SUSTAINABILITY ASSESSMENT PROGRAM

School of Civil and Environmental Engineering

# Assessment of the Challenges in Adapting Water Resources and Infrastructure to Climate Change—Literature Review

**Final Report**

M.D. Short, M. Schulz, E. Rocheta and G. Peters

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**Contact Details:**

Water Research Centre
School if Civil and Environmental Engineering
University of New South Wales

Name: Michael Short
Email: m.short@unsw.edu.au

**Physical:**
Building H22, Vallentine Annexe
Botany Street Gate 11
Kensington.

**Postal:**
UNSW, Sydney, 2052

**Telephone:** (02) 9385 5017
**Fax:** (02) 9313 8624

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## EXECUTIVE SUMMARY

There is widespread agreement amongst the international scientific community that climate change is occurring, that it is largely manmade and that it will have significant implications for humanity (Hegerl *et al.*, 2007; IPCC, 2007). Australia in particular has been described as one of the most vulnerable developed nations with respect to climate change (Garnaut, 2008b). Australia experiences a high degree of climate variability, including exposure to a range of climate extremes such as extreme rainfall, winds, tropical cyclones and drought (Preston *et al.*, 2008) and the largely arid nature of the continent already creates significant challenges for securing reliable water resources. Australia is said to be already experiencing impacts from recent climate change (increasing stresses on water supply and agriculture) and is expected to face more extreme future events with more intense and frequent heat waves, droughts, floods and storm surges (Hennessy *et al.*, 2007).

Just as the reality of climate change has been widely acknowledged, it is also generally acknowledged that some of its impacts are now either present or are inevitable and that they will most likely become more severe if we do not take action to modify current behaviour. Of the suite of possible active responses to climate change, human actions generally fall into two broad categories—mitigation and adaptation. *Mitigation* involves actions aimed at reducing the magnitude of our contribution to climate change (e.g., reducing greenhouse gas emissions and/or enhancing greenhouse gas sinks) in order to offset or reverse its effects. *Adaptation* represents an adjustment in natural or human systems aimed at reducing the severity of, or risks associated with, adverse climate change impacts that are seen as highly likely or inevitable, as well as actions seeking to harness any beneficial opportunities that may arise under a changed future climate system (IPCC, 2007). Although both mitigation and adaptation help to reduce climate change-related risks, adaptation represents an active 'risk management' approach aimed at reducing the negative impacts of climate change on human and natural systems (as well as exploiting any new positive outcomes) rather than a reactive post-adjustment to climate change impacts as they occur. The importance of adaptation action in the global response to climate change is now clear and was highlighted in the 2006 Stern Review, where it was noted that future "*adaptation is crucial to deal with the unavoidable impacts of climate change to which the world is already committed* (Stern, 2006, p. 404)."

Recognising the urgency of the adaptation challenge and the wide range of information needs required to meet this challenge, the Council of Australian Governments endorsed a National Climate Change Adaptation Framework in 2007, with this Framework to serve as the basis for government action on adaptation over the next five to seven years. In particular, the Framework seeks to identify possible actions to assist vulnerable sectors and regions to adapt to the impacts of climate change, including water resources, human health, settlements and infrastructure, and coasts. The Framework led to the establishment of a Facility to coordinate Australia's research resources and to deliver supporting information to climate change decision-makers—leading to the establishment of the National Climate Change Adaptation Research Facility (NCCARF) in 2008 (www.nccarf.edu.au/). One of the initial tasks of the NCCARF was to develop a suite of 'National Adaptation Research Plans' across eight priority thematic Adaptation Research Networks. This position paper forms part of the 'Water Infrastructure and Water Resources' component of the *Settlements and Infrastructure* Adaptation Research Network.

This paper firstly provides a brief synopsis of the current climate change adaptation challenges facing the water industry at large, with a particular focus is on water security issues in an Australian context. A review of past and current international adaptation activities and research agendas in relation to water infrastructure and water resources management is also provided. The paper also draws on the global literature to provide an overview of the critical knowledge gaps and necessary future research activities that will enable key stakeholders (policy- and decision-makers) to better understand the climate change risks and impacts to water infrastructure and resource security and then assist in the formulation of adequate adaptation responses to these potential impacts. Among the range of priority adaptation research agendas identified during the review, a number of key areas for future research effort became most apparent. These priority areas included:

- Data and information needs for water managers;
- Future climate scenarios, downscaling of climate models and uncertainty estimates for model outputs;
- Water efficiency, demand management, water pricing and water market measures;
- Policy and regulatory reform;
- Adaptive management and adaptation under uncertainty;
- Water and energy;
- Water quality issues and supply bio-security research;
- Collaboration, communication and education needs for the water sector;
- Water infrastructure and asset performance research;
- Sustainable adaptation directives for the water industry.

Given the extensive range of likely climate change-related impacts on water resources, the potential for research topics in this field is recognised as being almost limitless (USEPA, 2008). Consequently, information presented here by no means represents an exhaustive list of all future research needs; rather it provides a high-level overview of the identified priority research needs in the general areas of water infrastructure, water resources management and water supply security.

# 1 BACKGROUND

Australia has been described as one of the most vulnerable developed nations with respect to climate change (Garnaut, 2008b). Australia experiences a high degree of climate variability, including exposure to a range of climate extremes such as extreme rainfall, winds, tropical cyclones and drought (Preston *et al.*, 2008a). The largely arid nature of the continent also creates challenges for securing reliable water resources into the future (Marsden and Pickering, 2006). Climate change is expected to exacerbate current stresses on water resources from population growth and economic and land-use change, including urbanisation (IPCC, 2007a).

Available research suggests a significant future increase in heavy rainfall events in many regions, including some in which the mean rainfall is projected to decrease. The resulting increased flood risk poses challenges to society, physical infrastructure and water quality. According to IPCC (2007a), there is a >66% likelihood that up to 20% of the world population will live in areas where river flood potential could increase by the 2080s. Increases in the frequency and severity of floods and droughts are also projected to adversely affect sustainable development objectives. Increased temperatures will further affect the physical, chemical and biological properties of freshwater lakes and rivers, with predominantly adverse impacts on many individual freshwater species, community composition and water quality. In coastal areas, sea level rise will exacerbate water resource constraints due to increased salinity of groundwater supplies.

Traditionally water management was the art of matching the limited water resources with the present and projected water needs of people, food, economies and environment. The balancing act of water management was performed on the assumptions of historically stationary variability in climate and water availability and a defined forecast of water demand; however, this assumption is proving to be too simple and no longer valid (Allen *et al.*, 2008; CPWC, 2009), with the persistence of climate 'stationarity' now being seriously challenged (Milly *et al.*, 2008). With the demise of climate stationarity, it appears no longer appropriate to assume that past hydrological conditions will continue into the future and, due to the underlying uncertainty in climate change predictions, managers can no longer have confidence in single projections of future conditions (Kundzewicz *et al.*, 2007). Severe water shortages are driving water managers to seek new water sources, recycle wastewater and manage land and water use activities more effectively and in an integrated way. Future legislation and administration relating to water will need to provide water managers with the capacity to adjust and adapt to the impacts of climate change in order to achieve the best possible social, economic and environmental outcomes in the future (Flett *et al.*, 2008).

Whereas considerable effort has been directed toward climate change mitigation during the past two decades, comparatively little research effort has gone into climate change adaptation, and as such, implementations of adaptation measures are currently very limited (Parry *et al.*, 2007). This applies for all adaptation areas including water resource management. According to Kinrade and Justus (2008), climate change adaptation can be defined as "*actions in response to actual or projected climate change impacts that lead to a reduction in risks or realisation of benefits*". Adaptation, therefore, represents a planned and active response to combat the future effects of climate change rather than a reactive post-adjustment to climate change impacts. Adaptation can also be viewed as a dynamic process that evolves over time, involving five major pre-conditions for encouraging the implementation of adaptation actions (Figure 1). The importance of adaptation action in the global response to climate change is now clear, and was highlighted in the 2006 *Stern Review* (Stern, 2006; p. 404), where it was noted that future "*adaptation is crucial to deal with the unavoidable impacts of climate change to which the world is already committed*."

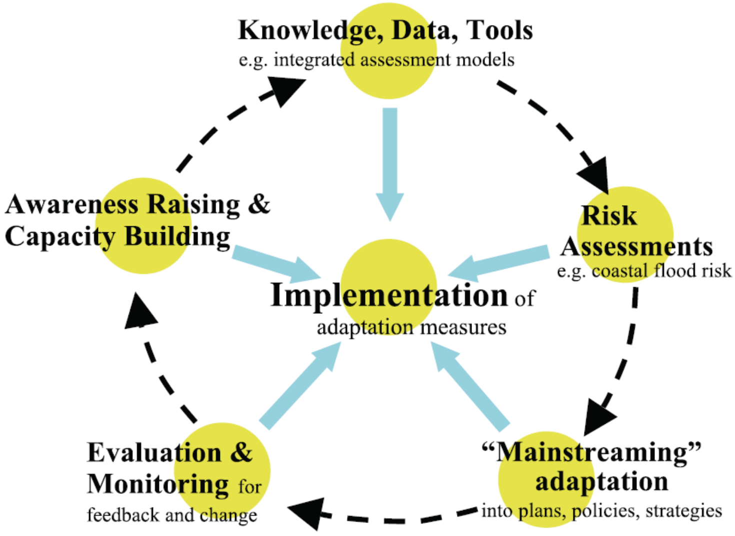


**Figure 1.** Overview of the adaptation process (Hennessy *et al.*, 2007).

## 2 OBJECTIVES

The aim of this literature review is to address water-related climate change adaptation research needs in the area of settlements and infrastructure. The particular focus of the review will be on water and wastewater infrastructure as well as water resource and supply management for urban and rural water sources.

The specific objectives of this report are:

- To identify the major issues and consequences caused by climate change with regards to urban and rural water sources and existing water and wastewater infrastructure;
- To identify what measures have already been proposed in order to adapt to these challenges and to secure sufficient water for human needs, economic activities and environmental health;
- To outline past as well as planned research activities in relation to water-related climate change adaptation measures; and
- To identify knowledge gaps and priority areas of research need with respect to water-related climate change adaptation measures.

## 3 CONSEQUENCES OF CLIMATE CHANGE FOR WATER MANAGERS

Climate change poses a major conceptual challenge to water managers; this is in addition to the future challenges relating to population and land-use changes. Predicted future climate changes are expected to lead to a general intensification of the global water cycle, with a consequent increase in the risk of flooding (Milly *et al.*, 2002; Huntington, 2006; Kundzewicz *et al.*, 2007). Changes to current water supply and demand chains, changes to water source quality and impacts on water infrastructure are just a few of the climate change-related challenges facing water managers in the future. In general terms the literature available in this field is relatively consistent regarding the direct consequences of climate change. A large number of consequences have direct and indirect effects regarding the quantity, the quality and the timing of different water sources and on existing water infrastructure. For example, an increase in annual average temperature by 0.4–2°C in 2030 and 1–6°C in 2070 will lead to increased evaporation, thus increasing the human water consumption but at the same time reducing the available fresh water supplies and putting additional stress on environmental water flows (Pittock, 2008). Furthermore, increasing ranges of soil moisture content will lead to increased ground movement which will have impacts on pipe works and foundations of buildings. A range of adaptation interventions will, therefore, need to be put in place in order to guarantee both water supply and water infrastructure security into the future (e.g., Table 1 and Figure 2).

**Table 1.** Examples of adaptation interventions for water supply security under climate change (UNFCCC, 2006).

| Use category | | Supply side | Demand side |
|---|---|---|---|
| Municipal or domestic | | • Increase reservoir capacity<br>• Desalinate<br>• Make inter-basin transfers | • Use "grey" water<br>• Reduce leakage<br>• Use non-water-based sanitation<br>• Enforce water standards |
| Industrial cooling | | • Use lower-grade water | • Increase efficiency and recycling |
| Hydropower | | • Increase reservoir capacity | • Increase turbine efficiency |
| Navigation | | • Build weirs and locks | • Alter ship size and frequency of sailings |
| Pollution control | | • Enhance treatment works<br>• Reuse and reclaim materials | • Reduce effluent volumes<br>• Promote alternatives to chemicals |
| Flood management | | • Build reservoirs and levees<br>• Protect and restore wetlands | • Improve flood warnings<br>• Curb floodplain development |
| Agriculture | Rain-fed | • Improve soil conservation | • Use drought-tolerant crops |
| | Irrigated | • Change tilling practices<br>• Harvest rainwater | • Increase irrigation efficiency<br>• Change irrigation water pricing |

The predicted sea level rise of 3–17 cm by 2030 and 7–52 cm by 2070 (Amitrano *et al.*, 2007) increases the risk of saltwater intrusion into coastal aquifers, estuaries, rivers and bays and is likely to increase the flood risk for low lying water and wastewater treatment and reticulation infrastructure in conjunction with extreme storm events (Midgley *et al.*, 2005; Sjerp and Charteris, 2008) as well as leading to a decreased capacity of stormwater outfalls (Sjerp and Charteris, 2008). Increased coastal erosion can also lead to damage to infrastructure such as water mains, sewer mains, pump stations, stormwater drainage systems and septic tanks (Sjerp and Charteris, 2008). Whilst gradual, the potential of sea level rise impacts for increased damages are real. This is especially so when they are accompanied by high tidal and storm events, and is relevant for key coastal areas that are identified as vulnerable due to high population densities and settlements and infrastructure of all types. Rising sea levels will serve to increase joint probability of high tide levels and intense storms and increase the coincidence of these events (Midgley *et al.*, 2007). These factors, combined with the intensifying development of coastal communities around the Australian coastline, means that the cost of damages from such events is likely to rise substantially.

The predicted change in rainfall patterns from winter-dominated to summer-dominated rainfall in some regions (DECC, 2008) and less rainfall across much of southern and eastern Australia will lead to longer and more intense low flow periods in rivers as well as a decrease in annual surface water run-off which again will put stress on available fresh water supplies (SMEC Australia, 2007). Climate change is also predicted to impact on future rates of groundwater recharge. For example, a report by Power and Water Corporation in the Northern Territory suggests that predictions of shorter and more intense rainfall patterns will increase surface runoff and reduce groundwater recharge capacity (IEC, 2008). Changes in rain patterns in some areas may increase sewer overflow events, while in other areas declining catchment in-stream flows will concentrate salts and pollutants and reduce the assimilative capacity for discharged wastewater effluent, necessitating greater treatment for solids, pathogens and nutrient removal (USEPA, 2008). Increases in water temperature can also make some contaminants, such as ammonia and pentachlorophenol more toxic for some species as well as foster the growth of microbial pathogens in drinking water sources (USEPA, 2008).

