfires, sea level rise, extreme weather events, heat waves and other climate change impacts is important for identifying vulnerable elements of the city's system. A majority of sectors identified a clear need for vulnerability mapping; in particular, understanding communities at risk from extreme heat and weather events.

Identifying especially vulnerable populations and communities is important for ensuring that adaptation responses are targeted at those who are most at risk. It will also help understand the types of strategies that may be needed to address the risks within those communities.

Identifying vulnerable assets and infrastructure will help to prioritise the implementation of adaptation responses for at-risk infrastructure and services, and also will help identify system weaknesses which could have flow-on effects for other services.

Securing water quality and supply

Adequate supplies of clean water are critical for the operation of all sectors in Sydney. Therefore, research into Sydney's ability to deliver sufficient supplies of clean water – especially in times of drought and extreme events – is crucial to understanding Sydney's ability to respond to climate change impacts. Further research would help understand how Sydney's water infrastructure is placed to deliver this essential service to all sectors and communities of the city.

Understanding infrastructure interdependencies

Significant interdependencies exist between various elements of Sydney's infrastructure – especially between its energy and water infrastructure. More research is needed to understand these interdependencies and to develop strategies to minimise vulnerabilities.

Promoting best practice in local government

Local governments are responsible for delivering a range of services and responsibilities closely linked to climate change impacts and adaptation, including biodiversity protection,

infrastructure maintenance, community service provision, cultural asset management and community development.

Currently, local governments may not have the resources or the capability to deliver key adaptation actions and strategies. There is a need to identify an optimal approach based on international best practice to ensure that local governments in Sydney are supported to implement adaptation responses.

Exploring the role of the private sector in urban adaptation

Understanding and clarifying the role of the private sector in facilitating and supporting adaptation, particularly where industry and infrastructure are concerned, will support cross-sectoral opportunities and responses. The insurance sector is closely aligned with adaptation efforts, through the minimisation of risk. Understanding the role of various insurance sector mechanisms, opportunities and interactions will be key for understanding the financial and market responses to a range of climate change impacts.

Improving community connectedness

There is a strong need to understand the level of community awareness of the potential impacts of climate change. A multitude of potential impacts will affect the community, and it is important to understand the level of knowledge within the community about these impacts.

Further, there is a need to understand and develop community resilience measures and indicators, to evaluate the community's ability to respond to the effects of a range of climate change impacts. Understanding community resilience will help target community development initiatives and community education campaigns. Programs that improve the community's self-reliance and educate people about key risks and challenges is needed to help advance adaptation to new risks and reduce vulnerabilities.

References

AECOM (2010), *Coastal Inundation at Narrabeen Lagoon: Optimising Adaptation Investment*, report prepared for the Department of Climate Change and Energy Efficiency, Canberra, www.climatechange.gov.au/sites/climatechange/files/documents/03_2013/narrabeen-lagoon.pdf.

Aldrich, DP (2011), 'The Externalities of Strong Social Capital: Post-Tsunami Recovery in Southeast India', *Journal of Civil Society,* **8** (1): 81–99.

Alexander, KS; Ryan, A & Measham, TG (2012), 'Managed retreat of coastal communities: understanding responses to projected sea level rise', *Journal of Environmental Planning and Management*, **55** (4): 409–433.

Bambrick, H; Dear, K; Woodruff, R; Hanigan, I & McMichael, A (2008), 'The impacts of climate change on three health outcomes: temperature-related mortality and hospitalisations, salmonellosis and other bacterial gastroenteritis, and population at risk from dengue', *The Garnaut Climate Change Review*, Final report, 2008, Commonwealth of Australia.

Beggs PJ & Bambrick HJ (2005), 'Is the global rise of asthma an early impact of anthropogenic climate change?' *Environmental Health Perspectives*, **113** (8): 915–919.

Birch, G; Murray, O; Johnson, I & Wilson, A (2009), 'Reclamation in Sydney Estuary, 1788–2002' *Australian Geographer*, **40** (3): 347–368.

Blashki, G; Armstrong, G; Berry, HL; Weaver, HJ; Hanna, EG & Bi, P; Harley, D & Spickett, JT (2011), 'Preparing Health Services for Climate Change in Australia', *Asia-Pacific Journal of Public Health*, **23** (2 suppl.): 133S–143S.

Blazey, P., & Govind, P. (2007), Financial adaptation challenges for the insurance industry due to climate change. *Macquarie J. Bus. L.*, *4*, 15.

Bottrill, M; Joseph, L; Carwardine, J; Bode, M; Cook, C; Game, E; Grantham, H; Kark, S; Linke, S; McDonald-Madden, E; Pressey, R; Walker, S; Wilson, K & and Possingham, H (2008), 'Is conservation triage just smart decision making?' *Trends in Ecology & Evolution*, **23** (12): 649–654.

