

Introduction

The main purpose of this study is to review and synthesise the academic and practice literatures relating to adaptation of neighbourhoods and built components of the urban environment to inform the development of the Sydney Adaptation Strategy (SAS). This Report reviews strategies and emerging innovations employed around the globe in adapting neighbourhoods and buildings for climate change; and has been prepared to support the development of a Climate Change Adaptation Strategy for the Sydney Metropolitan Area. It presents the argument for why adapting neighbourhoods and buildings now to prepare for future climates changes is not only important but needs to be considered as a current rather than future action in the development and ongoing life cycle of refurbishment of the built environment.

Based on the assessment of vulnerability to climate-induced impacts for the Sydney Metropolitan Area, the report reviews the options for adaptation of neighbourhoods and buildings across seven themes, which are called "exposures" in the report.

- Increased temperatures;
- Drought and water management;
- Bushfire Risks;
- Severe storm and flash flooding;
- Sea level rise and coastal flooding;
- Urban salinity; and
- Air quality.

Popular adaptation actions in reporting CDP cities

Table 1: Most popular adaptation actions in reporting CDP cities

THREE MOST POPULAR ADAPTATION ACTIONS REPORTED BY CITIES BY RISK TYPE.	Number of Cities	%
TEMPERATURE INCREASE / HEAT WAVES		
• Creation of green space including tree planting	30	42%
• Green Roof Programmes	15	21%
• Community Engagement & Public Education Programmes	15	21%
DROUGHT		
• Awareness Campaigns and Public Education to reduce water use	12	17%
• Water Supply Diversification (i.e. desalination)	6	8%
• Actions increasing supply / water storage capacity (i.e. reservoir storage)	4	5%
INTENSE RAINFALL / FLASH FLOODING		
• Stormwater Initiatives – Capture, Retardation or Detention	27	38%
• Flood Defences	16	22%
• Rainwater / Roof Capture (i.e. Blue Roof Programmes, Tanks etc.)	8	11%
SEA LEVEL RISE		
• Flood Defences	6	8%
• Building Resilience and Resistance Measures (i.e. elevation)	4	6%
• Restrictions on development in coastal hazard zones	3	4%
STORMS (INCLUDING CYCLONES) & FLOOD EVENTS		
• Disaster or Crisis Management, Early Warning & Evacuation Systems	11	15%
• Disaster Planning and Practice Exercises	8	11%
• Flood Defences	7	10%

Source: adapted from CDP 2012, pp. 46 – 47

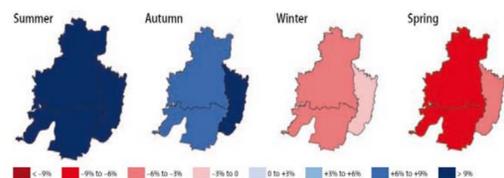


Figure 1: Estimated change in seasonal run-off projected to 2030 for Sydney (Vaze, et al. 2008)

Recommendations and strategies

Temperature increase - Urban heat

1. Using high-resolution climate change projections, undertaking research into the costs and human comfort benefits of passive design for buildings and neighbourhoods in Sydney.
2. Undertaking research to map areas of current and future exposure to Urban Heat Island effect within the Sydney Metropolitan Area, including scientific analysis of how buildings and neighbourhoods contribute to the UHI effect. This should be supported by a cost benefit analysis of a sample of different building and neighbourhood adaptation measures to heat.



Figure 2: Adaptation process in climate change

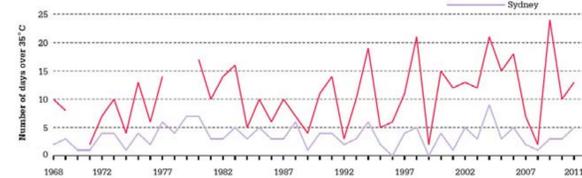


Figure 3: Number of hot days in Parramatta (red) and Sydney (Blue) from 1970 to 2011 (Steffen and Hughes, 2012)

Drought and water management

3. Undertaking research to identify the local relationships between water use and land cover type including characteristics of urban form within the Sydney Metropolitan Area. This research is considered critical if adaptation for increased water supply and strategies to decrease consumption are to be encouraged (EEA 2012).
4. Developing a rating system similar to the star rating system for white goods, found to be successful in promoting energy efficiency, is recommended as a way of promoting Water Sensitive Urban Design (WSUD) through fostering the public's recognition of the impact of consumer choices and behaviours on potable water consumption.
5. Undertaking research identifying how tools such as BASIX and WELS can incorporate and / or encourage consideration of adaptation measures for new buildings and when renovation is undertaken as part of the refurbishment cycle. See table 2.