Current predictions suggest that the majority of Australia is likely to experience increased average temperatures, more extreme high temperatures and less extreme low temperatures (Amitrano *et al.*, 2007). Increased temperature means elevated rates of evapotranspiration. Increased evapotranspiration is likely to then have direct implications for irrigation and reservoirs, while the indirect implications of increased evapotranspiration (through reduced soil moisture levels) are likely to impact runoff-generating mechanisms in urban and rural catchments; although in a complex interplay with rainfall changes (Midgley *et al.*, 2007). Due to widespread land use patterns that promote soil erosion and because of the increased future likelihood of flash flooding conditions, another likely impact on the current water supply system is an increase in sedimentation of rivers which could reduce the storage capacity of reservoirs. This could in turn influence their ability to mitigate the effects of droughts and floods (OECD, 2006). Although for many countries, and in particular for Australia, predictions about future rainfall patterns vary significantly across different regions (OECD, 2006; Vaze *et al.*, 2008), most model simulations suggest there will be an increase in extreme daily rainfall events (SMEC Australia, 2007) resulting in associated stresses on stormwater infrastructure and implications for infiltration and inflow into sewers. These are just a few of the water resource and water infrastructure-related consequences likely to arise from climate change based on current future impact modelling scenarios described by the Intergovernmental Panel on Climate Change

(IPCC, 2007b). Some climate change impacts and implications as they relate to water supply infrastructure in particular are shown below in Figure 2.

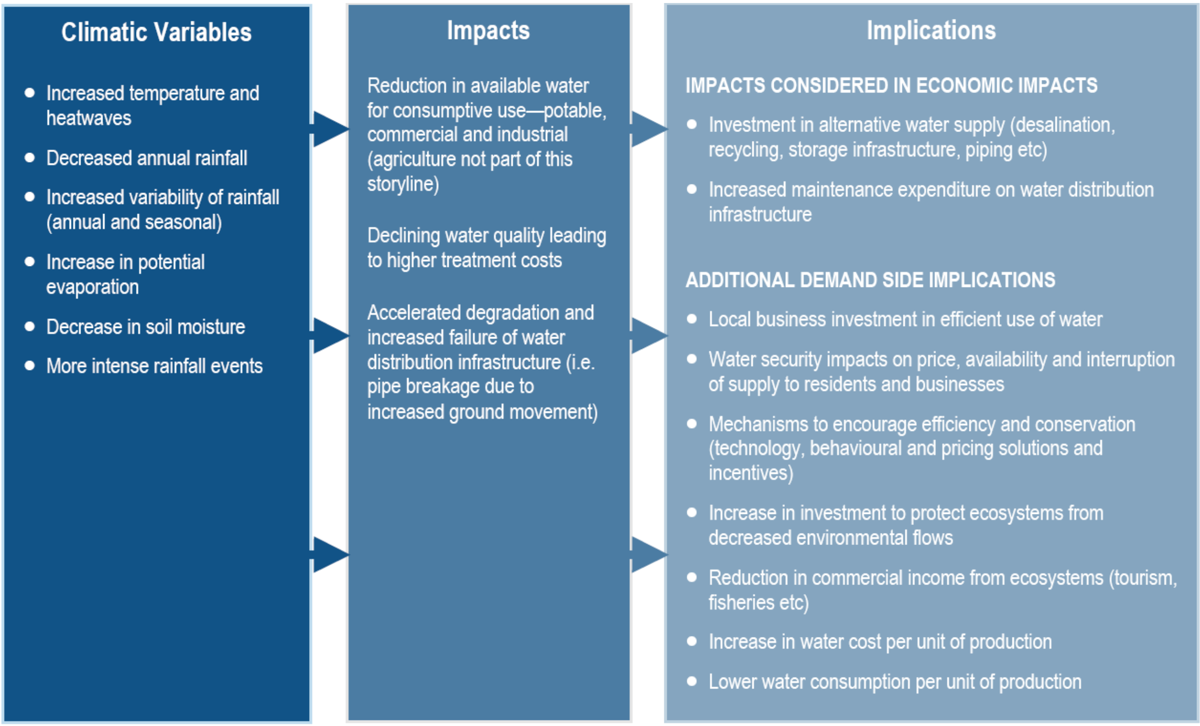


**Figure 2.** Climate change impact series for water supply infrastructure in major cities (Maunsell Australia and CSIRO, 2008).

There are of course other impacts on the existing water supplies which always have to be considered in conjunction with climate change related impacts. Most importantly, population growth will lead to an increased demand of water for human consumption, agriculture and other industrial processes (Pittock, 2008). Land use change is another factor which will have a major influence on future water supply availability and demand (Neal *et al.*, 2007). Increases in water demand throughout Australia have already placed stress on supply capacity for irrigation, cities, industry and environmental flows (Hennessy *et al.*, 2007). Furthermore, future climate change impacts have the potential to add to the already long list of problems for the Australian water cycle such as dryland salinity, alteration of river flows, over-allocation and inefficient use of water resources, land clearing, intensification of agriculture, and fragmentation of ecosystems (Hennessy *et al.*, 2007).

## 4 ADAPTATION MEASURES IDENTIFIED

Adaptive capacity is defined as the ability of a system to evolve in order to accommodate external changes or to expand the range of variability with which it can cope (Wilbanks *et al.*, 2007). The U.S. Climate Change Science Program (CCSP, 2008) further defines adaptation responses as being either *reactive* or *anticipatory*. Reactive adaptation is where climate change impacts are not planned for by the managing agency, and adaptation takes place after the impacts of climate change have been observed. Anticipatory adaptation on the other hand involves future climate change impacts being acknowledged as likely to occur by the managing agency, and responses to those changes are subsequently planned either for when changes are observed (responsive adaptation) or are planned for before the changes are observed (proactive adaptation). Midgley *et al*. (2007) further identifies two types of adaptation action: "resilience-type" adaptation, which addresses the potentially damaging effects of changing climate extremes on sectors; and "acclimation-type" responses, which address strategies to cope with the gradual changes in background climate. These include slow rates of warming that may ultimately require new behaviours and practices in human society. According to Midgley *et al*. (2007), differentiating adaptation responses into "resilience-type" and "acclimation-type" adaptation responses may allow adaptation strategies to be better prioritised, and implementing agencies and financing sources to be more effectively allocated to where needs are most urgent.

Regardless of the definition of adaptation measures, numerous potential climate change adaptation actions have been identified in relation to water resources and infrastructure management. Briefly, these have included:

- **Alternative water supplies** (groundwater prospecting, desalination, wastewater and greywater reuse, stormwater harvesting);
- **Expansion of storage capacity** (rainwater harvest and storage, building new and expanding existing reservoirs and dams, aquifer storage and recovery);
- **Demand management and water use efficiency** (reducing irrigation water use through importing certain crops (i.e. virtual water), public education to reduce water use, technological advancements through water saving product developments);
- **Regulatory and policy approaches** (adoption of integrated planning approaches, amending local planning schemes to give greater weight to flood risk, amending design standards);
- **Water markets** (expansion of water trading, economic incentives (e.g., metering and pricing) to encourage water conservation, water allocation reforms and reallocation of water to higher value uses);
- **Management approaches** (integrated water resources management (IWRM) and risk management / risk spreading approaches, catchment management measures such as afforestation and reforestation or restoration of native vegetation in riparian zones);
- **Research and development** (improve modelling of regionally-based climate change impacts, research effective education measures to increase public awareness about potential impacts of climate change and about climate change adaptation responses);

Of the above adaptation options for water resources management, a number of these measures are described in more detail within the following sections.

## 5 DEMAND MANAGEMENT AND WATER EFFICIENCY MEASURES

Efficient use of water is a key outcome of effective water resources management, and one that serves to both mitigate and adapt to climate change impacts. Water conservation reduces water resource demands, wastewater discharges and can also reduce energy demands and associated greenhouse gas emissions relating to water treatment and delivery (DWR, 2008).

Improved water use efficiency can also effectively reduce the strain on ageing water and wastewater utilities and has the potential to delay or even eliminate the need for costly new upgrades to expand network capacity (USEPA, 2006). Such is the importance of efficient use of water, California's State Water Plan concluded in 2005 that the largest single new water supply available to meet their expected growth over the next 25 years will be from the promotion of water-use efficiency measures (California Department of Water Resources, 2005).

Past research has shown that water conservation measures such as education, industrial and commercial reuse, modern plumbing standards, and pricing policies can be extremely effective at mitigating the effects of climate change on regional water supplies (Kiparsky and Gleick, 2003). In Australia, the federal and all state governments have various initiatives in place to promote water conservation. For example, the NSW Government—through its *Water for Life* initiative—plans to achieve a 24% reduction in water demand by 2015 in the Greater Sydney area (Water for Life, 2008). There are also a diverse range of government programs in place to help businesses reduce their water consumption. For example, in NSW the *Every Drop Counts* Business Program and the *NSW Green Business Program*, and in Victoria the *Environment and Resource Efficiency Plans* (EREP). Similar programs exist for public facilities such as government buildings and schools which focus on conserving water, installing rainwater tanks or leakage control (Water for Life, 2008). Government, through the Australian Greenhouse Office, has also developed a number of conditions which must be used in leases taken by commercial tenants of Australian Government-owned property and for leases entered into by the Australian Government as a tenant of privately owned commercial property. These provisions, known collectively as the *Green Lease Schedule*, set out a number of duties of both landlord and tenant to use the building in an ecologically sustainable manner by cooperating to directly reduce energy and water consumption and to participate in measures to bring about household 'sustainability' (Christensen and Duncan, 2007).

For households, many programs have already been and are still being delivered to increase water efficiency (e.g., rebates for water efficient appliances such as washing machines, showerheads or outdoor watering equipment, rebates for the installation of rainwater tanks as well as an approval process to make newly built or renovated buildings compliant with the Building and Sustainability Index (BASIX) State Environmental Planning Policy (BASIX, 2006)). A similar example is the Enviro-Development-Scheme – a performance-based tool developed by the Urban Development Institute of Australia (QLD) to encourage developments incorporating efficient energy use, water conservation, biodiversity protection and use of environmentally responsible materials (UDIA, 2009). The City of Melville in Western Australia has put in place initiatives such as offering free 'Greywater Reuse Packages' to local residents. These packages offer information resources for the selection and installation of greywater reuse systems that use household wastewater and to irrigate garden areas (SMEC Australia, 2007). A similar greywater project, funded by the NSW Government, was commissioned in 2006 by Waterwise Systems® (see http://projects.waterwisesystems.com/the-project/introduction) to reduce domestic outdoor water use and promote the benefits of greywater to the Sydney community. The project *Greywater Gardens – A Community Demonstration* targets high water users in the Sydney Water area and is now showcasing their water savings—post greywater system installation—to the community through a range of promotional activities. This is a means of outsourcing the water efficiency burden on local government and empowers members of the public looking for alternative ways to conserve water.

In relation to the wider promotion of water use efficiency, a number of water efficiency labelling schemes currently exist within Australia. The National Water Efficiency Labelling and Standards (WELS) scheme, for example, requires mandatory registration and water efficiency labelling of products including clothes washing machines, dishwashers, toilets, urinals, taps and showers (GWA, 2003). A sister scheme to the WELS scheme is the Smart Approved WaterMark scheme (see http://www.smartwatermark.info/home/default.asp). The scheme is a national, not-for-profit program established by four peak industry bodies (including WSAA and AWA) and is supported by the Federal Governments' National Water Commission. Smart Approved WaterMark is Australia's labelling scheme for products and services that are helping to reduce water use outdoors and around homes.

According to the Victorian Central Regional Sustainable Water Strategy (DSE, 2005), substantial volumes of water can be made available to meet future needs by increasing the efficiency of existing residential water use patterns and ensuring that new uses are as efficient as possible. Continuing to reduce water consumption will defer or reduce the need to seek new water supplies, and will have significant economic benefits to both customers and the Government. Achieving this will require behavioural changes by all water users, and such changes can be influenced by factors such as: the pricing regime of water; regulation; education; and level of investment and financial support offered to make changes. A study commissioned by Melbourne Water (Howe *et al.*, 2005) also highlighted the important role for encouraging efficient domestic and industrial water use efficiency in adapting water supply management to climate change. It was suggested that such long term behavioural changes can be achieved through a range of levers including education and regulation (e.g., restrictions, incentives, pricing and rating schemes). History has shown that sustained water savings are best achieved through a complementary mix of the above measures (DSE, 2005).

Another important area to consider is the irrigation water used in agriculture. The agricultural sector is the largest single user of water in Australia, consuming some 65% of national water resources (ABS, 2006). Furthermore, in some places a substantial fraction of this water is lost as it moves through leaky distribution and irrigation networks and open aqueducts as it is distributed to farmers and applied to crops (Kiparsky and Gleick, 2003). Changes in irrigation technology (e.g., drip irrigation instead of spray or flood irrigation), switching to more drought resistant crops and cropping systems as well as establishing soil-moisture conservation practices are among the most discussed measures (Midgley *et al.*, 2005). There are also other agricultural climate change adaptation measures including varying sowing dates, cultivar coefficients (e.g., photoperiod sensitivity, duration of grain filling and maximum leaf area index) or soil profile properties (Tingem and Rivington, 2008); however, these fall outside the scope of this review.

Improved metering also has a vital role to play in adaptive water resource management by: assisting with the uptake of water efficiency practices; ensuring that water use will be consistent with water sharing plans and new licence conditions; aiding leak detection; and facilitating a water trading market (OECD, 2006; Water for Life, 2008). For example, a study using 1996 data found that in different parts of Canada, residential water use in metered municipalities was up to 37% lower than in those that did not (OECD, 2006). Additionally, French irrigators must be equipped with water meters wherever they exceed defined abstraction thresholds (CEC, 2007). Individual metering of water use in multi-unit apartment blocks has proved to be a successful measure to achieve substantial water savings compared to the usual bulk metering situation

(Water for Life, 2008). Similarly, the City of Melville in Western Australia, as part of its sustainable water management objective, has adopted the rationale "*if you can't measure it, you can't manage it*" and has subsequently been adding meters to its groundwater bores to enable monitoring and sustainable management of groundwater resource extraction (SMEC Australia, 2007). To provide for effective water management and adaptation to climate change all water abstractions need to be monitored through registration, even if permits are not required. Abstraction permits and registration allow governments to really account for and understand the volume and nature of water use in their country (OECD, 2006).