Britton, E; Hales, S; Venugopal, K & Baker, MG (2010), 'The impact of climate variability and change on cryptosporidiosis and giardiasis rates in New Zealand', *Journal of Water and Health*, **8** (3): 561–571.

Brook, B (2008), 'Synergies between climate change, extinctions and invasive vertebrates'. *Wildlife Research*, **35** (3): 249–252.

Burgess, CP; Johnston, FH; Berry, HL; McDonnell, J; Yibarbuk, D; Gunabarra, C; Mileran, A & Bailie, RS (2009), 'Healthy country, healthy people: the relationship between Indigenous health status and "caring for country"*', Medical Journal of Australia,* **190** (10): 567–572.

California Climate Change Adaptation Policy Guide, draft, (2012), http://resources.ca.gov/climate/safeguarding/adaptation_policy_guide [accessed 29 January 2015]

CCAD (2007), *Climate Change Adaptation by Design: A guide for sustainable communities*, by Shaw, R., Colley, M., and Connell, R., Town and Country Planning Association (TCPA), London.

CCAP (2011), *The Value of Green Infrastructure for Urban Climate Adaptation*, (Authors Foster, J; Lowe, A & Winkelman, S), The Center for Clean Air Policy, Washington DC.

CCAP (2007) The Climate Change Action Partnership, Chan F. C., Lebedeva J., Otero J., and Richardson G, *Urban Heat Islands: A climate change adaptation strategy for Montreal*, McGill University School of Urban Planning, Montreal.

Chessman, BC (2009), 'Climatic changes and 13-year trends in stream macroinvertebrate assemblages in New South Wales, Australia', *Global Change Biology*, **15** (11): 2791–2802.

CSIRO & Bureau of Meteorology (BoM) (2007), *Climate Change in Australia: Technical Report 2007*, CSIRO, ACT.

Cusack L, de Crespigny C, Athanasos P. (2011), Heatwaves and their impact on people with alcohol, drug and mental health conditions: a discussion paper on clinical practice considerations. *J Adv Nurs*. **67** (4): 915-22.

DCC (2009), *Climate Change Risks to Australia's Coast – A First Pass National Assessment*, Department of Climate Change, Canberra.

DCCEE (2011), *Climate Change Risks to Coastal Buildings and Infrastructure – A Supplement to the First Pass National Assessment*, Department of Climate Change and Energy Efficiency, Canberra.

DECC (2008), *Summary of Climate Change Impacts – Sydney Region – NSW Climate Change Action Plan*, Department of Environment and Climate Change NSW, Sydney.

DECCW (2010a), *NSW Climate Impact Profile – The impacts of climate change on the biophysical environment of New South Wales*, Department of Environment, Climate Change and Water NSW, Sydney, www.environment.nsw.gov.au/resources/climatechange/10171climateimpactprof.pdf.

DECCW (2010b), *Priorities for Biodiversity Adaptation to Climate Change*, Statement of intent in response to the listing of Anthropogenic Climate Change as a Key Threatening Process under the NSW *Threatened Species Conservation Act 1995*, Department of Environment, Climate Change and Water NSW, Sydney, www.environment.nsw.gov.au/biodiversity/2010771prioritiesbioadaptcc.htm.

DECCW (2009), *NSW Sea Level Rise Policy Statement*, Department of Environment, Climate Change and Water NSW, Sydney, www.environment.nsw.gov.au/resources/climatechange/09708sealevrisepolicy.pdf.

DLWC (2000), *NSW Salinity Strategy*, NSW Department of Land and Water Conservation, Sydney, www.environment.nsw.gov.au/salinity/government/documents.htm.

DLWC (2002), *Guidelines to accompany map of salinity potential in Western Sydney*, NSW Department of Land and Water Conservation, Sydney, www.environment.nsw.gov.au/salinity/government/documents.htm.

DNR (2006), Local Government Salinity Initiative series of booklets, Department of Natural Resources, Sydney.

Dobbs, R; Smit, S; Remes, J; Manyika, J; Roxburgh, C & Restrepo, A (2011), *Urban world: Mapping the economic power of cities*, McKinsey Global Institute.

Dodman, D (2009), 'Urban Density and Climate Change', *Analytical Review of the Interaction between Urban Growth Trends and Environmental Changes,* United Nations Population Fund (UNFPA).

Dufty, N (2012), 'Learning for disaster resilience', *Earth: Fire and Rain, Proceedings of the Australian & New Zealand Disaster and Emergency Management Conference*, Brisbane, Queensland, April 2012, pp.149–164.

ECE (2009), *Guidance on Water and Adaptation to Climate Change*, Economic Commission for Europe, Convention on the Protection and Use of Transboundary Watercourses and International Lakes, United Nations, New York and Geneva.