Table 2: Prevention actions

Actions	Description/Details	Example
Xeriscaping (CCAD 2007)	Xeriscaping is an alternate form of landscaping that relies on drought-tolerant plants to reduce outdoor watering requirements during the summer.	Regina, Saskatchewan (ACC 2010)
Lessen the impacts to infrastructure	- applying proactive solutions that encourage groundwater infiltration of stormwater, such as increasing permeable surfaces in built-up areas - improving protection on electrical and telecommunications infrastructure so that these services are not lost in situations of extreme weather	

Bushfire risks

6. Commissioning research to identify 'best practice' for bushfire evacuation at a neighbourhood scale to assist Local Government within the Sydney Metropolitan Area develop strategies for vulnerable suburban areas within their jurisdictions including assessment of the various types and overall effectiveness of Community Fire Refuges and Safe Haven areas.
7. Undertaking research to evaluate the effectiveness of Vendor Statements mandating compulsory disclosure of bushfire hazard and level of compliance of both buildings and their curtilage to current bushfire code standards at the time of property sale, such as the legislation recently introduced within Victoria, in encouraging the retrofit and upgrade of privately owned building and exterior works to support the ongoing adaptation of neighbourhoods for bushfire threat.
8. Conducting research to determine the cost and benefits of the use of Fuel Clearance Regulations and/or Abatement Schemes aimed at creating defensive perimeters to housing and other forms of development; and ensuring their regular maintenance within private property. Secondly in providing a mechanism in the event of non-compliance, allowing for remedial works to be undertaken and funded in neighbourhoods vulnerable to bush fire threat and the contribution of such schemes may make to city-wide bushfire mitigation. See table3.

Severe storm and flash flooding

9. Undertaking detailed investigation to identify vulnerability at the neighbourhood scale to flash flooding within the Sydney Metropolitan Area. This will require assessment of individual streets and associated stormwater drainage and retardation systems to increasing seasonal runoff volumes at a localised scale within individual Local Government Areas.
10. Commissioning research into the skills training and budget requirements associated with the maintenance of emerging forms of flood mitigation works, such as swales and permeable surfaces.
11. Undertaking research aimed specifically at identifying the cost effectiveness and multiple benefits such as greening and drought proofing neighbourhoods delivered by many flooding management works proven successful in reducing the threat of flash flooding to encourage Local Governments to prioritise the use of more innovative 'plug in' approaches over the use traditional infrastructure.
12. Conducting research to determine the cost / benefits of policies including Hail Resistant Roofing Discount Schedules support an Insurance Premium incentive, in encouraging construction or replacement with more robust roofing materials (metal sheet roofing) given the region's vulnerability to hail impact.

Sea level rise and coastal flooding

13. Using case studies of coastal suburbs with the Sydney Metropolitan Area to identify the range of adaptation responses potentially available to Local Government in addressing sea level rise and coastal flooding. Through the use of case studies, the research can consider the varied local coastal conditions, and level and type of development.
14. Commissioning research to focus on how a mix of retreat, defence, elevation or reclamation strategies addressing sea level rise and coastal flooding can be interfaced to support the development of a comprehensive coastal management strategy and coordinate individual efforts of neighbouring Local Governments given the range of local conditions and types of development needed to be accommodated along Sydney's coastline.
15. Commissioning research to develop a holistic strategy aimed at identifying and prioritising actions to reduce the city's vulnerability to loss and disruption to a range of critical infrastructures as a result of sea level rise and coastal flooding, including identifying the interdependencies and relationships among individual components of these infrastructures to the city's functioning and wellbeing.
16. Undertaking research to evaluate the effectiveness of recent policies or mechanisms used by individual Local Governments in NSW and Australia designed to improve the community's access to flood information including predictions for coastline advancement, and potential use of vendor statements, to determine if such mechanisms have been success in increasing awareness of the hazard risks or resulted in pro-active adaptation.