## 6 EXISTING WATER INFRASTRUCTURE

According to the 2008 *Garnaut Climate Change Review* (Garnaut, 2008b), Australia's urban water supply infrastructure is old, inadequate for current population levels, and is not designed to cope with changing climate conditions. At the same time, it has been recognised that the effectiveness of current water distribution networks in Australia will have to be maximised to meet future demands and that this could require major investments (ATSE, 2008). In the past, decisions on the capacity of new infrastructure were heavily based on historical climate data. For example, drought plans are commonly based on the worst drought conditions observed in the last 50–100 years. In today's climate, however, it is no longer appropriate to assume that past hydrological conditions will continue into the future and, due to climate change uncertainty, managers can no longer have confidence in single projections of future conditions (Kundzewicz *et al.*, 2007).

With an increased likelihood of sea level rise and extreme storm surges, the Australian coastline is under threat. Besides the danger these scenarios pose to the part of the population living very close to the coast, there is also an increased risk to existing water infrastructure. For example, many major wastewater treatment plants around Australia are positioned near the ocean at elevations close to sea level. Furthermore, there exists a large number of sewage pumping stations located at the bottom of catchments in our coastal cities which could be overwhelmed by seawater. Another possible effect of rising sea levels is subsidence of physical assets near the coast which include water infrastructure. For example, it has been predicted that subsidence along the Gippsland coastline between Port Albert and Loch Sport could be in the order of 0.5 m by between 2030 and 2060 (Sjerp and Charteris, 2008). As part of a combined adaptation response, scientists from RMIT are calling for the implementation of a buffer zone along the Australian coastline to restrict the coastline to uses that are dependent on a coastal location (ABC TV, 2008). Similarly, there is growing international emphasis on restricting development in natural floodplain areas, and future land-use policies that discourage development on floodplains will facilitate this adaptation (OECD, 2006; Hanak and Lund, 2008).

Water and wastewater infrastructure can have design and effective operational lives spanning many decades. As a result, their planning, design, construction and maintenance need to take into account projected climatic changes. As highlighted by the Allen Consulting Group (2005), infrastructure decisions with long payback periods and/or long term consequences (decades or greater) are most vulnerable to assumptions regarding both short term variation and long term changes in future climate. On one hand, decision makers may underestimate the risk associated with climate variability and climate change, leading to choices that fail to deliver appropriate levels of adaptation. Alternatively, the climate risk may be overestimated, resulting in over adaptation and perhaps the unnecessary use of resources. In a document outlining

Sydney Water's response to climate change (Allen *et al.*, 2008), a number of potential adaptation responses were identified following a 2008 qualitative risk assessment of its infrastructure and operations-related climate change risks (this qualitative assessment is to be followed up with a quantitative review in 2009). The adaptation responses identified were classified into six general categories:

1. **Material selection** – for infrastructure exposed to changing climatic conditions (based on the desired life expectancy of the infrastructure and maintenance regime). This involved investment in research for new materials and technologies for infrastructure maintenance and construction to reduce their environmental footprint, and enhance their resilience to climate change impacts.
2. **Design standards** – to cope with expected extreme events as well as accelerated degradation of materials and structures. This involves reviewing and updating design standards to ensure new projects can withstand projected climate changes. Relevantly, Lorenz *et al*. (2008) also highlighted the need for modification of existing infrastructure design standards to adequately address future climate related needs.
3. **Maintenance regimes** – to accommodate acceleration in the degradation of materials and structures. This involves enhancing funding, inspection and maintenance regimes for water and wastewater infrastructure to accommodate accelerated degradation from climate impacts.
4. **Technologies** – to meet required standard of performance or service under changed climatic conditions. This involves investment in alternative warning and information systems and power backup for extreme events, where water and wastewater network function would cease in the event of power failure.
5. **Planning** – at all levels to meet changed physical conditions arising from climate change. This includes:
    a. Continuing to conduct comprehensive and robust climate change risk analyses on a project-by project basis and use the information to inform site selection, planning, design and maintenance regimes.
    b. Continuing to review existing emergency response plans, and existing business continuity plans to integrate detailed responses to catastrophic events that may impact on the water and wastewater network.
    c. Ensuring inbuilt redundancies in the water and wastewater network to enable sustainable water supply and treatment.
6. **Cultural change** – to raise the awareness of potential climate change risks, and the need to adopt and implement revised approaches and protocol for materials, design standards, technologies and planning. This involves making proactive decisions regarding information to inform standards at the earliest possible time and integrate these decisions into the business through standards, regulations and change management planning.

From 1910 to the mid- to late-1990s, heavy rainfall events have increased in areas of eastern Australia but decreased in the southwest (Hennessy *et al.*, 1999; Haylock and Nicholls, 2000). Changes to the predicted number and intensity of storm-flow events (IPCC, 2007b) may require modifications to stormwater harvest/disposal systems. The City of Melbourne (CoM) has identified that the expansion of its stormwater harvesting and reuse systems constitutes one of the highest value, highest priority adaptation actions that can be undertaken in response to climate change (Lorenz *et al.*, 2008). According to Lorenz *et al*. (2008), the high value of this adaptation option for the CoM was based on a number of factors:

- Harvesting and re-using stormwater effectively works to reduce likelihood and consequence of many risks, and addresses impacts and implications central to controlling the cascading effect of consequences. Harvesting and reusing stormwater:
    - Reduces the likelihood of urban flash flooding in major rainfall events, which works to control multiple cascading consequences.
    - Diversifies the water supply to CoM, reducing any impacts of drought and low rainfall, most notably in the maintenance of parks, gardens and sports fields.
    - Helps to cool the urban environment by the proliferation of urban water bodies, contributing to control of several extreme heat related risks (when combined with greater efforts to tackle the urban heat island affect).
    - Improves water quality for rivers, contributing to greater river health and resilience of biodiversity in periods of low flow.
    - Can provide new, high quality amenity values through the creation of urban water features.
- The management of stormwater is one of the areas of greatest local government control. Risks relating to stormwater management are among the most foreseeable for local government, and hence potentially carry the greatest liability in relation to reasonable adaptation that is required to manage the impacts of climate change.

Other known water infrastructure adaptation measures can include enhanced water catchment management as well as upgrading existing water supply and sewage networks. One important measure to cope with more extreme weather events is to have more and bigger water storage facilities (e.g., stormwater detention tanks, wetlands, and also aquifer storage facilities) to cope with increased inflow and infiltration into wastewater networks (SMEC Australia, 2007; Pittock, 2008). These urban-based drainage systems should be linked to catchment based flood management to avoid impacting on other areas in the catchment. New wastewater systems should also be designed to prevent overflows from forecast wet weather events (SMEC Australia, 2007). Another measure to adapt to more extreme wet weather events is ensuring an ongoing and periodic review of sewerage system strategies and operations to address hydraulic constraints and overflow risks. Sewer rehabilitation and thorough cleaning regimes should also be adopted to ensure optimal infrastructure performance (SMEC Australia, 2007). One of the ongoing problems, however, is that forecasting peak flows under different climate scenarios remains highly uncertain because of difficulties in projecting the details of regional precipitation patterns. According to Kiparsky and Gleick (2003) it may be valuable to re-evaluate design and management practices of existing water infrastructure, with the goal of updating the information used for these purposes; in particular, more frequent updating of statistics on rainfall and runoff timing, frequency, and magnitude would be valuable.

# 7 ALTERNATIVE WATER SOURCES

The concept of *water security through supply diversity* has been highlighted as the way forward, particularly for Australia (AwwaRF, 2008). As traditional surface and ground water supplies become stressed, alternative evolving technologies such as desalination, water recycling and reuse, and weather modification offer opportunities for augmentation of existing supplies and increased supply efficiency (WGA, 2008). The list of alternative water sources is diverse and includes:

- Accessing freshwater supplies from further a field (water from rivers, lakes, canals, etc.);
- Groundwater prospecting and harvesting;
- Groundwater recharge / aquifer storage and recovery;
- Desalination;
- Recycled wastewater for irrigation and other non-potable uses as well as indirect and direct potable recycling;
- Rainwater harvesting;
- Weather modification;
- Stormwater harvesting, treatment and reuse.

Ultimately, a balance of the above suite of supply sources is needed that includes a range of less-climate-dependent water sources. There is also a parallel need to define appropriate trigger levels for the commissioning of new water supply investments as the future impacts of climate change are realised (NWC, 2010).

# 8 GUIDELINES, POLICIES AND MARKETS

For more than a decade, Australia's urban water sector has experienced extensive economic reform under the 1994 Council of Australian Governments (CoAG) Water Reform Agenda, and more recently through the 2004 National Water Initiative (Marsden and Pickering, 2006). One of CoAG's major achievements was to commit governments to separating the responsibility for water resource management policy, standard setting, regulatory enforcement and service provision from the agencies which actually delivered and sold water to customers. Despite these major reforms and their benefits, many urban centres are facing adverse climatic changes that are affecting their ability to maintain the correct balance between consumptive demand and reliable supply (Marsden and Pickering, 2006). The recent drought (and associated supply shortfalls) as well as future predicted climate change-related reductions in rainfall in some Australian regions, focuses attention on the need for rigorous long-term water resource management, water conservation and infrastructure planning (Marsden and Pickering, 2006).

Chapter 15 of the Garnaut Review (Garnaut, 2008a) discusses how the development of broad and flexible markets for water will be important in spreading and transferring risk to those best placed to deal with it and also dispersing concentrated risks across a wide base of industries, communities and regions. Markets provide the most immediate and well-established avenue for addressing many of the uncertainties posed by climate change, and will also provide the most efficient mechanism for dissipating the future price impacts of an Australian emissions trading scheme (Garnaut, 2008a), and according to the recommendations of the *Garnaut Review*, such markets may require increased policy attention in the future. Open, robust water markets are expected to provide numerous benefits to individuals, communities, the environment and the economy more broadly (The Allen Consulting Group, 2007).

Water trading, and the benefits it can deliver, has been a centrepiece of water reform in Australia and has proven effective in reallocating scarce water supplies to the benefit of both buyers and sellers (The Allen Consulting Group, 2007). While water trading and the use of price signals have been in place in some parts of the rural sector for over 20 years (e.g., extraction of in-stream flows), access to groundwater and surface flow is less regulated (Garnaut, 2008a). Artificial jurisdictional boundaries have also resulted in restrictions on trading between rural consumers, and have largely prohibited trading between the rural and urban water sectors. While this has been done to manage the pace of the transition that a region exporting water undergoes, it has resulted in a distorted price signal in some areas, and no price signal in others. This effect has also occurred in the urban sector and been compounded by the absence of a competitive water market (Garnaut, 2008a).

The expansion and opening of water markets would allow the emergence of the lowest-cost supply options and the optimal balance between reduction of use and expansion of supply. According to Garnaut (2008a), an effective water market could minimise *ad hoc* infrastructure investment decisions, promote optimal timing of large infrastructure investments and assist in bringing a broader range of supply options to the marketplace. The 2008 *Garnaut Review* endorses a set of common principles put forward as a way of delivering effective long-term management of Australia's water resources and assist in the adjustment to a new climate future:

- Water rights need to be clearly defined, with exclusive ownership, and be separable from other resources, such as land;
- The total quantity of water rights allocated in each catchment and over time needs to be flexible enough to accommodate new scientific information on climate change and sustainable water use;
- Security levels for water rights need to be defined in a way that is consistent with the variability and uncertainty of aggregate supplies;
- Clearly defined rules are needed to set the boundaries of the market and acceptable behaviour by market participants, and reduce transaction costs by providing greater certainty;
- Reliable and timely information is needed to allow buyers and sellers to make informed decisions;
- Clear administrative processes are necessary for effective trade and to support the enforcement of the trade;
- Arrangements must secure low transaction costs compared to the value of the trade, with costs known in advance;
- The market should have few limitations on who can participate.

Garnaut (2008a) proposes that with a well-designed and comprehensive water market in place, price signals will reflect the scarcity value of water across rural and urban Australia; such that households, businesses and other consumers will then modify their water use patterns accordingly. Pricing mechanisms which reflect the true value of water can also provide incentives for all consumers to use water more efficiently (Midgley *et al.*, 2005; SMEC Australia, 2007). As highlighted by Hanak and Lund (2008), water rates are generally quite a small fraction of total household income, and there is considerable scope for improving rate structures to increase incentives for water conservation—a key adaptation tool. In light of probable future increases in consumer costs of service, sustainable water strategies developed in the United States have suggested that water utilities will need to adjust rates to reflect the life-cycle costs and climate-related risks associated with water supply; however, a transparent planning and rate setting processes that includes stakeholder/public education and participation should be adopted to ensure public acceptance of new rate structures (WGA, 2008). In Australia, the National Water Initiative calls for the use of independent bodies to set or review water prices (or price setting processes) for monopoly water storage and delivery services provided by water and wastewater service providers.

Other innovative policy reform measures recently identified by the National Water Commission (NWC, 2010) include:

- Unbundling water entitlements from land title;
- Issuing shares, not volumes, of available water – in perpetuity;
- Offering different levels of water security – at different prices;
- A major voluntary buy-back program for the environment to expand economic options for water users;
- Independent public assessment of governments' reform achievements; and
- Providing Federal fiscal incentives for reform by the States;
- Policies that facilitate, not resist, adjustment;
- Further initiatives to bridge the lingering policy–science gap;
- Policies that maximise certainty for investment (e.g., policies that maximise security of supply for irrigators) and policies that take into consideration diversity of land use and diversity of local processing and other employment opportunities.