EERE (2008), *20% Wind Energy by 2030: Increasing Wind Energy's Contribution to U.S. Electricity Supply*, Office of Energy Efficiency and Renewable Energy, U.S. Department of Energy, Washington, DC.

Elsworth, G; Gilbert, J; Robinson, P; Rowe, C & Stevens, K (2009), *National Review of Community Education, Awareness and Engagement for Natural Hazards*, report by RMIT University commissioned by the National Community Safety Working Group of the Australian Emergency Management Committee.

English, AJ & Brown, I (2001), 'Biodiversity, Environmental Health and Aboriginal people: Challenges for the NSW Planning System', in proceedings of the 'I Have A Cunning Plan' conference, Sydney, Environmental Defender's Office, Sydney.

Fernandes, P. M., & Botelho, H. S. (2003). A review of prescribed burning effectiveness in fire hazard reduction. *International Journal of Wildland Fire*, **12** (2), 117-128.

Gilbert, J (2005), *Development of an Evaluation Framework for Community Safety Policy and Programs for Bushfire*, Bushfire CRC Project C7, Bushfire Cooperative Research Centre, Melbourne.

Glatz, M (2010), *Eurobodalla Shire Coastal Hazards Scoping Study – Draft Final Report*, Eurobodalla Shire Council.

Gosling, S. N., Lowe, J. A., McGregor, G. R., Pelling, M., & Malamud, B. D. (2009). 'Associations between elevated atmospheric temperature and human mortality: a critical review of the literature'. *Climatic Change*, **92** (3-4): 299-341.

Gunn, RG (2011), 'The impact of bushfires and fuel reduction burning on the preservation of shelter rock art', *Rock Art Research,* **28** (1): 53–69.

Hallegatte, S & Corfee-Morlot, J (2011), 'Understanding climate change impacts, vulnerability and adaptation at city scale: an introduction', *Climatic Change,* **104**: 1–12.

Hanna, E, Bi, P, Dwyer, S, Morris, P, McKeller, R, Stadler, F, (2012) *National Climate Change Adaptation Research Plan Human Health*: *Update Report 2012*, National Climate Change Adaptation Research Facility, Gold Coast pp.54. ISBN: 978-1-921609-79-4

Hansen A, Bi P, Nitschke M, Ryan P, Pisaniello D, Tucker G. (2008), The effect of heat waves on mental health in a temperate Australian city. *Environ Health Perspect.* **116** (10): 1369-75.

Horton, G; Hanna, L & Kelly, B (2010), 'Drought, drying and climate change: emerging health issues for ageing Australians in rural areas', *Australasian Journal on Ageing*, **29** (1): 2–7.

Hunt, A & Watkiss, P (2011), 'Climate change impacts and adaptation in cities: a review of the literature', *Climatic Change*, **104**: 13–49.

Hunter, G (2012), *Impacts of Climate Change on Urban Stormwater Infrastructure in Metropolitan Sydney*, Mehl, P (ed.), Sydney Metropolitan Catchment Management Authority, Parramatta.

ICE (2010), Facing up to Rising Sea-Levels: Retreat? Defend? Attack? – The future of our Coastal and Estuarine Cities, Building Futures RIBA and the Institution of Civil Engineers, UK, accessed 19/05/2012, www.buildingfutures.org.uk/assets/downloads/Facing_Up_To_Rising_Sea_Levels.pdf.

IPCC (2007), *Climate Change 2007: The Physical Science Basis*, Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, UK and New York, USA.

Kallus, R & Law-Yone, H (2000), 'What is a neighbourhood? The structure and function of an idea', *Environment and Planning B: Planning and Design,* **27** (6): 815–826.

Keeley, M (2011), 'The Green Area Ratio: an urban site sustainability metric', *Journal of Environmental Planning and Management,* **54** (7): 937–958.

Kinesis (2013), *City of Sydney Decentralised Energy Master Plan – Trigeneration 2010–2030*, City of Sydney, Sydney.

Kjellstrom, T & Weaver, HJ (2009), 'Climate change and health: impacts, vulnerability, adaptation and mitigation', *NSW Public Health Bulletin*, **20** (1-2): 5–9.

Lambert, D & Welsh, B (2011), 'Fire and Rock Art', *Rock Art Research,* **28** (1): 45–48.

Mandarano, L (2010), 'Sustainable land-use planning: revitalising a flood prone office park', *Journal of Environmental Planning and Management*, **53** (2): 183–196.

McCarthy, DT; Hathaway, JM; Hunt, WF; Deletic, A (2012), 'Intra-event variability of *Escherichia coli* and total suspended solids in urban stormwater runoff', *Water Res*earch, **46** (20): 6661–6670.

McMichael, A; Weaver, H; Berry, H; Beggs, P; Currie, B; Higgins, J; Kelly, B; McDonald, J & Tong, S (2009), *National Climate Change Adaptation Research Plan for Human Health – First Edition*, National Climate Change Adaptation Research Facility, Gold Coast, Queensland.