Table 3: Mechanisms to reduce Fuel Loads

Mechanism	Description	Examples
Controlled or Prescribed Burning / Burning Permits	Prescribed burning is the controlled application of fire under specified environmental conditions to a predetermined area and at the time, intensity, and rate of spread required to reduce accumulated fuel load that if not reduced may result in more intense and damaging bushfires.	Used throughout Australia as a management tool.
Fuel Clearance Regulations and Abatement Schemes.	Used overseas to ensure establishment and maintenance of defensive perimeter on private property to assist in protecting housing and assist with fire fighting. Non-compliance result in substantial fine and/or remedial works being undertaken by local fire services with the cost charged to the property owners.	Ventura & Santa Barbara Counties, California, US

Table 4: Mechanisms to retard stormwater runoff

Mechanism	Description	Examples
Reduce areas of Impervious Pavements - reducing roadway widths.	Reduction in overall area of impervious pavements through narrowing trafficable road widths. Typically to avoid removing existing stormwater structures / kerb and guttering, "Rain Gardens" or a strip of permeable pavement is added between the trafficable carriageway and existing kerbline.	Portland's Green Streets Program.
Rain Gardens		

Table 5: Defence strategies

Mechanism	Description	Examples
Floating Islands	Floating islands – recycled plastic beds allowing plants to be woven into the system and are being used to attenuate wave action as a method of reducing erosion and encourage silt deposits and as an alternative form of wetland creation.	Isle de Jean Charles, Louisiana – installed as a wave attenuation device.
Temporary Flood Barriers	Demountable systems that are either semi-permanent (fixed structural posts) or temporary that are constructed to protect property threatened by flood inundation. Semi-permanent solutions are more robust and can assist with more rapid installation where the frequency of inundation is high or barriers are installed on a seasonal basis.	Deployed throughout UK and recently in Australia.

Urban salinity

17. Undertaking analysis of current salinity mapping and development controls to ensure that current and future development in Western Sydney can adequately respond to the impacts of future climate change on salinity expression.
18. Conducting research to evaluate the effectiveness of adaptations currently being trialled across NSW and Australia that are aimed at reducing salinity impacts, in order to guide future strategy development within the Sydney Metro Area.

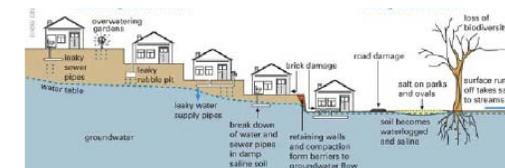


Figure 4: Drivers and impacts of urban salinity (DNR, 2006)

19. Commissioning research to identify complimentary building and neighbourhood scale adaptation to reduce the future impacts of salinity, which do not result in mal-adaptation to flooding and water management.

Energy efficiency

20. Undertaking research to identify the quantifiable benefits of urban scale improvements such as transport management, on local air quality within the Sydney Metropolitan Area. Such research may be of benefit in helping to raise public awareness about the linked between the built environment and its impacts on the city's environmental quality but also the potential for adaptation for future climate change.

Table 6: Energy efficient systems and low-carbon materials strategies

Strategy	Description	Example
Building Energy Efficiency	Better performing buildings will be designed, with an appropriate mix of end-uses and through the intelligent planning of the spaces between them. Energy demand management tools and techniques such as smart meters and behavioural change prompts will encourage residents to contribute reduce energy consumption.	Helsinki; Low carbon Building Project'. Empire State Building NXC retrofit
Use of sustainable materials and methods	Which have a lower impact on the environment in terms of toxicity and embodied carbon will be used.	Helsinki; Low carbon Building Project
Cooling technology	The building's underfloor displacement system is a new cooling technology that, together with carbon dioxide monitoring and control, improves air quality.	6 Green Star Building, 36 Hunter Street, Sydney Refurbishment of 90-year-old building, first heritage-listed building in Australia

Findings and recommendations

The cumulative evidence suggests prudence and advance action to minimise the immense risks stemming from climate change. Therefore to encourage proactive adaptation in response to climate change, governments need not only to identify opportunities and 'best practice' approaches to deal with specific impact, but support their adoption by:

- Developing a clear framework as a guide for local planning and adaptive action;
- Prioritising adaptation strategies for all levels of government and stakeholders;
- Educating the broad community regarding climate change risks, as "understanding" is the first stage of adaptation.

Two important 'governance' issues need to be highlighted include: Firstly in developing such a strategy, the NSW Government will need to consider the raft of existing legislation and Australian Buildings Standards or performance codes already in place that directly or indirectly influence adaptation for climate change. In the same way, the State Government will need to consider if it will continue to encourage or mandate Local Governments across the metropolitan area to develop climate change adaptation strategies addressing vulnerabilities presented within their LGAs.