## 9 SELECTION OF ADAPTATION APPROACHES AND ADAPTIVE MANAGEMENT

After taking into account confidence levels and data uncertainty, and following the selection of adaptation approaches, adaptive management is likely to be an effective method for implementing those approaches. Adaptive management emphasises managing based on observation and continuous learning, and provides a means for effectively addressing varying degrees of uncertainty in our knowledge of current and future climate change impacts (CCSP, 2008). Adaptive management to address climate change issues is an iterative process that involves the consideration of potential climate impacts, the design of management actions and management experiments that take those impacts into account, monitoring of climate-sensitive species and processes to measure management effectiveness, and the redesign and implementation of improved (or new) management actions (CCSP, 2008). The adaptive management process also includes building the necessary local and regional capacities and the establishment of appropriate planning tools (Sjerp and Charteris, 2008).

In order to facilitate adaptive management approaches and to make informed and consistent decisions, it is a prerequisite for government to provide a clear policy direction. Policies have to be flexible so that approaches can be adjusted as knowledge on the effects from climate change improves. However, since the threats from climate change on water infrastructure and supply are real and significant, important decisions will have to be taken now. The adaptive management approach should be both pro-active, i.e. involving planning for change and increasing community awareness through the engagement of stakeholders, and re-active which involves actually responding to changes as they occur and can comprise of the following options:

- Doing nothing;
- Retreating from affected areas;
- Accommodating the change; or
- Protecting (or defending) an area against the impact of the change.

The NSW Government has recognised the need for adaptive approaches to policy principles. For example, the recent Draft Sea Level Rise Policy Statement (DECC, 2009) specifically promotes an adaptive, risk-based approach to managing the impacts of sea level rise. This adaptive approach recognises that projections of sea level rise will be continually refined as new information comes to hand, and also that this continuous improvement in the accuracy of sea level rise projections is expected to continue. The adaptive risk-based approach put forward in this policy statement recognises that there are potentially significant risks from sea level rise and that the accuracy of sea level rise projections will improve over time. The NSW policy adopts two benchmark values for sea level rise (an increase above 1990 mean sea levels of 40 cm by 2050 and 90 cm by 2100) whilst recognising that Government will need to periodically review these planning benchmarks based on updated information, such as the release of future IPCC assessment reports.

Recent Australian research has identified the lack of adaptability as a gap in traditional strategic planning for addressing flood risk associated with climate change (Mirfenderesk and Corkill, 2009). Some public institutions, for example, do not have adequate flexibility and promptness to enable adaptive changes to high-level strategic plans. An adaptive strategic plan should have adequate flexibility, promptness and responsiveness to allow itself to adapt to new realities as they emerge and can sustain itself and remain relevant in a changing environment. Most research on the topic of adaptation to climate change has been focused on developing strategies that offer adaptive solutions to pressing problems such as flooding. Something that has attracted less attention is the issue that the strategic plans themselves (or in a sense the decision-making framework) need to be equally adaptive (Mirfenderesk and Corkill, 2009). To enable government institutions to become more responsive to change, Mirfenderesk and Corkill (2009) identify the need for a strategic decision support system (SDSS) decision-making framework that allows new scientific findings to be converted into new policies in a short period of time.

## 10 SUSTAINABILITY OF ADAPTATION MEASURES

In a carbon-constrained world, ignoring the sustainability of adaptation measures will be expensive in the short term and counterproductive in the long term. While many adaptation measures are mentioned in Section 4 of this report, some (e.g., desalination) have the potential to contribute significantly to the underlying cause of climate change and, therefore, face both public resistance and additional cost where for example carbon offsets are required. Increases in catchment storages may also contribute to a number of problems identified in Section 3. For this reason, the selection of adaptation strategies needs to be informed not just by simple cost–benefit analysis, but within a sustainability framework that incorporates multiple objectives and appropriate stakeholder engagement (Lundie *et al.*, 2006). The Water Environment Research Foundation (WERF) in the United States published a comprehensive framework for developing and implementing sustainable water resources management (SWRM) plans from an interdisciplinary perspective, and to demonstrate how this framework can lead to prolonged water resources (WERF, 2006). The SWRM emphasises the importance of not only identifying the elements that should be considered as part of any management plan, but also their interactions. The elements identified were: hydrology; ecology; engineering; economic; social/cultural factors; and legal/political/institutional factors. SWRM must, therefore, address each of these sectors individually, as well as the links and tradeoffs among them.

Both adaptation and mitigation can help to reduce the risks of climate change to nature and society; however, their effects vary over both time and space (Parry *et al.*, 2007). Inter-relationships between adaptation and mitigation can exist at each level of decision-making, and the analysis of these inter-relationships may reveal ways to promote the most effective implementation of both adaptation and mitigation actions (Parry *et al.*, 2007). In general, there is a need for an improved understanding of the inter-relationship between adaptation and mitigation strategies in order to enable us to minimise the potential negative impacts of adaptation actions whilst taking advantage of potential positive impacts from climate change. For example, because mitigation options may have deleterious ecological consequences on local to regional scales and adaptation options may also have associated greenhouse gas (GHG) emissions and negative environmental impacts, it will be important to assess potential tradeoffs between the two approaches and to seek strategies that achieve synergistic benefits (CCSP, 2008). The Californian water sector, for example, has recognised the need for a greater recognition of the links between adaptation and mitigation (Hanak and Lund, 2008). The water industry in the United Kingdom has also emphasised the need for greater recognition of the links between adaptation and mitigation by policy makers, regulators and other key decision-makers (Water UK, 2008). More attention needs to be given to the impacts of proposed adaptation strategies (e.g., water/energy efficiency measures, sustainable drainage systems, catchment protection and management and the promotion of policies that do not potentially increase emissions) (Water UK, 2008).

In order to be able to assess the relative impacts of adaptation options, there is first a need for accurate and relevant data on water industry products, processes and services. This data need has been recognised for Australia and is being addressed through the Australian Life Cycle Inventory Database Initiative (AusLCI). A joint project between the Australian Life Cycle Assessment Society (ALCAS) and CSIRO, AusLCI seeks to provide a national, publicly-accessible database with easy access to authoritative, comprehensive and transparent environmental sustainability information on a wide range of Australian products and services. AusLCI will enable industry organisations to more easily and accurately perform product- and process-based sustainability assessments, and will also provide a consistent, peer-reviewed, national baseline for comparing the environmental impact of their products and services. In relation to water industry sustainability data, work is soon to commence on an ARC Linkage project (ARC LP0991017; Chief Investigators Peters and Lundie) to collect life cycle inventory data for a limited number of priority chemicals used by the industry; however more research is needed to collect data for other industry products and processes. At the same time that there is a need for data to enable sustainability assessments of future adaptation actions, the UK water industry has emphasised that there is a primary need for further collaborative research into the water-related impacts of climate change in order to reduce the underlying uncertainty associate with climate change adaptation measures (Water UK, 2008). Toward that end, new approaches for assessing (or evaluating) uncertainty with quantitative and qualitative management methods are also needed (CCSP, 2008).

## 11 PAST, CURRENT AND PLANNED RESEARCH ACTIVITIES

During the review process, a number of past, current and/or planned research activities in the area of water-related climate change adaptation were identified. These research activities have been reviewed, consolidated and the full detail of these are presented in Appendix A. Table 2 below contains only the detail of the administering organisations and the source of referenced material.

**Table 2.** List of administering organisation and information source for past, current and/or planned activities in the area of water-related climate change adaptation research.

| Administering organisation | Referenced source | URI |
|---|---|---|
| Sydney Water Corporation | Allen *et al*. (2008) | |
| CSIRO Transport & Infrastructure Flagship (Utilities Program) | | http://www.csiro.au/science/Infrastructure-Technologies.html |
| CSIRO Climate Adaptation National Research Flagship | | http://www.csiro.au/org/ClimateAdaptationFlagship.html |
| Federal Government National Water Commission | Australian Government, (2009c); Australian Government (2009a) | |
| Federal Government (*National Water Information System*) | Australian Government (2009b) | http://www.environment.gov.au/minister/wong/2009/mr20090605.html |
| University of New South Wales (*CITY FUTURES* research group) | | http://www.fbe.unsw.edu.au/cf/ |
| RMIT University Climate Change Adaptation Program (*Global Cities Research Institute* and *Urban Infrastructure* research program) | | http://gc.nautilus.org/gci; http://www.nautilus.org/mailman/listinfo/adaptnet; http://www.global-cities.info/urbaninfra |
| Australian Greenhouse Office, Department of Environment and Heritage | AGO (2006) | |
| Australian Government Department of Climate Change | Preston *et al*. (2008b) | |
| Victorian Government | | www.greenhouse.vic.gov.au/index.htm |
| eWater CRC | Rassam and Werner (2008); Reid *et al*. (2009); Turner (2009) | http://www.ewatercrc.com.au/ |
| Water Research Foundation (*Climate Change Strategic Initiative* and *The Climate Change Clearinghouse* and *Climate Change Knowledge* area) | | http://www.waterresearchfoundation.org/theFoundation/ourPrograms/ResearchProgramSIClimateChange.aspx; www.theclimatechangeclearinghouse.org; http://www.werf.org/AM/Template.cfm?Section=Climate_Change |
| United States Environmental Protection Agency (*Sustainable* | USEPA (2006) | http://www.epa.gov/waterinfrastructure/; www.epa.gov/water/greeninfrastructure; |

| | | |
|---|---|---|
| *Infrastructure Initiative*, *Green Infrastructure Initiative* and *Water Resource Adaptation Program*) | | http://www.epa.gov/nrmrl/wswrd/wqm/wrap/ |
| US Department of Water Resources | DWR (2008) | |
| California Energy Commission (*Public Interest Energy Research* program) | Vine (2008) | |
| California Climate Change Research Centre (water-related impacts and adaptation research) | OECD (2006) | http://www.energy.ca.gov/publications/searchReports.php?pier_sub=GCC |
| US National Center for Atmospheric Research – Water Research Foundation partnership | | http://www.isse.ucar.edu/awwarf/ |
| American Water Works Association Research Foundation (now Water Research Foundation) | AwwaRF (2008) | |
| | | |

## 12 IDENTIFIED ADAPTATION RESEARCH NEEDS

Given the extensive range of likely climate change-related impacts on water resources, the potential for research topics in this field has been recognised as being almost limitless (USEPA, 2008). During an in-depth review of the relevant literature, a number of research needs were identified, summarised and the detail of these are presented in Appendix B. It should be noted that Appendix B contains a preliminary (and by no means exhaustive) list of research needs and is not ranked in terms of relative priority; rather a range of research needs are put forward in the general areas of water infrastructure, water resources and water supply.

### 12.1 KEY AREAS FOR FUTURE ADAPTATION RESEARCH FOCUS

Following the review process, several key priority research themes surfaced repeatedly as areas for future research effort. In general these were:

- **Data needs**: since infrastructure decisions have long-term implications, it is important that such decisions are made with the most relevant information at hand, including the most accurate regional projections of temperature and precipitation. More data is, therefore, needed to reduce uncertainty of climate models and to detect and monitor the effects of climate change as they occur. This data also needs to be made more broadly available to all stakeholders, since broadening access to available observational data is a prerequisite to improving our understanding of the ongoing changes. There is a need to extend and upgrade monitoring programs for critical variables such as temperature, precipitation, evapotranspiration, wind, snow level, vegetative cover, soil moisture and stream flow. In this respect, increased monitoring efforts are needed to collect the hydro-meteorological data on the ground, since weather stations around Australia are relatively sparse and the interior of the continent is particularly poorly represented.

  Similarly, improved observations of atmospheric conditions are also needed to help define and better understand the mechanisms of the underlying atmospheric processes that drive seasonal and geographical distribution of rainfall. This will help climate modellers to better project future rain and snow patterns on a regional scale and will allow for more accurate assessments of short- and long-term water supply yields (this will in turn drive more reliable future studies of likely sustainable yields). More detailed information on future water quality and quantity is also needed in order to facilitate better water planning and management. In general, progress in research depends on improvements in data availability – calling for enhancement of monitoring endeavours worldwide, addressing the challenges posed by projected climate change to freshwater resources, and reversing the current trend of shrinking observation networks (Kundzewicz *et al*., 2008). Data on water use, water quality, and sediment transport are also urgently needed.

  In Australia, water data and information required to support sound management decisions is gathered and held by numerous agencies, authorities and corporations in a multitude of formats. Hence, there is an identified need for a central data repository to facilitate access to water and climate data. This need should ideally be addressed via the ongoing development and rollout of the Australian Water Resources Information System (WRIS), with the goal of the System being to facilitate better management of Australia's water resources by providing a national, authoritative water data and information resource—giving users access to relevant and recent Australian water data. The recently developed Water Data Transfer Format (WDTF) also provides the Bureau of

Meteorology with the means to more efficiently collect and process the many millions of water resource information data files supplied to them each year, requiring a standards-based information model and transfer format in order to accept water information submitted electronically. The web-based WDTF has been developed to allow data providers to efficiently deliver water observations data to the Bureau in a format that is more easily loaded into the WRIS.

- **Future climate scenarios, downscaling of climate models and uncertainty estimates for model outputs**: One of the difficulties in using climate model projections to support decision-making is the low spatial resolution from general circulation models (GCMs). These models project climate change on grid areas that are generally too coarse to be useful for catchment-level water resource planning and decision-making. Spatial downscaling refers to the process of translating climate projections from coarse resolution GCMs to finer spatial resolution regional climate models (RCMs) that are considered more useful for assessing local and regional climate change impacts. There is an overwhelming need for downscaling of GCMs to produce RCMs that can provide regional climate data that state- and catchment-level water resource managers can use to make local predictions of climate change impacts and trends relevant to their water resources. It is generally recognised that there is a need for climate models at the country, region, and provincial level.

  More work is also needed to enable accurate estimates to be made of relative certainty or uncertainty regarding future climate change predictions based on local and global climate model outputs—'uncertainty' and 'probability' need to be clearly explained for policy makers. There is also a general need for a clearer understanding by water managers of how to conduct future vulnerability assessments. Existing climate and planning scenarios based on *stationarity*—the idea that natural systems fluctuate within an unchanging envelope of variability—are outdated and no longer relevant. Planning activities for water supplies are also currently based on historical climate records, and considering the predictions in future climate variability, such planning may create water supply systems that are unreliable. It is no longer appropriate to assume that past hydrological conditions will continue into the future and, due to climate change uncertainty, managers can no longer have confidence in single projections of future conditions (Kundzewicz *et al*., 2007).