Measham T.G., Preston B.L., Smith T.F., Brooke C., Gorddard R. Withycombe G., and Morrison C. (2011), 'Adapting to climate change through local municipal planning: barriers and challenges, Mitigation and Adaptation Strategies for Global Change'. *Mitigation and Adaptation Strategies for Global Change*, 16(8): 889-909

Morgan, G; Corbett, S; Wlodarczyk, J & Lewis, P (1998), 'Air pollution and daily mortality in Sydney, Australia, 1989 through 1993', *American Journal of Public Health*, **88** (5): 759–64.

National Notifiable Diseases Surveillance System. (2012) Number of notifications for all diseases, NSW, 1991 to 2011 and year-to-date notifications for 2012. [cited 21 May 2012]; Available from: http://www9.health.gov.au/cda/Source/CDA-index.cfm

Nitschke, M; Tucker, GR; Hansen, AL; Williams, S; Zhang, Y & Bi, P (2011), 'Impact of two recent extreme heat episodes on morbidity and mortality in Adelaide, South Australia: a case-series analysis', *Environmental Health,* **10:** 42.

NSW Public Works (2011), *Analysis of impacts on NSW infrastructure of extreme events under climate change – Telecommunication Sector Workshop – Record of Discussion and Outcomes*, NSW Public Works, Sydney.

OECD (2010), *Cities and climate change*, Organisation for Economic Co-operation and Development (OECD) Publishing.

OEH (2011a), *New South Wales Climate Impact Profile Technical Report – Potential impacts of climate change on biodiversity*, Office of Environment and Heritage, Department of Premier and Cabinet, Sydney.

OEH (2011b), *New South Wales Climate Impact Profile Technical Report – Potential impacts of climate change on soils*. Office of Environment and Heritage, Department of Premier and Cabinet, Sydney.

OEH (2012), 'Knowledge Strategy – Landscape Management Knowledge: Strategic Plan 2012–2015', internal document, Office of Environment and Heritage, Sydney.

Parry, M.L., Canziani, O.F.; Palutikof, J.P.; van der Linden, P.J.; & Hanson, C.E. (eds.), 2007, *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change,* Cambridge University Press, Cambridge, UK, 982pp.

Paton, D (2006), 'Disaster Resilience: building capacity to co-exist with natural hazards and their consequences', *Disaster Resilience – An Integrated Approach*, Paton, D & Johnston, D (eds.), Charles C Thomas Publishers Ltd, Springfield.

Pearson, M (2007), Climate Change and its impacts on Australia's Cultural Heritage, Australia ICOMOS 'Extreme Heritage' Conference 2007, Cairns, Queensland.

Preston B. L., Smith T., Brook C., Gorddard R., Measham T, Withycombe G., McInnes K., Abbs D., Beveridge B. and Morrison C. (2008), *Mapping Climate Change Vulnerability in Sydney Coastal Councils Group*, prepared for the SCCG by the Commonwealth Scientific and Industrial Research Organisation (CSIRO) Climate Adaptation Flagship.

PwC (2011), *Protecting human health and safety during severe and extreme heat events – A national framework*, PricewaterhouseCoopers Australia, report prepared for the Department of Climate Change and Energy Efficiency, Canberra.

Ravi, S; Breshears, D; Huxman, T & D'Odorico, P (2010), Land degradation in drylands: Interactions among hydrologic–aeolian erosion and vegetation dynamics, *Geomorphology,* **116** (3–4): 236–245.

Rosenzweig, C; Solecki, WD; Hammer, SA & Mehrotra, S (eds.) (2011), *Climate change and cities – First Assessment Report of the Urban Climate Change Research Network*, Urban Climate Change Research Network, Center for Climate Systems Research, Earth Institute, Columbia University, Cambridge University Press, Cambridge and New York.

Rosenzweig, C & Hillel, D (2000), 'Soils and global climate change: Challenges and opportunities', *Soil Science,* **165** (1): 47–56.

SCCG (2010) *2010-2014 Strategic Plan*, Sydney Coastal Councils Group, Sydney, http://sydneycoastalcouncils.com.au/sites/default/files/strategicplan2010-2014.pdf [Accessed 22/05/2012]

Schenk, T; Karl, H; Raab, J & Spector, C (2010), *Adaptation Planning in Boston: Lessons Learned from New York, London, Toronto, and Beyond*, draft, January 8 2010, www.cityofboston.gov/Images_Documents/Learning%20From%20Adaptation%20Elsewhere%20-%20Draft_tcm3-16589.pdf

Schipper, L (2009), 'Meeting at the crossroads?: Exploring the linkages between climate change adaptation and disaster risk reduction', *Climate and Development*, **1** (1): 16–30.