Introduction

This report reviews local and international scientific research and professional reports on adaptation to climate change options with regard to settlements and communities. It has been prepared to support effective planning and design of a Sydney Adaptation Strategy for the Metropolitan Area.

Sydney is expected to experience warmer temperatures, more variable rainfall, increased evaporation, rising sea levels and an increased risk of flooding and bushfires in the future.

This report examines Sydney's expected impacts on the key sector of settlements and communities.

The report reviews the options for adaptation of settlements and communities across seven themes in the report.

- Urban Form, Land Use and Sustainability - Impact of Climate Change on the City Structure
- Temperature and Urban Heat Island Effect
- Bushfires
- Riverine flooding including flash flooding
- Coastal flooding
- Social Impacts and Adaptive Capacity
- Emerging Policy and Governance Initiatives

Sydney Climate Change Projections

Table 1 shows the seasonal projections of the maximum and minimum temperature, rainfall and evaporation to 2050, estimated sea level rise, flood and bushfire assessment to 2050 and 2100.

	Climate Change Projections to 2050				2100
	Spring	Summer	Autumn	Winter	
max. Temperature	2.0–3.0°C warmer	1.5–2.0°C warmer	1.5–3.0°C warmer	2.0–3.0°C warmer	
min. Temperature	2.0–3.0°C warmer	1.5–3.0°C warmer	1.5–3.0°C warmer	1.5–3.0°C warmer	
Rainfall	10–20% increase	20–50% increase	No significant change	10–20% decrease	
Evaporation	10–20% increase	10–20% increase	No clear pattern	No clear pattern	
Sea Level Rise	0.4m				0.9m
Flood	increased risk due to sea level rise and catchment driven flooding; more intense rainfall events				
Dushfire	increased fire frequency and intensification of fire danger levels; very high to extreme fire danger days are projected to increase by 10–50%				

Table 1. Seasonal projections due to climate change in 2050 and 2100

A moderate increase in evaporation is projected for spring and summer, leading to slightly drier soil conditions. Figure 1 indicates increased run-off during summer and autumn with decreases in winter and spring by 2030.

Sydney Subregions

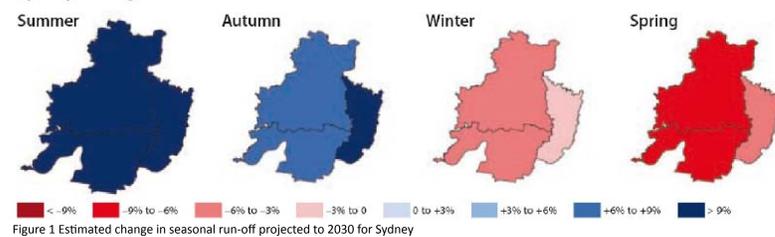


Figure 1. Estimated change in seasonal run-off projected to 2030 for Sydney

Parramatta experiences 4 times as many hot days as Sydney at present. Overall, NSW is becoming hotter, heat waves will become more severe and will likely last longer, and Western Sydney is more vulnerable than coastal locations to extreme heat waves. Figure 2 shows that over the period from 1970 to 2011, western suburbs of Sydney have experienced an increase of 60% in the number of hot days whilst coastal Sydney has not shown a significant trend.

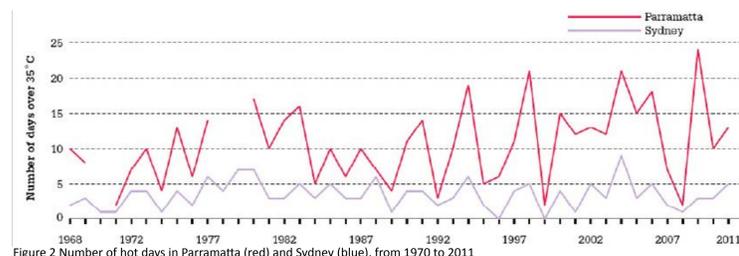


Figure 2. Number of hot days in Parramatta (red) and Sydney (blue), from 1970 to 2011

Adaptation Strategies

Urban form, land use and sustainability - impact of climate change on the city structure

Sydney's metropolitan planning concepts can be described, in part, as 'multi-centralisation', which promote many large regional centres which serve catchment areas across the metropolitan area. Up to a certain degree, urban compactness can be more energy efficient, especially in terms of transport if viable public transport options are available, but may decrease green space and increase urban heat island effects and air pollution. To date, most compact city planning and design strategies that have incorporated climate change have focused on mitigation and not adaptation.