  The basis for all climate change adaptation research should be plausible climate scenarios and associated quantitative impact scenarios for assessing the vulnerability of water resources and infrastructure (Pittock, 2008). The development of adequate simulation methodologies remains a principal research challenge in the presence of uncertainty, and since impacts vary significantly for different regions, these analyses have to take a localised approach. Equally, seasonal as well as medium- and long-term effects have to be distinguished and more research is required to achieve this. In addition to the need for new scenarios in relation to regional climate change outcomes, new scenarios are also needed for use by water planners and managers in relation to: future water (and energy) use patterns; long-term sea level rise projections; climate change-related water resource and infrastructure impact scenarios (for vulnerability assessments).

  Considering that current scientific consensus suggests that extreme weather events (e.g., very hot and very cold days and spells, droughts, extreme rainfall, extreme winds and storm surges) are likely to increase in intensity in the future, work is also needed to evaluate the various water supply system vulnerabilities under multiple and compounding extreme events. Determinations of critical infrastructure that may be susceptible to compounding or cascading impacts during extreme climate events need to be made (e.g., implications of multiple events such as storm surge, wave action and extreme rainfall on coastal infrastructure, coastal erosion and flooding) and plans formulated regarding how these impacts may best be avoided. At the same time, there is a need to research alternative infrastructure options to minimise the potential exposure to cascading failures. Realistic multiple event scenarios are, therefore, also needed in order to be able to analyse and assess infrastructure vulnerability and service supply risks under future compounding extreme event situations.

- **Water end use efficiency and demand management**: increasing water use efficiency and reduced user demand for water offers excellent potential for combined water and greenhouse gas emissions savings. Research into both the technological and public awareness and implementation sides of water use efficiency and demand management measures is needed. Another important area to consider is the irrigation water used in agriculture. The agricultural sector is the largest single user of water in Australia and in some places a substantial fraction of this water is lost through leaky distribution and irrigation networks and open aqueducts during on-farm distribution processes. Research into changes in irrigation technology (e.g., drip irrigation instead of spray or flood irrigation), switching to more drought resistant crops and cropping systems as well as establishing soil-moisture conservation practices are among the most discussed research areas. Improved metering also has a vital role to play in adaptive water resource management and efficient end use by: assisting with the uptake of water efficiency practices; ensuring that water use will be consistent with water sharing plans and new licence conditions; aiding leak detection; and facilitating a water trading market.

- **Water and energy**: Water and energy are intrinsically linked: energy generation uses water in a variety of ways and similarly, energy is consumed in the provision of water (e.g., extraction, treatment and distribution). Water and energy are also inextricably linked on a broader global scale with the issues of climate change and water and energy security. A holistic approach is needed to energy and water management that considers all of these linkages and looks for creative solutions to co-optimise the efficiency of power and water provision in a synergistic manner. In Australia, WSAA (2009b) has recognised that an improved understanding of the water–energy nexus is critical for moving forward so that investment can be directed to where the biggest emissions reductions can be realised. This 'water–energy' overlap also highlights the need for the energy and water sectors to work toward joint solutions rather than as individual sectors, and requires water industry collaborations reaching "outside the water box". A greater understanding of water–energy interconnections could be used to inform the design of both water and energy policies in the future. While several water–energy models already exist internationally across both the energy and water sectors, limitations of current models reduce their effectiveness for policy analysis (Marsh and Sharma, 2006). A more integrated model that links water and energy industries with the economy at large (e.g., based on input–output analysis) may be better suited to assist policy makers in making more informed decisions on issues affecting these industries. The possibility of expanding the water–energy nexus to *water–energy–food* should also be investigated. Given the vulnerability of water utilities to disruptions in reticulated power supply, it is suggested that there should also be continued exploration of the potential for 'cogeneration' during water and wastewater treatment operations in order to reduce future reliance on centralised power.

- **Water pricing and water markets**: There is a need to develop new water rate structures that wholly embrace 'full cost' pricing approaches to reflect the true cost of water and water service provisions, and that can also take into account the future changes in patterns of water use, different water sources, etc. There is also a recognised need in Australia for detailed research in order to determine how consumers are likely to behave in the face of rapidly increasing water prices in response to future climate change-related changes in the nature and availability of water supplies (this question may be partly addressed through an up-coming community survey to come out of the CITY FUTURES Research Centre at The University of New South Wales). Other measures such as the expansion of water trading, economic incentives (e.g., new metering and pricing approaches) to encourage water conservation, water allocation reforms and reallocation of water to higher value uses also need to be explored. The development of broad and flexible markets for water will be important in spreading and transferring risk to those best placed to deal with it and also dispersing concentrated risks across a wide base of industries, communities and regions. Markets are suggested as providing the most immediate and well-established avenue for addressing many of the uncertainties posed by climate change, and will also provide the most efficient mechanism for dissipating the future price impacts of an Australian emissions trading scheme (Garnaut, 2008a) and such markets may require increased attention in the future. Open, robust water markets are also expected to provide numerous benefits to individuals, communities, the environment and the economy more broadly (The Allen Consulting Group, 2007).
- **Policy and regulatory reform**: The Australian water industry has undergone over a decade of reform since the introduction of the Water Reform Framework in 1994, resulting in changes to the structure, ownership and regulatory arrangements of the industry. More recently, the 2004 intergovernmental National Water Initiative was signed in an attempt to 'refresh' the reform program, with the overall aim of the initiative being to develop a nationally-compatible, market-, regulatory- and planning-based system for managing surface and groundwater resources (AGO, 2004). According to a recent Position Paper *Vision for a sustainable urban water future* published by the Water Services Association of Australia (WSAA, 2009a) new approaches to environmental regulation of the urban water sector will be required in the future. At present, most conventional environmental regulations are single-issue based, such as point-source regulations on effluent water quality standards. While recognising the benefits of improved environmental regulation, the adoption of environmental sustainability principles requires a more holistic and integrated regulatory approach. It is suggested that new approaches should recognise the need to balance competing environmental, social and economic outcomes in partnership with the water industry. New regulatory approaches should also weigh up any incremental benefit of increased effluent quality standards against the cost of incremental increases in wider environmental burdens, such as greenhouse gas emissions, required to achieve such standards; calling for the adoption of a 'life cycle' approach to avoid perverse outcomes. For example, it is recognised that there is a need for investigating the scope for reform of environmental regulations such as the 'single-issue-based' point-source regulations on wastewater quality standards (with the aim of possibly relaxing these regulations). The adoption of sustainability principles necessitates a more holistic and integrated approach to be taken by environmental regulators so as to avoid over-treatment of wastewater for protection of the local environment at the expense of the wider environment (WSAA, 2009a).
- **Adaptive management and adaptation under uncertainty**: There are major uncertainties in quantitative projections of changes in hydrological characteristics for catchments. This significant source of uncertainty poses problems for adaptation

planning, particularly for large infrastructure projects that are vulnerable to under or over design. Laws and regulations are not stationary; just as the physical environment adapts to climate change, laws and regulations must also adapt. Traditional strategic planning approaches for addressing climate change risks do not have adequate flexibility and promptness to enable adaptive changes to high-level strategic plans. Adaptive strategic planning and adaptive management approaches are, therefore, needed if government institutions are to become more responsive to the impacts of climate change.

Recent Australian research has identified the lack of adaptability as a gap in traditional strategic planning for addressing flood risk associated with climate change. An adaptive strategic plan should have adequate flexibility, promptness and responsiveness to allow itself to adapt to new realities as they emerge and can sustain itself and remain relevant in a changing environment. Most research on the topic of adaptation to climate change has been focused on developing strategies that offer adaptive solutions to pressing problems such as flooding. Something that has attracted less attention, however, is the issue that the strategic plans themselves (or in a sense the decision-making framework) need to be equally adaptive. To enable government institutions to become more responsive to change, there is an identified need for a strategic decision support system or decision-making framework that allows new scientific findings to be converted into new policies in a short period of time. Additional research on methods of adaptation in the face of climate change uncertainties (e.g., 'resilience' over 'resistance' strategies, or broadening the scope of climate scenario-based water resource impact assessments) is also needed.

Fane and Patterson (2009) suggest the following strategies as water service providers' current or potential response to climate change-related uncertainty:

1. 'Plan for certainty' – Based in hypothetical 'worst-case' scenarios that use repeated drought sequences projected indefinitely into the future. To attempt to avoid further rainfall-related uncertainty, climate-independent supplies are favoured (potable and non-potable reuse, desalination). Such an approach has in most cases been a response to a perceived climatic structural shift.
2. 'Plan for uncertainty' – Contingency measures and trigger points for new supplies. This involves planning for an emerging scenario that includes a 'worst-case' but without building for it up-front until certain defined trigger points are met. This approach implies the application of a form of adaptive management and requires careful planning in terms of lead times and preparatory works. For example it will take so many months to build a desalination plant but only once it has been preapproved, predesigned and the site for it has been prepared. Such an approach has a focus on contingency measures of flexibility in terms of timing and potentially also scale of implementation. In a similar way to water restrictions, readiness options are characterised by trigger points based on existing systems capacities. This is a risk analysis approach that incorporates flexibility in decisions and accounting for new information to characterise uncertainty over time.
3. 'Build for resilience' – This is an approach that would encourage the development of an urban water system that is resilient to climate and other changes through having a wide range of public and privately owned of supply at varying scales, ranging from household rain tanks or greywater systems to local reuse to

centralized supplies. To take such an approach requires a long period of adjustment and is, therefore, not focused on short-term supply risk.

- **Water quantity and quality**: Much of prior research has evaluated uncertainties in the quantities of water supplies over relatively short periods during or immediately after a specific drought event, and has usually focused at the scale of a single watershed or at a hierarchy of locally nested watersheds. There is a need for more long-term, spatially integrated research at regional, trans-regional, or continental scales to address the impacts of extreme climate variability on ecosystems and water supplies. Uncertainties associated with diminished water quality (as well as quantity) are very likely to increase as a result of future climate change-related alterations to local hydrology. In general, higher temperatures and increased rainfall variability are predicted to increase the intensity and frequency of water-borne disease in Australia (Pittock, 2003). Research is needed to investigate the effects of changing temperatures and runoff patterns on aquatic ecosystems, sedimentation and contaminant deposition rates, and chemical and biological processes and contaminants. The effects of climate change on geographical distribution and regional transmission of some pathogens (e.g., Ross River Virus) also remains unclear (Tong *et al.*, 2004; Tong *et al.*, 2008; Woodruff and Bambrick, 2008).

  Current thinking suggests that regional and global climatic change may lead to a general increase in the prevalence of harmful cyanobacteria (Wiedner et al., 2007; Paerl and Huisman, 2009), with toxic algal blooms likely to become more frequent and longer lasting in Australia as a result of climate change (Hennessy *et al*., 2007). Uncertainties still remain relating to the likely impacts of climate change on the incidence and severity of cyanobacterial blooms in Australia, and more research into the projected effects of climate change on the occurrence of cyanobacterial blooms (both toxic and non-toxic) in water supply networks and the downstream effects of these blooms in terms of resulting taste and odour compounds is required. Research is also needed to understand the impacts of climate change-related catchment and water quality alterations on downstream water treatment process efficiency. Parallel modifications to water quality standards and guidelines will also be a necessity in response to climate change; however, potential conflicts with stakeholders will need to be considered during the reform process. Incidentally, work on the current round of revisions to the Australian Drinking Water Guidelines is nearing completion, with a number of draft items already at the technical editing stage (WQRA, 2009).

- **Collaboration, communication and education**: Climate scientists are generally focused on answering science-related questions and not solving planning problems. There is a need for cross-disciplinary interaction between researchers and also for improved communication between scientists and water managers/policy makers. The feasibility of establishing some form of information broker/translator utility to act as the intermediary between climate scientists and water practitioners, and to facilitate discussion on practitioners' needs as well as involving practitioners in the development of relevant research questions, should be investigated. There is a parallel need for climate change adaptation education of water industry members and awareness building of the need for and nature of future adaptation measures in the wider community. Knowledge transfer and capacity building within the water industry will empower water managers and other stakeholders with the necessary skills to enable: better management of water resource allocations; plan for and monitor floods and droughts; develop more accurate long-term supply–demand forecasts; and more appropriately evaluate and integrate alternative future climate scenarios into future water management activities. The creation of information does not inherently guarantee its optimal uptake by end-users, such that information must be prepared and released in a form that is usable by its intended beneficiaries. Correcting gaps in the public knowledge base rests not just on the research effort itself, but also on the interpretation and presentation of scientific findings in a meaningful and relevant form that can be factored into local risk management and decision-making processes. For example, water managers need to have climate model outputs in useful and interpretable formats amenable to incorporation into resource management models and available at scales (regional and catchment scales) useful for resource management activities.

The Draft Report on the Californian climate change adaptation strategy (NRA, 2009) highlights a general need for public outreach and educational campaigns to communicate information about climate change impacts and risk reduction strategies to the wider community. There is growing understanding that climate change is happening now and that it is being driven by human activities; however, there is less public knowledge of current and projected climate impacts, who and what systems are at greatest risk and the actions necessary to reduce these risks. The report suggests that a well-developed campaign could not only work to ensure transparency in decision-making, but could also potentially change community behaviour. On such communication tool suggested by the report was the development of an internet-based map that would allow individuals to assess climate change impacts and strategies for their region, and a climate change adaptation protocol (depending on available resources) to allow communities to initiate a preliminary screening for climate change risks. Furthermore, climate change is a global problem and there is a subsequent need to research the most appropriate mechanisms and tools for sharing of the knowledge base and experience of developed nations with low and middle income countries (IWA, 2009).

Some additional general research questions in relation to education and communication identified during the review include investigations into: how different sources of information are viewed by different stakeholders, as well as the content of the information they provide; stakeholders' opinions and expectations regarding different approaches to managing conflict to gain agreement; and longitudinal studies of the variation in different stakeholders' opinions and expectations in relation to the issues within specific water resource management projects.