Stadler, F; McKellar, R; Capon, A & Thomas, P (2011), *Human Health and Climate Change, National Adaptation Research Plan: Update of the Literature*, National Climate Change Adaptation Research Facility, Gold Coast, Queensland.

Steffen, W; Burbidge, A; Hughes, L; Kitching, R; Lindenmeyer, D; Musgrave, W; Stafford Smith, M & Werner, PA (2009), *Australia's Biodiversity and Climate Change*, CSIRO Publishing, Collingwood.

Steffen, W & Hughes, L (2012), *The Critical Decade – New South Wales climate impacts and opportunities*, Climate Commission Secretariat, Department of Climate Change and Energy Efficiency, Canberra.

Stone, B & Rodgers, M (2001), 'Urban Form and Thermal Efficiency: How the Design of Cities Influences the Urban Heat Island Effect', *Journal of the American Planning Association* **67** (2): 186–198.

Stone, B; Hess, JJ & Frumkin, H (2010), 'Urban Form and Extreme Heat Events: Are Sprawling Cities More Vulnerable to Climate Change Than Compact Cities?', *Environmental Health Perspectives*, **118** (10): 1425–1428.

TfNSW (2012), *NSW Long Term Transport Master Plan – Discussion Paper*, Transport for NSW, Sydney.

Twigg, J (2004), *Disaster risk reduction: mitigation and preparedness in development and emergency programming*, Humanitarian Practice Network, Overseas Development Institute, London, UK.

UN-Habitat (2010), 'Cities and Climate Change Initiative' – 'About' [Online], Nairobi: United Nations Human Settlements Programme (UN-Habitat), http://unhabitat.org/urban-initiatives/cities-and-climate-change-initiative/ [Accessed 28 January 2015].

UNISDR Asia and Pacific (2011), *At the Crossroads – Climate Change Adaptation and Disaster Risk Reduction in Asia and the Pacific – A Review of the Region's Institutional and Policy Landscape*, United Nations Office for Disaster Risk Reduction (UNISDR) Asia and Pacific Secretariat.

Wald, M; & Schwartz, J; (2012) 'Rise in Weather Extremes Threatens Infrastructure', *The New York Times* online, New York, http://www.ashtonadvertising.com/blasts/earthwell/August_2012/rise-in-weather-extremes-t.pdf [Accessed 28 January 2015]

Williams, K; Joynt, J & Hopkins, D (2010), 'Adapting to Climate Change in the Compact City: The Suburban Challenge', *Built Environment*, **36** (1): 105–115.

Wisner, B (2011), 'Are we there yet? Reflections on integrated disaster risk management after ten years', *Integrated Disaster Risk Management (IDRiM) Journal*, **1** (1): 1–14.

Wheeler, D. (2011) 'Quantifying Vulnerability to Climate Change: Implications for Adaptation Assistance.' CGD Working Paper 240. Washington, D.C.: Center for Global Development. http://www.cgdev.org/content/publications/detail/1424759

Woodruff R, & Bambrick H. (2008) 'Climate change impacts on the burden of Ross River virus disease', *Garnaut Climate Change Review*.

WSAA (2012), *Occasional Paper 27 – Climate Change Adaptation and the Australian Urban Water Industry*, Water Services Association of Australia.