Studies show that increasing the density in existing areas reduces greenhouse gas emissions due to a decrease vehicular usage, however, other issues, such as urban heat island effect become more prevalent. Much more research needs to be done on urban climate change adaptation strategies vis-à-vis urban form and structure. To be most effective, this research would evaluate future options and scenarios using comparative life cycle methods, which employ an expanded 'cradle to cradle' approach.

Although there is an increasing amount of research on climate change impacts on human settlements in regard to urban planning, an integrative research framework for adaptation to climate change is needed to develop more robust public strategies, policies, plans and programs, design guidelines and implementation measures.

Temperature and urban heat island effect

Urban form has a significant impact on Extreme Heat Events (EHE). Sprawling suburbs and sprawling cities experience EHE at a higher rate compared to most compact cities, distinct from the urban heat island effect. On the other hand, the lack of vegetative cover and the amount and intensity of built areas are the main factors that contribute to the Urban Heat Island effect (UHI). Air-conditioning units, vehicular usage and the constant use of generators exacerbate the high thermal loads within cities. Figure 3 shows the thermal imaging of Sydney CBD in February 2009, with a temperature range of 22.2 to 29.2 degrees Celsius.



Figure 3. Thermal Image of Sydney CBD

Adaptation strategies include preserving and incorporating more green spaces and green infrastructures, creating light coloured reflective surfaces on paved surfaces and building rooftops, and creating more compact city design. Green infrastructure also provides numerous other benefits as part of an ecosystem service.

Bushfires

Hazard reduction burns are the single-most widely used tool for managing bush fire risk but is a high risk, resource intensive operation with relatively short-term benefits and a heavy dependence on favourable weather conditions. Evidence suggests that community education and engagement increases preparedness and lowers the impact of fire events. California has developed the Cal-Adapt Online Tool (Figure 4) to assist in estimating climate change impacts. This online tool supports local efforts by providing increased spatial resolution and an ability to quickly evaluate several climate impacts for any location in California.



Figure 4. Wildfire risk map for California

Questions have been raised concerning both mitigation strategies and the logic of land-use planning decisions that support the continued development of housing and associated infrastructure in bushfire prone areas, as well as prioritising hazard reduction at the expense of reducing urban vulnerability. Local, place-based planning that is sensitive to bushfires can play a greater role in achieving climate adaptation. 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 community education, networks and engagement to increase the preparedness and thus lowering the impact of fire events.

Riverine flooding including flash flooding

Extensive areas within the North West Subregion (Figure 5) already lay within the floodplain, which is defined as all land up to the probably maximum flood (PMF), and is considered the largest conceivable flood to occur in any particular location. Residences that are within the land above the 1 in 100 year ARI will need to be evacuated in instances of large flood events.

The most effective way of reducing flood risk is to (re)locate property outside of the floodplain. A secondary option is to place new buildings within the lowest risk areas, guided by sound flood risk management policies that consider the long term economic, environmental and social needs over year periods and longer. Adaptation options include the widespread distribution and decentralisation of green infrastructure as an way of reducing stormwater and excessive water flows, the adoption of early warning systems where emergency services and the public is informed about the possible severity and timing of the flooding.

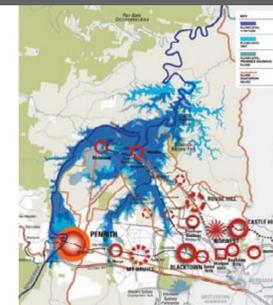


Figure 5. Map of Flood Evacuation Network in Hawkesbury LGA

Coastal flooding

Property and infrastructure are at increasing risk from sea level rise, increased frequency of storm surges and resulting coastal inundation and erosion. This is particularly so in developments near estuary entrances and beaches on coastal floodplains. In Sydney, many private properties and community facilities, including fire stations, hospitals, water treatment plants, and emergency services are situated within 200 metres of the shore.