- **Water infrastructure performance (including flood management and urban water infrastructure)**: There is currently very high-level confidence that climate change will adversely affect the function and operation of existing water infrastructure as well as the capacity of current water management practices to reduce the negative impacts of climate change on water-supply reliability, flood risk, human health, energy and aquatic ecosystems (Parry *et al.*, 2007). Australia's major urban water authorities are currently responsible for managing and maintaining water and sewer pipelines in the order of 89,500 and 81,000 km respectively (CSIRO, 2009), yet the estimation and especially quantification of urbanisation and climate change impacts on urban water infrastructure faces great uncertainty due to the lack of existing data and research on the issue. There remains considerable uncertainty and gaps in current understanding in relation to the effects of climate change on urban water (particularly underground) infrastructure. Adequate preparedness of urban water infrastructure for climate change is critical, and more research is needed to provide policy and planning guidance for adapting urban growth to global environmental change (Bobylev, 2009). In Australia, many assets are more than 50 years old and while they often have lives of over 100 years, failure to adequately manage their ongoing maintenance and timely replacement can significantly impact on the reliability of services to customers (WSAA, 2008). The immediate challenge for the water industry is to manage asset maintenance and replacement to achieve a balance between risk and service. The emerging challenge is in understanding how climate change will impact on assets and drive future maintenance and replacement decisions. According to WSAA (2008) and also Fane and Patterson (2009), the use of 'Real Options Analysis' offers potential for taking into consideration risk and uncertainty in decision-making, while at the same time taking into account the opportunity cost of funds involved. The risk-based approach incorporates flexibility in the decision-making process and allows for the inclusion of new information to characterise uncertainty over time. Research is currently being rolled out with industry and academic partners to better understand how assets fail, to develop ways of maximising their lives, and to improve our understanding of when to rehabilitate or replace them (WSAA, 2008).

Similarly, there is a need for measures to improve performance of existing water infrastructure in the context of effective flood management through enhanced cooperation between relevant parties (stakeholders, local, state and federal agencies). There is also a need for modification of existing infrastructure design standards and re-evaluation of probable maximum precipitation and design floods for dams, bridges, river protection and major urban infrastructure to account for expected future extreme events as well as accelerated degradation of materials and structures. This involves reviewing and updating design standards to ensure new projects can withstand projected climate changes. Current design and management protocols enable infrastructure to function effectively under a range of conditions; however, they are based almost entirely on analyses of historical observation, risk, and reliability (e.g., based on a 1 in 100-year event). Methods for estimating flood risk, for example, are also frequently standardised, yet there are currently no such standard methods for application under the new paradigm of climate 'non-stationarity' (Milly *et al.*, 2008; Wagener *et al.*, 2008). Under a changing climate, engineers now face the additional question of how to accommodate climate change uncertainties into the design of sustainable water infrastructure. New design and management protocols need to be developed that account for future extremes in weather events as well as the associated uncertainties in future climate predictions. Because of the large uncertainties associated with possible future climate scenarios, as well as the random nature of extreme events, a risk management approach may need to be applied to the development of such planning and engineering standards.

There is also a parallel need to reconsider the design flood intensity for infrastructure as well as a need to re-think and re-design current methodologies (e.g., continuous simulation methods and determination of antecedent moisture conditions) used for the prediction of design flood intensity to enable more accurate assessments of potential impacts of future flooding events on infrastructure projects. On this note, Engineer's Australia is presently revising the guideline document (Australian Rainfall and Runoff) for assessment of rainfall, runoff, water resources and flooding to include issues related to climate change (Thom *et al.*, 2009).

- **Sustainable adaptation**: Climate change adaptation and mitigation are closely inter-related. While adaptation measures can offer a means of coping with climate change impacts, adaptation strategies also have the potential to impart their own direct and negative environmental consequences—potentially contributing to the problem at hand (e.g., desalination and potable reuse schemes have high energy consumptions, and if the energy supplying these systems is non-renewable, these adaptive options may be at odds with mitigation objectives). There is a need for improved understanding of the inter-relationships between adaptation and mitigation strategies in order to enable us to minimise the potential negative impacts of adaptation actions whilst taking advantage of potential positive impacts from climate change. Research into adaptation–mitigation interactions has been highlighted by the recent 2009 IWA position paper on Climate Change as something that is required for the implementation of IWRM strategies (IWA, 2009).

In general, there is a recognised need for a future emphasis on conducing sustainability assessments (e.g., life cycle assessments and carbon footprinting) for all significant infrastructure projects. Additionally, and given the recent interest in decentralised treatment systems, there is also a need for detailed assessments of the economic, environmental and social 'sustainability' of these types of systems relative to conventional centralised systems operated by the water utilities (WSAA, 2009). The price of energy is likely to increase following the implementation of the CPRS, and there will be further pressure on utilities to look at ways of optimising systems and minimising their energy use (WSAA, 2008). The application of sustainability assessment tools such as life cycle assessment will be important in helping water utilities identify suitable process improvements and viable energy efficiency measures. There is also a general need to explore and fully understand the impacts and opportunities that a future carbon trading environment (i.e. under the CPRS) will provide for the Australian water industry (WSAA, 2009).

David suggests we should also talk about the need for research into fugitive emissions (e.g., from marine wastewater disposal). I initially left this out because I thought it was more mitigation than adaptation, but perhaps it needs to be mentioned. If we do mention it, we need to put it in the context of a life cycle approach to assessing its current validity as a water management practice (as we've proposed to do for the ARC Discovery Project), because it may not be as bad as we think / or it could be a whole lot worse?

## 13 REFERENCE MATERIAL


ABC TV (2008). Prepare for climate change coastal flooding, scientists urge. ABC News online. http://www.abc.net.au/news/stories/2008/08/21/2341936.htm (accessed May 2009).

ABS (2006). Australian Bureau of Statistics, Catalogue No. 4610.0 – Water Account, Australia, 2004–05, Released 28/11/2006.

AGO (2004). Intergovernmental Agreement on a National Water Initiative between the Commonwealth of Australia and the Governments of New South Wales, Victoria, Queensland, South Australia, the Australian Capital Territory and the Northern Territory, June 2004. Available at: http://www.nwc.gov.au/resources/documents/Intergovernmental-Agreement-on-a-national-water-initiative.pdf (accessed 11/05/09).

AGO (2006). Climate Change Impacts & Risk Management: A Guide for Business and Government. Prepared for the Australian Greenhouse Office, Department of Environment and Heritage by: Broadleaf Capital International and Marsden Jacob Associates. Published by the Australian Greenhouse Office, in the Department of the Environment and Heritage. ISBN: 1 921120 56 8.

Allen Consulting Group (2005). Climate Change Risk and Vulnerability: Promoting an Efficient Adaptation Response in Australia, Report to the Australian Greenhouse Office by the Allen Consulting Group, published by the Australian Greenhouse Office, in the Department of the Environment and Heritage. ISBN: 1 920840 94 X.

Allen, G., G. Longmuir and J. Sullivan (2008). Sydney Water's Response to Climate Change. Sydney Water Corporation, Sydney, NSW.

Amato, A., M. Ruth, P. Kirshen and J. Horwitz (2005). Regional Energy Demand Responses To Climate Change: Methodology And Application To The Commonwealth Of Massachusetts. *Climatic Change* **71**(1): 175-201.

Amitrano, L., R. Hargreaves, I. Page, K. Hennessy, T. Lee, M. Snow, L. Winton, R. Woodruff and T. Kjellstrom (2007). An Assessment of the Need to Adapt Buildings for the Unavoidable Consequences of Climate Change. Final Report to the Australian Greenhouse Office, Department of the Environment and Water Resources. ISBN: 978-1-921297-64-9.

ATSE (2008). Assessment of impacts of climate change on Australia's physical infrastructure, Report of a study by the Australian Academy of Technological Sciences and Engineering (ATSE), Victoria. ISBN 1 875618 96 1.

Australian Government (2009a). $1.5 million to assess climate change impacts on groundwater, Media Release, Senator the Hon. Penny Wong, Minister for Climate Change and Water, and The Hon Dr Mike Kelly AM MP, Parliamentary Secretary for Water. 2 September 2009 (PW 255/09). Available at: http://www.environment.gov.au/minister/wong/2009/mr20090902a.html (accessed 08 September 2009).

Australian Government (2009b). IT partner selected for online Water Information System, Media Release, Senator the Hon. Penny Wong, Minister for Climate Change and Water, 5 June 2009

(PW 150/09). Available at: http://www.environment.gov.au/minister/wong/2009/mr20090605.html (accessed 16 June 2009).

Australian Government (2009c). Low flows initiative to improve river management, Media Release, Senator the Hon. Penny Wong, Minister for Climate Change and Water, and The Hon Dr Mike Kelly AM MP, Parliamentary Secretary for Water. 2 September 2009 (PW 258/09). Available at: http://www.environment.gov.au/minister/wong/2009/mr20090902c.html (accessed 08 September 2009).

AwwaRF (2008). Water Industry Climate Change Research Needs Workshop. Project #4160, outcomes from an expert workshop held in Denver, Colorado, January 7-9, 2008.

Baggett, S. (2007). Exploring a social learning model of participative planning: stakeholder group uniformity in the context of water resource management, PhD thesis, Centre for Water Science, School of Water Sciences, Cranfield University, Cranfield, UK**:** 398 p.

BASIX (2006). Guideline to the BASIX SEPP, available at http://www.basix.nsw.gov.au/information/resources.jsp (accessed May 2009).

Bobylev, N. (2009). Urban Underground Infrastructure and Climate Change: Opportunities and Threats. Cities and Climate Change: Responding to an Urgent Agenda, Fifth Urban Research Symposium. Marseille, France, June 28–30, 2009.

California Department of Water Resources (2005). California Water Plan Update 2005: A Framework for Action, Department of Water Resources Bulletin 160-05. Division of Planning and Local Assistance, California Department of Water Resources, Sacramento, California. http://www.waterplan.water.ca.gov/previous/cwpu2005/index.cfm.

CCSP (2008). Preliminary review of adaptation options for climate-sensitive ecosystems and resources. [Julius, S.H., J.M. West (eds.), J.S. Baron, B. Griffith, L.A. Joyce, P. Kareiva, B.D. Keller, M.A. Palmer, C.H. Peterson, and J.M. Scott (Authors)]. A Report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research. U.S. Environmental Protection Agency, Washington, DC, USA**:** 873 pp.

CEC (2007). Addressing the challenge of water scarcity and droughts in the European Union. Communication from the Commission of the European Communities to the European Parliament and the Council, Brussels, COM(2007) 414 final.

Christensen, S. and W.D. Duncan (2007). Green leases: a new era in landlord and tenant cooperation. *Australian Property Law Journal* **15**(1): 54–65.

CPWC (2009). Topic Report: Topic 1.1 – Adapting to Climate Change, Theme 1: Global Change and Risk Management, 5th World Water Forum, Istanbul 2009, Topic coordinators: Cooperative Programme on Water and Climate (CPWC) and the World Bank. Available at: http://www.worldwaterforum5.org/index.php?id=2473&L=0.

CSIRO (2009). Overview – Science: Sewerage overview, Available at: http://www.csiro.au/science/SewerageOverview.html (accessed 08 September 2009).

DECC (2008). The Impacts of Climate Change on NSW's Biophysical Environment, NSW Department of Environment & Climate Change (unpublished).

DECC (2009). Draft Sea Level Rise Policy Statement, Department of Environment and Climate Change NSW, February 2009. ISBN 978 1 74232 148 6.

DSE (2003). Melbourne 2030: Planning for sustainable growth, Published by the Victorian Govenrment Department of Sustainability and Environment and the Department of Infrastructure, October 2002. ISBN 0 7311 8739 3.

DSE (2005). Discussion Paper: Sustainable Water Strategy Central Region. Published by the Victorian Govenrment Department of Sustainability and Environment, October 2005. ISBN 1741521831.

DWR (2008). Managing an Uncertain Future: Climate Change Adaptation Strategies for California's Water. State of California Resources Agency, Department of Water Resources, Sacramento, CA.

Fane, S. and J. Patterson (2009). Urban water planning in the face of climate change. *Water – Journal of the Australian Water Association* **36**(3): 84-89.

Flett, D., I. Varley, N. Schofield and T. Ladson (2008). New water entitlement products for Australia—A Thinkpiece. Waterlines Report Series No. 12, November 2008. Published by the National Water Commission, Canberra ACT. ISBN: 978-1-921107-66-5.

Garnaut, R. (2008a). Chapter 15: Adaptation and Mitigation Measures for Australia. The Garnaut Climate Change Review, Cambridge University Press, Port Melbourne, Victoria, ISBN 9780521744447**:** 363-384.

Garnaut, R. (2008b). Introduction. In: *The Garnaut Climate Change Review*, Cambridge University Press, Port Melbourne, Victoria, ISBN 9780521744447**:** xvii-xlv.

GWA (2003). A Mandatory Water Efficiency Labelling Scheme for Australia. Final Report prepared for Environment Australia by George Wilkenfeld and Associates Pty. Ltd., Sydney.

Hamstead, M., C. Baldwin and V. O'Keefe (2008). Water Allocation Planning in Australia – Current Practices and Lessons Learned. Waterlines Occasional Paper No 6, April 2008. Published by the National Water Commission, Canberra ACT. ISBN: 978-1-922107-62-7.

Hanak, E. and J. Lund (2008). Adaptation of California's Water Management to Climate Change, Public Policy Institute of California.

Haylock, M. and N. Nicholls (2000). Trends in extreme rainfall indices for an updated high quality data set for Australia, 1910-1998. *Int. J. Climatology* **20**: 1533-1541.

Hennessy, K., B. Fitzharris, B.C. Bates, N. Harvey, S.M. Howden, L. Hughes, J. Salinger and R. Warrick (2007). Australia and New Zealand. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. M.L. Parry, O.F. Canziani, J.P. Palutikor, P.J. van der Linden and C.E. Hanson. Cambridge, U.K., Cambridge University Press**:** 507-540.

Hennessy, K.J., R. Suppiah and C.M. Page (1999). Australian rainfall changes, 1910-1995. *Aust. Met. Mag* **48**: 1-13.

Howe, C., R.N. Jones, S. Maheepala and B. Rhodes (2005). Implications of Potential Climate Change for Melbourne's Water Resources. A collaborative Project between Melbourne Water and CSIRO Urban Water and Climate Impact Groups, March 2005.

Huntington, T.G. (2006). Evidence for intensification of the global water cycle: review and synthesis. *Journal of Hydrology* **319**: 83-95.