Appendix A: Further reading for each sector

Sector	References
Emergency management	Bradstock, RA; Cohn, JS; Gill, AM; Bedward, M & Lucas, C (2009), 'Prediction of the probability of large fires in the Sydney region of south-eastern Australia using fire weather', *International Journal of Wildland Fire*, **18** (8): 932–943. Clarke, HG; Smith, PL & Pitman, AJ (2011), 'Regional signatures of future fire weather over eastern Australia from global climate models', *International Journal of Wildland Fire*, **20** (4): 550–562. Environmental Defenders Office of NSW (2010), *Audit of Sea Level Rise, Coastal Erosion and Inundation Legislation and Policy*, report prepared for the Sydney Coastal Councils Group. Howard, B (2009), 'Climate Change and the Volunteer Emergency Management Sector', *Journal of Emergency Management* **24** (3), https://www.em.gov.au/Documents/AJEM_24-3_Climatechange.pdf. Mella, S & Madill, P (2007), 'Climate Changes, Heat Illness and Adaptation in NSW', *Environmental Health*, **7** (3): 98–106. Molino Stewart (2011), *Community and Stakeholder Consultation Program for Lake Macquarie Waterway Flood Management Plan*, A report for Lake Macquarie City Council, Parramatta. http://www.lakemac.com.au/downloads/198071980416125FD8EE3D023659D44B460A753F.pdf NSW State Disaster Sub Plans relevant for Sydney – Botany Bay Precinct, Bushfire, Flood, Hawkesbury-Nepean Flood Emergency, Heatwave, Storm, Sydney CBD Emergency. Pearce, T; Handmer, J; Higgins, J; King, D; McDonald, J; Pagano, F; Schneider, J & Whetton, P (2009), *National Climate Change Adaptation Research Plan for Emergency Management*, National Climate Change Adaptation Research Facility. Takahashi, K (2011), 'Introduction to Research Projects in Japan relevant to DRR/CCA', *Climate Change Adaptation and emergency management: A workshop on research and policy*, Friday May 20, RMIT.
Human health	Bambrick, HJ; Capon, AG; Barnett, GB; Beaty, RM & Burton AJ 2011, 'Climate change and health in the urban environment: adaptation opportunities in Australian cities', *Asia-Pacific Journal of Public Health*, **23** (2 suppl.): 67S-79S Bambrick H, Banwell C, Dixon J, Edwards F, Kjellstrom T. (2010), Resilience and vulnerability among older Australians: Adaptive responses to heat. International Climate Change Adaptation Conference, *Climate Adaptation Futures: Preparing for the unavoidable impacts of climate change*. Gold Coast. Green D, Webb L (2014) Climate change, health and well-being in Indigenous Australia. In: *Healthy People, Places and Planet: Reflections Based on Tony McMichael's Four Decades Contribution to Epidemiological Understanding*, Butler C, Dixon J, Capon A (editors), Canberra: ANU Press Kjellstrom T, Gabrysch S, Lemke B, Dear K. (2009) 'The 'Hothaps' programme for assessing climate change impacts on occupational health and productivity: an invitation to carry out field studies', *Global Health Action*. **2**. Mason, D; Dixon, J; Issacs, B; Edwards, F; Hall, G; Capon, T & Friel, S (2011), 'The dynamic situation of urban agriculture in the Sydney basin', briefing paper, Urbanism, Climate Adaptation and Health Cluster, climatehealthcluster.org/about. Morgan G, Corbett S, Wlodarczyk J. (1998) Air pollution and hospital admissions in Sydney, Australia, 1990 to 1994. *Am J Public Health*.**88** (12): 1761-6.

Sector	References
	Morgan G, Corbett S, Wlodarczyk J, Lewis P. (1998), Air pollution and daily mortality in Sydney, Australia, 1989 through 1993. *Am J Public Health*. **88** (5): 759-64. Vaneckova P & Bambrick H (2013), 'Cause-specific hospital admissions on hot days in Sydney, Australia', *PLoS ONE,* **8** (2): e55459. Vaneckova, P; Beggs, PJ; de Dear, RJ & McCracken, KW (2008), 'Effect of temperature on mortality during the six warmer months in Sydney, Australia, between 1993 and 2004', *Environmental Research*, **108** (3): 361–369.
Economy and industry	Bureau of Resources and Energy Economics (BREE) 2012, *Energy in Australia*, Bureau of Resources and Energy Economics, Canberra. Hallegatte, S; Henriet, F & Corfee-Morlot, J (2011), 'The economics of climate change impacts and policy benefits at city scale: a conceptual framework', *Climatic Change*, **104**: 51–87. IPCC (2007), *Climate Change 2007: Impacts, Adaptation and Vulnerability – Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge UK and New York USA. Measham, T; Preston, BL; Brooke, C; Smith, TF; Morrison, C; Withycombe, G & Gorddard, R (2010), *Adapting to Climate Change through Local Municipal Planning: Barriers and Opportunities*, Socio-Economics and the Environment in Discussion (SEEDS) CSIRO Working Paper Series, 2010–05.
Infrastructure	AGIC (2011), AGIC Guideline for Climate Change Adaptation, Revision 2.1, Australian Green Infrastructure Council (now Infrastructure Sustainability Council of Australia), Brisbane, www.isca.org.au/images/pdf/cca_guideline_v2.1.pdf. ATSE (2008), *Assessment of Impacts of Climate Change on Australia's Physical Infrastructure*. Australian Academy of Technological Sciences and Engineering, Parkville, Victoria. Bedsworth, LW & Hanak, E (2010), 'Adaptation to Climate Change, A Review of Challenges and Tradeoffs in Six Areas', *Journal of the American Planning Association*, **76** (4): 477–495 Engineering the Future (2011), *Infrastructure, Engineering and Climate Change Adaptation – Ensuring Services in an Uncertain Future*, The Royal Academy of Engineering, London. Lambous, C & Moss, J (2009), 'Sustainability and the RTA – Current Thinking'. Meeting of the Sydney Division of Engineers Australia, 25 May 2009, Sydney. Standards Australia (2011), *Draft for Public Comment: Australian Standard DR AS 5334: Climate change adaptation for settlements and infrastructure*, Standards Australia.
Settlements and communities	Alexander, KS; Ryan, A & Measham, TG (2012), 'Managed retreat of coastal communities: understanding responses to projected sea level rise', *Journal of Environmental Planning and Management*, **55** (4): 409–433. Blakely, E & Carbonell, A 2012, *Resilient Coastal City Regions – Planning for Climate Change in the United States and Australia*, Lincoln Institute of Land Policy, Cambridge, MA. Geis, DE (2000), 'By Design: The Disaster Resistant and Quality-of-Life Community', *Natural Hazards Review*, **1** (3): 151–160. Greater London Authority (2011), *Managing Risks and Increasing Resilience – The Mayor's Climate Change Adaption Strategy*, www.london.gov.uk/sites/default/files/Adaptation-oct11.pdf.