Protection, accommodation and retreat are the principal adaptive strategies for sea level rise risk mitigation. One of the key adaptation challenges where the coastline is already developed is how to deal with future permits for armouring (protection) and determining the appropriate type of protection. In Sydney, where there are highly valued and immovable assets, while sea level rise risks will likely be mitigated through protection and accommodation, comparative life cycle cost-benefit analyses are recommended to assess the most appropriate and effective strategies case by case. 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 such as heat waves and storm surges. Figure 6 indicates the relative vulnerabilities in the region investigated.

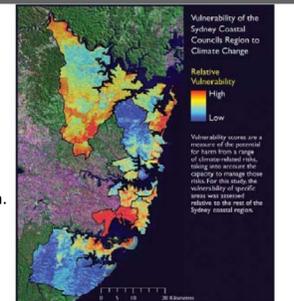


Figure 6. Relative Vulnerability of the Sydney Coastal Councils Region to Climate Change

Social impacts and adaptive capacity

Adaptation to climate change can have both positive and negative impacts on social equity and its spatial distribution. Positive impacts include enhanced, metro-wide accessibility to public transport. On the other hand, existing vulnerable communities may suffer dramatically from climate change if inadequate adaptation measures are not taken, especially if ameliorative infrastructures and facilities are not provided.

Australia's ageing population may be more vulnerable to climate impacts associated with temperature, natural hazards, and water, food-borne, and vector diseases. They may require smaller dwellings and senior living accommodation, and will need better access to services and public transportation.

Sea level rise and flooding will likely significantly impact Aboriginal cultural heritage due to damage to coastal ceremonial sites, stone artefacts, rock art, middens, grinding grooves and rock shelters.

Emerging Policy and Governance Initiatives

International Case Study: Berlin

The Green Area Ratio (GAR), used in Berlin, is a mechanism to encourage private owners to incorporate sustainable design into their parcels since 1997. It has 3 components:

- 1) set of ratings or prioritise green techniques that provide environmental service (established by municipal planners);
- 2) set of targets or minimum percentage of green infrastructure on the parcel (established by municipal planners); and
- 3) final ratio to determined for each parcel (sum of green techniques actually implemented), which is determined by the property owner.

In **Boston**, a working group of eight city agencies and departments, coordinate municipal adaptation efforts. The adaptation program looks beyond the basic physical phenomena like sea-level rise, flooding, heat waves, and so on to address their health, economic, and social consequences. A weakness of many adaptation strategies is that the lines are not explicitly drawn connecting identified risks with potential solutions and subsequently through to the relevant implementing agencies and collateral impacts. A clear link between proposed responses, responsible agencies and impacted parties needs to be established. The **Toronto** strategy is the most comprehensive that we have found in this regard, clearly linking potential actions with competent parties throughout.

London's climate change adaptation strategy centres on the *three policy pillars of retrofitting, greening, and cleaner air*. Retrofitting London's buildings reduces London's CO2 emissions, energy and water use, and reduces energy bills. Greening London reduces the impact of noise and air pollution and makes the city more resilient to flooding and extreme weather such as heatwaves. Greening programs are in place to increase tree cover by five per cent by 2025 (equivalent to one tree for every Londoner) and creating a better network of interlinked, multifunctional and high quality open and green spaces.

Research Recommendations

Key research priorities were identified throughout the paper and are summarised as follows:

1. There is a need to be able to quantify the impact of adaptation options such as green infrastructure, greening urban spaces or reduction in anthropogenic warming. However, 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.
2. An understanding of which material and colour of facades that best reflect heat, the impact of building orientation and height on radiant building temperature and the use of thermal sinks (carbon sequestration plantings) in urban basins
3. Bushfire and other hazard planning needs to be more closely linked to community based development of local environmental plans, this includes the responsible state agencies working closely with local government.
4. Explore the economic, environmental and social costs and benefits of zoning flood prone areas in Sydney versus adapting existing buildings in flood prone areas.
5. Developing a set of criteria that are specific to Sydney in order to develop the metro area as a "disaster resistant community", including urban planning and design guidelines, policies, and strategies.
6. Develop a life-cycle based cost and impact assessment model for climate change in the Sydney metro area.
7. Develop GIS based tools that display and help visualise the projected impacts and effects of climate change in the Sydney metro area.
8. Research that enables the modelling and assessment of 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.

Overall, we identify **three key challenges to incorporate climate change adaptation** into land use planning and disaster risk reduction:

- 1) securing ongoing, sustainable funding for adaptation
- 2) communicating the need for adaptation to elected officials and local departments
- 3) gaining commitment and generating appreciation from national government for the realities of local adaptation challenges.