IEC (2008). Indigenous Essential Services Annual Report 2008, A report by Power and Water Corporation and Indigenous Essential Services Pty. Ltd.

IPCC (2007a). Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Core Writing Team, Pachauri, R.K and Reisinger, A. (Eds.)]. IPCC, Geneva, Switzerland.

IPCC (2007b). Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate change, Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K. B., Tignor, M. and Miller, H. L. [Eds.], Cambridge University Presss, Cambridge, UK and New York, NY.

IWA (2009). Submission by IWA International Water Association relevant for the preparation of the 6th session of the AWG LCA. International Water Association, London, 24 April 2009. Available at: http://unfccc.int/resource/docs/2009/smsn/ngo/146.pdf (accessed 11/05/09).

Kenway, S.J. (2009). The water–energy nexus: what is it and how do we break it in Australian cities? Presentation to Engineers Australia, 26 May 2009, Chatswood, Sydney.

Kenway, S.J., G.M. Turner, S. Cook and T. Baynes (2008). Water–energy futures for Melbourne: the effect of water strategies, water use and urban form. CSIRO Water for a Healthy Country National Research Flagship Report, ISBN 978 0 643 09566 3.

Kinrade, P. and M. Justus (2008). Impacts of Climate Change on Settlements in the Western Port Region: Climate Change Risks and Adaptation. Report to the Australian Government, Department of Climate Change and the Department of Sustainability and Environment, Victoria, ISBN 978 0 9577225 3 8.

Kiparsky, M. and P.H. Gleick (2003). Climate Change and California Water Resources: A Survey and Summary of the Literature. A report to the California Energy Commission, Public Interest Energy Research Program by the Pacific Institute for Studies in Development, Environment and Security. Report No. 500-04-073.

Kirby, A., C. Stuhlberger, C. Heberlein and S. Tveitdal (2009). Climate in Peril: A Popular Guide to the Latest IPCC Reports, United Nations Environment Programme (UNEP) and GRID-Arendal. ISBN: 978-82-7701-053-3.

Klein, R.J.T., S. Huq, F. Denton, T.E. Downing, R.G. Richels, J.B. Robinson and F.L. Toth (2007). Inter-relationships between adaptation and mitigation. Climate Change 2007: Impacts, Adaptation and Vulnerability. M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, UK: 745-777.

Kundzewicz, Z.W., L.J. Mata, N.W. Arnell, P. Döll, P. Kabat, B. Jiménez, K.A. Miller, T. Oki, Z. Sen and I.A. Shiklomanov (2007). Freshwater resources and their management. Climate Change 2007: Impacts, Adaptation and Vulnerability. M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, UK**:** 173-210.

Leary, N.A. (1999). A Framework for Benefit-Cost Analysis of Adaptation to Climate Change and Climate Variability. *Mitigation and Adaptation Strategies for Global Change* **4**(3): 307-318.

LGSA NSW (2006). Responses to needs analysis survey to identify the climate change adaptation and mitigation needs for local government in New South Wales. Available at: http://www.lgsa.org.au/resources/documents/needs_analysis_findings_final_report_climate_change_mitigation_and_adaptation_project.pdf (accessed 04/06/09).

Lorenz, D., B. Heard, L. Hoekstra-Fokkink, J. Orchard and S. Valeri (2008). Towards a City of Melbourne Climate Change Adaptation Strategy: A Risk Assessment and Action Plan Discussion Paper (DRAFT). Prepared for City of Melbourne by Maunsell Australia Pty. Ltd., Melbourne.

Lundie, S., G. Peters, N. Ashbolt, E. Lai and D. Livingston (2006). A sustainability framework for the Australian water industry. *Water – Journal of the Australian Water Association* **33**(7): 83-88

Marsden, J. and P. Pickering (2006). Securing Australia's Urban Water Supplies: Opportunities and Impediments. A discussion paper prepared for the Department of the Prime Minister and Cabinet by Marsden Jacob Associates Pty Ltd, Victoria. Available at: http://www.environment.gov.au/water/publications/urban/pubs/urban-water-report.pdf.

Marsh, D. and D. Sharma (2006). Water–energy nexus: a review of existing models. 1st Australian Young Water Professionals Conference. 15-17 February, 2006. The University of New South Wales, Sydney.

Maunsell Australia and CSIRO (2008). Impact of climate change on infrastructure in Australia and CGE model inputs, Maunsell Australia Pty Ltd, in association with CSIRO Sustainable Ecosystems. Report commissioned by the Garnaut Climate Change Review, June 2008. Available at: http://www.garnautreview.org.au/ (accessed 07 September 2009).

MDBA (2009). The Basin Plan: a concept statement. Murray–Darling Basin Authority (MDBA), Canberra. Publication no. 02/09, ISBN 978-1-921557-07-1.

Mehdi, B.B., C.A. Madramootoo and A. Cobbina (2004). Water resources at risk due to climate change: identifying knowledge gaps and research needs. Knowledge Gaps and Research Needs Ensuing from *Water Resources at Risk due to Climate Change*, workshop held on September 9-10, 2002, Holiday Inn, Montréal, Qc. Published by the Canadian Climate Impacts and Adaptation Research Network (C-CIARN) - Water Resources.

Midgley, G., R. Chapman, P. Mukheibir, M. Tadross, B. Hewitson, S. Wand, R. Schulze, T. Lumsden, M. Horan, M. Warburton, B. Kgope, B. Mantlana, A. Knowles, A. Abayomi, G. Ziervogel, R. Cullis and A. Theron (2007). Impacts, Vulnerability and Adaptation in Key South African Sectors: An input into the Long Term Mitigation Scenarios process. Report to:

Department of Environment Affairs and Tourism South Africa, LTMS input Report 5 (Summary report), Energy Research Centre, University of Cape Town.

Midgley, G.F., R.A. Chapman, B. Hewitson, P. Johnston, M.D. Wit, G. Ziervogel, P. Mukheibir, L.V. Niekerk, M. Tadross, B.W.V. Wilgen, B. Kgope, P.D. Morant, A. Theron, R.J. Scholes and G.G. Forsyth (2005). A Status Quo, Vulnerability and Adaptation Assessment of the Physical and Socio-economic Effects of Climate Change in the Western Cape. Report to the Western Cape Government, Cape Town, South Africa. CSIR Report No. ENV-S-C 2005-073, Stellenbosch

Milly, P.C.D., J. Betancourt, M. Falkenmark, R.M. Hirsch, Z.W. Kundzewicz, D.P. Lettenmaier and R.J. Stouffer (2008). Stationarity Is Dead: Whither Water Management? *Science* **319**(5863): 573-574.

Milly, P.C.D., R.T. Wetherald, K.A. Dunne and T.L. Delworth (2002). Increasing risk of great floods in a changing climate. *Nature* **415**(6871): 514-517.

Mirfenderesk, H. and D. Corkill (2009). The need for adaptive strategic planning: Sustainable management of risks associated with climate change. *International Journal of Climate Change Strategies and Management* **1**(2): 146-159.

Mitchell, C., S. Fane, J. Willetts, R. Plant and A. Kazaglis (2007). Costing for Sustainable Outcomes in Urban Water Systems – A Guidebook. Research Report No 35, Published by The Cooperative Research Centre for Water Quality and Treatment. ISBN: 1 8766 16 601.

Mukheibir, P. and G. Ziervogel (2007). Developing a Municipal Adaptation Plan (MAP) for climate change: the city of Cape Town. *Environment and Urbanization* **19**(1): 143-158.

Neal, B., J. Radcliffe, T. McMahon and R. Nathan (2007). Urban Water – Review of Water Supply Planning for Australia's Non-Metropolitan Urban Water Utilities, Published by the Australian Academy of Technological Sciences and Engineering (ATSE), Victoria. ISBN 1 875618 93 7.

NGA (2009). National Local Government 2009: Climate Change Discussion Paper. The National General Assembly of Local Government, Australian Local Government Association.

NRA (2009). California Climate Adaptation Strategy: Discussion Draft. A Report to the Governor of the State of California in Response to Executive Order S-13-2008. Natural Resources Agency, California, USA, August 2009.

NSW Government (2009). New water pressure technology to stop water leakage, Media Release, Phil Costa, Minister for Water and Regional Development. 7 October 2009 (PW 255/09). Available at: http://www.sydneywater.com.au/WhoWeAre/MediaCentre/documents/ministerial/Costa_New%20water%20pressure%20technology071009.pdf#Page=1 (accessed 18 October 2009).

NWC (2010). Building resilience through water reform. Presentation by Ken Matthews to Australia 21 conference,18 February 2010. Available at: http://www.nwc.gov.au/www/html/2727-introduction-2010-speeches-presentations-and-articles.asp.

OECD (2006). Domestic Policy Frameworks for Adaptation to Climate Change in the Water Sector – Part I: Annex I Countries. Report prepared by the OECD and IEA Secretariats in March-May 2006 in response to the Annex I Expert Group on the United Nations Framework Convention on Climate Change (UNFCCC).

Origin Energy Australia (2009). Darling Downs Power Station. Available at: http://www.originenergy.com.au/2081/Darling-Downs-Power-Station (accessed 15/09/09).

Paerl, H.W. and J. Huisman (2009). Climate change: a catalyst for global expansion of harmful cyanobacterial blooms. *Environmental Microbiology Reports* **1**(1): 27-37.

Pardo, A., V. Meneu and E. Valor (2002). Temperature and seasonality influences on the Spanish electricity load. *Energy Economics* **24**(1): 55-70.

Parry, M.L., O.F. Canziani and J. P. Palutikof and Co-authors (2007). Technical Summary. Climate Change 2007: Impacts, Adaptation and Vulnerability. M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge UK**:** 23-78.

Peterson, C.H., R.T. Barber, K.L. Cottingham, H.K. Lotze, C.A. Simenstad, R.R. Christian, M.F. Piehler and K. Wilson (2008). National Estuaries. Preliminary review of adaptation options for climate-sensitive ecosystems and resources. [Julius, S.H., J.M. West (eds.), J.S. Baron, B. Griffith, L.A. Joyce, P. Kareiva, B.D. Keller, M.A. Palmer, C.H. Peterson, and J.M. Scott (Authors)]. A Report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research. U.S. Environmental Protection Agency, Washington, DC, USA**:** 873 pp.

Pittock, B., Ed. (2003). Climate Change: An Australian Guide to the Science and Potential Impacts, Published by the Australian Greenhouse Office. ISBN: 1 920840 12 5.

Pittock, J. (2008). Climate Change and Water Supply. *Water21 (magazine of the International Water Association)* **June issue**: 12-14.

Preston, B., B. Beveridge, G. Withycombe, C. Morrison, T.F. Smith, C. Brooke, R. Gorddard, T. Measham, D. Abbs and K. McInnes (2007). Integrated approaches to regional climate change adaptation strategies: project methodology, results and key lessons learnt New South Wales Coastal Conference. Yamba, NSW, 7–9 November, 2007.

Preston, B., T.F. Smith, C. Brooke, R. Gorddard, T.G. Measham, G. Withycombe, B. Beveridge, C. Morrison, K. McInnes and D. Abbs (2008a). Climate Change Vulnerability Mapping as a Stakeholder Engagement Tool: Case Study from Sydney, Australia. Coastal Cities Summit 2008, Values and Vulnerabilities. November 17–20, St. Petersburg, Florida USA.

Preston, B.L., T. Smith, C. Brooke, R. Gorddard, T. Measham, G. Withycombe, K. McInnes, D. Abbs, B. Beveridge and C. Morrison (2008b). Mapping Climate Change Vulnerability in the Sydney Coastal Councils Group. Prepared for the Sydney Coastal Councils Group and the Commonwealth Department of Climate Change by the CSIRO Climate Adaptation Flagship, Canberra.

Preston, B.L., R. Westaway, S. Dessai and T.F. Smith (2009). Are we adapting to climate change? Research and methods for evaluating progress. Fourth Symposium on Policy and Socio-Economic Research, Phoenix, Arizona, American Meterological Society.

Proust, K., S. Dovers, B. Foran, B. Newell, W. Steffen and P. Troy (2007). Climate, energy and water: accounting for the links. Published by Land & Water Australia, Canberra. ISBN: 978-1921253348.

Rassam, D.W. and A.D. Werner (2008). Review of groundwater–surfacewater interaction modelling approaches and their suitability for Australian conditions. eWater Technical Report. eWater Cooperative Research Centre, Canberra. ISBN 978-1-921543-02-9. Available at: http://ewatercrc.com.au/reports/Rassam_Werner-2008-Groundwater_Review.pdf.

Reid, M.A., X. Cheng, E.W. Banks, J. Jankowski, I. Jolly, P. Kumar, D.M. Lovell, M. Mitchell, G.M. Mudd, S. Richardson, M. Silburn and A.D. Werner (2009). Catalogue of conceptual models for groundwater–stream interaction. eWater Technical Report. eWater Cooperative Research Centre, Canberra. ISBN 978-1-921543-22-7. Available at: http://ewatercrc.com.au/reports/Reid_et_al-2009-Model_Catalogue.pdf.

Sailor, D.J. (2001). Relating residential and commercial sector electricity loads to climate—evaluating state level sensitivities and vulnerabilities. *Energy* **26**(7): 645-657.

Sjerp, E. and A. Charteris (2008). Climate Change, Sea Level Rise and Coastal Subsidence along the Gippsland Coast. Final report, published by the Gippsland Coastal Board.

SMEC Australia (2007). Climate Change Adaptation Actions for Local Government. Canberra, Report to the Australian Greenhouse Office, Department of the Environment and Water Resources, ISBN: 978-921297-27-4.

Smit, B. and J. Wandel (2006). Adaptation, adaptive capacity and vulnerability. *Global Environmental Change* **16**(3): 282-292.

Stern, N. (2006). Stern Review: the Economics of Climate Change. HM Treasury, London.

The Allen Consulting Group (2007). Improving market confidence in water intermediaries. Waterlines Occasional Paper No 3, July 2007. Published by the National Water Commission, Canberra ACT. ISBN: 978-1-921107-52-8.