Sector	References
	Gurran, N; Norman, B; Gilbert, C & Hamin, E (2011), *Planning for climate change adaptation in Coastal Australia: State of practice*, Report No. 4 for the National Sea Change Taskforce, Faculty of Architecture, Design and Planning, University of Sydney, Sydney. Harvison, T; Newman, R & Judd, B (2011), *Ageing, the Building Environment and Adaptation to Climate Change*, ACCARNSI Discussion Paper, National Climate Change Adaptation Research Facility. Norman, B & Sullivan, K (2011), 'Planning for risk and uncertainty: new approaches for managing urban growth', Urban and Regional Planning, University of Canberra, www.curf.com.au/storage/AFAC%20powerpoint%20presentation%20BNKS%202 8%20Aug%202011.pdf.
Buildings and neighbourhoods	ARUP (2008), *Your Home in a Changing Climate – Retrofitting Existing Homes for Climate Change Impacts – Report for policy makers*, prepared by ARUP for the Three Regions Climate Change Group, Greater London Authority, London. FEMA (2010), *Protecting Your Home and Property from Flood Damage: Mitigation Ideas for Reducing Flood Losses*, FEMA P-805, Federal Emergency Management Administration, Washington, DC. Foster, J; Lowe, A & Winkelman, S (2011), *The Value of Green Infrastructure for Urban Climate Adaptation*, Center for Clean Air Policy, Washington DC. Hacker, JN & Holmes, MJ (2007), 'Thermal Comfort: Climate Change and the Environmental Design of Buildings in the United Kingdom', *Built Environment*, **33** (1): 97–114. Maller, CJ & Horne, R (2011), 'Living Lightly: How Does Climate Change Feature in Residential Home Improvements and What are the Implications for Policy', *Urban Policy and Research*, **29** (1): 59–72. Shaw, R; Colley, M & Connell, R (2007), *Climate Change Adaptation by Design: A guide for sustainable communities*, Town and Country Planning Association (TCPA), London. Ravetz, J (2008), 'State of the Stock – What do we know about existing building and their future prospects?', *Energy Policy*, **36** (12): 4462–4470. RMS (2009), *The 1999 Sydney Hailstorm: 10-Year Retrospective*, RMS Special Report, Risk Management Solutions Inc., Sydney, NSW.
Cultural assets	Altman, J & Jordan, K (2008), *Impact of Climate Change on Indigenous Australians – Submission to the Garnaut Climate Change Review*, Centre for Aboriginal Economic Policy Research, Australian National University, Canberra. ANU (2009), *Implications of climate change for Australia's World Heritage properties: a preliminary assessment*, report to the Department of Climate Change and Department of Environment, Water and the Arts, prepared by the Fenner School of Environment and Society, Australian National University, Canberra. Barham, T (2010), 'Archaeological Records as Guides to Managing Coastal Retreat in Response to Rising Sea Levels: opportunities to forecast shorefaces of the future by hindcasting those of the past', paper presented at the Australian Archaeological Association Conference, NSW. Brindlecombe, P & Grossi, CM (2007), 'Climate Change Critical to Cultural Heritage', in *Heritage, Weathering and Conservation*, Taylor and Francis/Balkema. Buhrich, A (2010), 'Literature Review – Climate change and Indigenous communities'. Report prepared for James Cook University and funded by the Christensen Fund.

Sector	References
	Cassar, M (2005), *Climate Change and the Historic Environment*, University College, London. Heruc, S; Groot, C & Von Konow, T (2002), 'The use of climate chamber simulations as a protection analysing tool against moisture and salt deterioration processes in monumental brick constructions', *Estrategias relativas al patrimonio cultural mundial. La salvaguarda en un mundo globalizado. Principios, practicas y perspectivas*, 13th ICOMOS General Assembly and Scientific Symposium, ICOMOS, Madrid. English Heritage (2008), *Climate Change and the Historic Environment*, www.english-heritage.org.uk/publications/climate-change-and-the-historic-environment/climate-change.pdf, accessed 14 July 2012. Harvey, C (2011), 'More than enough thanks: responding to severe weather events and their recent impacts on Queensland heritage places', paper presented at AICOMOS annual conference, Melbourne 2011. McIntyre-Tamwoy, S (2008), 'The impact of global climate change and cultural heritage: grasping the issues and defining the problem', *Historic Environment*, **21** (1): 2–9. McIntyre-Tamwoy, S & Buhrich, A (2012), 'Lost in the wash: predicting the impact of losing Aboriginal coastal sites in Australia', *The International Journal of Climate Change: Impacts and Responses*, **3** (1): 53–66. Pearson, M (2007), 'Climate Change and its impacts on Australia's Cultural Heritage', Australia ICOMOS 'Extreme Heritage' Conference, Cairns, Queensland. Pearson, M (2008), 'Climate Change, Fire and Cultural Heritage in Australia', *Heritage at Risk 2006/2007*: 218–219. Smith, BJ; McCabe, S; McAllister, D; Adamson, C; Viles, HA & Curran, JM (2011), A commentary on climate change, stone decay dynamics and the 'greening' of natural stone buildings: new perspectives on 'deep wetting', *Environmental Earth Science*, **63**:1691–1700. Watson, PJ & Lord, DB (2008), *Fort Denison Sea Level Rise Vulnerability Study*, Coastal Unit, Department of Environment and Climate Change, Sydney. Watson, PJ & Lord, DB (2009), *Goat Island Sea Level Rise Vulnerability Study*, Coastal Unit, Department of Environment and Climate Change, Sydney.
Natural assets	ANU (2009), *Implications of climate change for Australia's World Heritage properties: a preliminary assessment*, report to the Department of Climate Change and Department of Environment, Water and the Arts, prepared by the Fenner School of Environment and Society, Australian National University, Canberra. Barnosky, A (2008), 'Climatic change, refugia, and biodiversity: where do we go from here? An editorial comment', *Climatic Change*, **86**: 29–32. Brook, B (2008), 'Synergies between climate change, extinctions and invasive vertebrates'. *Wildlife Research*, **35** (3): 249–252 Burbidge, AA; Byrne, M; Coates, D; Garnett, ST; Harris, S; Hayward, MW; Martin, TG; McDonald-Madden, E; Mitchell, NJ; Nally, S & Setterfield, SA (2011), 'Is Australia ready for assisted colonization? Policy changes required to facilitate translocations under climate change', *Pacific Conservation Biology*, **17** (3): 259–269. Convention on Biological Diversity (CBD) (2009), *Connecting Biodiversity and Climate Change Mitigation and Adaptation*, Report of the Second Ad Hoc Technical Expert Group on Biodiversity and Climate Change, CBD Technical Series No. 41, Secretariat of the Convention on Biological Diversity, Montreal, Canada.

Sector	References
	DECCW (2011), *Observed changes in New South Wales climate 2010 – Our climate is changing*, Office of Environment and Heritage, http://climatechange.environment.nsw.gov.au/~/media/Files/PDF%20resources/10171climateimpactprof.pdf. DPI (2007), *Climate Change Research Priorities for NSW Primary Industries*, discussion paper, NSW Department of Primary Industries, www.dpi.nsw.gov.au/__data/assets/pdf_file/0004/195610/Climate-change-research-priorities-for-NSW-primary-industries---discussion-paper.pdf. Dunlop, M & Brown, PR (2008), *Implications of climate change for Australia's National Reserve System: A preliminary assessment*, report prepared for the Department of Climate Change and Department of the Environment, Water, Heritage and the Arts, Canberra. Eco Logical Australia (2010), *Climate change vulnerability assessment – Key natural assets in the Hawkesbury Nepean catchment*, Hawkesbury-Nepean Catchment Management Authority, Penrith. Rosenzweig, C & Hillel, D (2000), 'Soils and global climate change: Challenges and opportunities', *Soil Science,* **165** (1): 47–56. Saintilan, N & Rogers, K (2006), 'Coastal Wetland Elevation Trends in Southeast Australia', in Gilman, E (ed.), *Proceedings of the Symposium on Mangrove Responses to Relative Sea-Level Rise and Other Climate Change Effects, 13 July 2006 – Catchments to Coast, The Society of Wetland Scientists 27th International Conference, 9–14 July 2006, Cairns Convention Centre, Cairns, Australia*, Western Pacific Regional Fishery Management Council, Honolulu, USA. Steffen, W; Burbidge, A; Hughes, L; Kitching, R; Lindenmeyer, D; Musgrave, W; Stafford Smith, M & Werner, PA (2009), *Australia's Biodiversity and Climate Change*, CSIRO Publishing, Collingwood. Williams, RJ; Bradstock, RA; Cary, GJ; Enright, NJ; Gill, AM; Liedloff, AC; Lucas, C; Whelan, RJ; Andersen, AN; Bowman, DJMS; Clark, PJ; Cook, GD; Hennessey, KJ & York, A (2009), *Interactions between climate change, fire regimes and biodiversity in Australia – A Preliminary Assessment*, report to the Department of Climate Change and Department of the Environment, Water, Heritage and the Arts, Canberra.