Thom, B., J. Cane, R. Cox, C. Farrell, P. Hayes, R. Kay, A. Kearns, D.L. Choy, J. McAneney, J. McDonald, M. Nolan, B. Norman, J. Nott, T. Smith, F. Crick and D. Stock (2009). National Climate Change Adaptation Research Plan: Settlements and Infrastructure, National Climate Change Adaptation Research Facility.

Tingem, M. and M. Rivington (2008). Adaptation for crop agriculture to climate change in Cameroon: Turning on the heat. *Mitigation and Adaptation Strategies for Global Change* **14**(2): 153-168.

Tong, S., P. Dale, N. Nicholls, J.S. Mackenzie, R. Wolff and A.J. McMichael (2008). Climate Variability, Social and Environmental Factors, and Ross River Virus Transmission: Research Development and Future Research Needs. *Environmental Health Perspectives* **116**(12): 1591-1597.

Tong, S., W. Hu and A.J. McMichael (2004). Climate variability and Ross River virus transmission in Townsville region, Australia 1985 to 1996. *Tropical Medicine and International Health* **9**(2): 298-304.

Troy, P., D. Holloway and B. Randolph (2005). Water use and the built environment: patterns of water consumption in Sydney. City Futures Research Centre, Research Paper No. 1, University of New South Wales, ISBN 1 74044 019 6.

Turner, J.V. (2009). Estimation and prediction of the exchange of groundwater and surfacewater: field methodologies. eWater Technical Report. eWater Cooperative Research Centre, Canberra. Available at: http://ewatercrc.com.au/reports/Turner-2009-Field_Methodologies.pdf.

UDIA (Urban Development Institute of Australia) (2009). EnviroDevelopment. www.envirodevelopment.com.au (accessed May 2009).

UNFCCC (2006). Technologies for adaptation to climate change. Peter Stalker [Ed.], United Nations Framework Convention on Climate Change. ISBN: 92-9219-029-6.

UNFCCC (2008). Climate change: Impacts, vulnerabilities and adaptation in developing countries. United Nations Framework Convention on Climate Change.

USEPA (2006). Sustaining our nation's water infrastructure, United States Environmental Protection Agency, Office of Water, EPA-832-E-06-004.

USEPA (2008). National Water Program Strategy: Response to Climate Change, Published by the U.S. Environmental Protection Agency, Office of Water (4101M), Report No. EPA 800-R-08-001.

Vaze, J., J. Teng, D. Post, F. Chiew, J.-M. Perraud and D. Kirono (2008). Future climate and runoff projections (~2030) for New South Wales and Australian Capital Territory. NSW Department of Water and Energy, Sydney. ISBN 978 0 7347 5894 1.

Vine, E. (2008). Adaptation of California's Electricity Sector to Climate Change, Public Policy Institute of California.

Wagener, T., M. Sivapalan and B. McGlynn (2008). Catchment Classification and Services–Toward a New Paradigm for Catchment Hydrology Driven by Societal Needs. Encyclopedia of Hydrological Sciences. M.G. Anderson, John Wiley & Sons, Ltd.**:** 12 p.

Water for Life (2008). Metropolitan Water Plan: 2008 Progress Report. NSW Government, available at http://www.waterforlife.nsw.gov.au/about/2008_progress_report (accessed May 2009).

Water UK (2008). Adaptation to climate change: Water UK briefing, December 2008.

WEF (World Economic Forum) (2008). Energy Vision Update 2009 – Thirsty Energy: Water and Energy in the 21st Century. World Economic Forum in partnership with Cambridge Energy Research Associates. Published by the World Economic Forum, Geneva, Switzerland.

WERF (2006). Moving Toward Sustainable Water Resources Management: Synthesis Report, Report No. 00-WSM-6a, published by Water Environment Research Foundation.

WGA (2008). Water Needs and Strategies for a Sustainable Future: Next Steps. Western Governors' Association, June 2008.

Wheaton, E.E. and D.C. Maciver (1999). A Framework and Key Questions for Adapting to Climate Variability and Change. *Mitigation and Adaptation Strategies for Global Change* **4**(3): 215-225.

Wiedner, C., J. Rücker, R. Brüggemann and B. Nixdorf. (2007). Climate change affects timing and size of populations of an invasive cyanobacterium in temperate regions. *Oecologia* **152**(3): 473-484.

Wilbanks, T.J., P.R. Lankao, M. Bao, F. Berkhout, S. Cairncross, J.-P. Ceron, M. Kapshe, R. Muir-Wood and R. Zapata-Marti (2007). Industry, settlement and society. Climate Change 2007: Impacts, Adaptation and Vulnerability. M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge UK**:** 357-390.

Woodruff, R. and H. Bambrick (2008). Climate change impacts on the burden of Ross River Virus disease, Report commissioned by the Garnaut Climate Change Review, June 2008. Available at: http://www.garnautreview.org.au/ (accessed 07 September 2009).

WQRA (Water Quality Research Australia) (2009). WQRA Health Stream Newsletter, Issue 54 – June 2009. Available at: http://www.waterquality.crc.org.au/hs/hs54web.htm (accessed July 25, 2009).

WSAA (the Water Services Association of Australia) (2008). WSAA Report Card 2007/2008: Performance of the Australian Urban Water Industry and projections for the future. Published by the Water Services Association of Australia Ltd. ISBN 1 920760 32 6.

WSAA (the Water Services Association of Australia) (2009a). Vision for a sustainable urban water future: Position Paper No. 3. Published by the Water Services Association of Australia Ltd. ISBN 1 920760 34 2.

WSAA (the Water Services Association of Australia) (2009b). WSAA Report Card 2008/2009: Performance of the Australian Urban Water Industry and projections for the future. Published by the Water Services Association of Australia Ltd. ISBN 1 920760 46 6.

WUCA (2008). Water Sector Statement on Climate Change and Water Resources, Water Utility Climate Alliance, May 2008.

Wurtz, W. and R. Peltier (2008). Air-cooled condensers eliminate plant water use. *POWER magazine* **September 15 issue**: 2 p.

# 14 APPENDIX A. PAST, CURRENT AND PLANNED RESEARCH ACTIVITIES

According to Allen *et al*. (2008), **Sydney Water Corporation** is using a host of targeted research activities to inform its climate change adaptation response. This research includes:

- Downscaling of climate modelling to support water resource planning and assess the likelihood of future extreme rainfall events;
- Assessment of long-term rainfall patterns through analysis of natural archives such as floodplain sediments and cave stalagmites (a Sydney Catchment Authority project under the Metropolitan Water Plan);
- Investigations into sea level rise impacts on stormwater asset degradation;
- Optimal management of corrosion and odours in sewers (with Australian Research Council and national utility industry funding) which includes investigations into how future conditions may impact sewer management;
- Impacts of weather changes and expansive soils on buried assets, with implications for drying soils and asset condition;
- Application of leading edge technologies in wastewater treatment; and
- Greenhouse gas and pollution inventories for sewage treatment plants and treatment processes.

Research within **CSIRO's Transport and Infrastructure Flagship** (see http://www.csiro.au/science/TransportInfrastructure.html) has a *Utilities Program* concerned with ensuring that Australian utilities are safeguarded from the natural and man-made emergencies of the 21st century (including environmental stressors relating to climate change). Work within the *Utilities Program* is also directing efforts toward research that will optimise the performance of existing urban water infrastructure and help modernise our ageing water systems (see http://www.csiro.au/science/Infrastructure-Technologies.html). To accommodate the predicted future growth in population and industry within Australia, the *Infrastructure Technologies* research team is developing new technologies and strategic models aimed at enabling greater efficiencies to be obtained from the systems used to store, treat and transport our water resources. The team is conducting research in the following key areas:

- Strategic asset management;
- Network dynamics and performance; and
- Advanced water treatment technologies.

**CSIRO's Climate Adaptation National Research Flagship** (see http://www.csiro.au/org/ClimateAdaptationFlagship.html) has a *Sustainable Cities and Coasts* Research Program aimed at conducting research that can help us understand and plan for the likely local impacts of climate change, including:

- Coastal inundation due to sea level rise and storm surge;
- More frequent or severe storms, cyclones, hail events and floods;
- Heightened risk of bushfires at the urban fringe;
- Pressure on water supplies; and
- Climate-related health risks including heat stress and vector borne diseases.

CSIRO researchers within this Flagship Program are developing planning, design, infrastructure and management solutions to help Australia adapt to climate change, while working toward reducing greenhouse gas emissions from homes, buildings and transport. Flagship researchers are working with partners to develop new planning, design, infrastructure, management and governance solutions via three main research theme areas:

- Developing new design tools and materials for buildings and infrastructure to improve the resilience of cities to climate change and reduce greenhouse emissions;
- Working with partners in the urban development sector to create exemplar sustainable urban development projects that promote climate adaptation in the built environment and showcase the benefits of integrated urban planning; and
- Integrated social, economic and environmental analyses to assess the vulnerability of coastal and urban regions to climate change, and help communities, industry and governments adapt and prepare for future impacts.

Initiated by the **National Water Commission**, the **Federal Government** has recently announced $700,000 in research funding to improve knowledge and management of low river flows (Australian Government, 2009c). According to the media announcement, the impacts of climate change in southern Australia will mean that being able to understand and properly manage low flow rivers will play an increasingly important role in sustaining healthy and productive river systems. The research funding aims to fill important data and information gaps for water planners and managers, with the goal of producing better water plans and improved implementation and monitoring. Work will be done to improve the modelling and prediction of low flows, as well as to understand how ecosystems respond to declining stream flows. An additional $1.5 million in funding has also been announced for a project to help water managers better understand the expected impacts of climate change on Australian groundwater resources (Australian Government, 2009a). Building upon the sustainable yields work undertaken by the CSIRO, the project will investigate how climate change is expected to affect rainfall, along with water losses and the impact of these factors on groundwater recharge and base flows to water systems at a regional level.

**The University of New South Wales' Faculty of the Built Environment** has a *CITY FUTURES* research group (see http://www.fbe.unsw.edu.au/cf/). *CITY FUTURES* is a University Research Centre dedicated to developing a better understanding of our cities, their people, the policies that manage their growth, the issues they face, and the impacts they make on the environment and economy. Some of the current and completed research projects from the *CITY FUTURES* group of particular relevance to this review include:

- *Planning for Socially Sustainable Urban Renewal in Suburban Sydney* (ARC funded);
- *Water and Energy Profiles for Sydney: Towards Sustainability* (ARC funded); and
- *Social Determinants of Domestic Water and Energy Consumption* (funded by Environmental Trust).

**RMIT University Climate Change Adaptation Program (CCAP)** (see http://gc.nautilus.org/gci) has a *Global Cities Research Institute*. The RMIT University CCAP has four integrated program activities each containing a range of supporting research projects of relevance to this review:

1. Assess and map the vulnerability of urban infrastructure in selected cities in the Asia Pacific region to climate change impacts. Research is looking at risk–hazard analysis of urban physical infrastructure, especially sensitivity to climate change impacts on water, built assets, waste management, and energy systems; and socio-economic analysis of vulnerability arising from climate change urban infrastructural impacts due to differential availability of and access to resources needed for adaptation;
2. Develop scenarios and strategic pathways for urban infrastructural adaptation. Research aims to develop a set of basic adaptation scenarios and strategies as a strategic tool to be used by policy-makers in regional cities, including sustainability-driven retreat, highly-built defences, and riding-out the storm, with each scenario containing technological, economic, demographic, cultural, and security strands; for energy and built-infrastructure, quantitative analysis of adaptive paths will be developed in order to: identify robust urban adaptation strategies; develop strategies with other cities in a common analytical framework (possibly new software decision tool focused on urban managers, which are currently non-existent); and ascertain opportunities for co-ordination, sharing, collaboration, and possible initiatives with counterpart cities;
3. Implement an adaptive infrastructural initiative in two cities – one Australian and one in the Asia-Pacific region; and
4. Propose a global framework for equitable and efficient allocation of adaptation costs and convene a global or regional mayoral event on World Environment Day, 2009, to launch a global city compact for implementing city-level adaptation commitments. The aim is to convene a research group of eminent philosophers, economists, development practitioners, political scientists, and sociologists who will develop a set of qualitative and quantitative indices that should govern the allocation of incremental adaptation driven by anthropogenic climate change. This group will: examine the evolving climate change adaptation practices and rationales of international institutions such as the Global Environment Facility, the World Bank, the IFC, the WTO, etc; and will engage prominent practitioners in the field of climate change adaptation such as insurance companies, bankers, architect and engineering firms, etc. It will also evaluate the potential for cities to become the prime drivers for an equitable and efficient global strategy to adapt to climate change; and examine the potential for a city–city level global compact on climate change adaptation to supplement or complement the post-Kyoto Protocol state-level framework for climate change mitigation and adaptation and introduce this institutional concept to mayors throughout the region.

To support adaptation researchers and to increase our collective ability to respond to adaptation needs quickly, RMIT University CCAP is also undertaking two activities which do not fit within the above four categories:

1. *Adaptnet* – a free weekly report on climate change adaptation issues (subscribe at: http://www.nautilus.org/mailman/listinfo/adaptnet). This email report makes it easy for those interested in climate change adaptation issues to keep up to date on the latest information on adaptation strategies, measures, tools, research and analysis, best practice and implementation; and
2. *Assessment of Climate Change Adaptation Actual and Latent Research Capacity*. This project focuses on identifying climate change adaptation-related expertise throughout RMIT University and The University of Melbourne; although it is intended to expand this to other institutions in the future. Data on researchers and their expertise are being collated into a repository that can be searched by name or issue. The database provides a summary of their expertise, past research and publications, plus contact details. This work will be further expanded to identify capacity clusters and relevant experts within

those clusters. A capacity cluster is a grouping of inter-related issues that we can expect to see arise in relation to climate change.

The **RMIT University CCAP** also has an *Urban Infrastructure* research program focused on the physical infrastructure side of adaptation to globalisation and climate change. The emphasis throughout the Program's research will be on developing adaptive strategies to ameliorate the globally induced urban pressures; thus the program will have a strong applied research and public-policy cast.

The **Australian Greenhouse Office**, Department of Environment and Heritage has published a *Risk Management* guide for business and government to deal with climate change impacts (AGO, 2006). This document is a guide to integrating climate change impacts into risk management and other strategic planning activities in Australian public and private sector organisations. The Guide provides a framework for managing the increased risk to organisations due to climate change impacts and the prime focus of the Guide is on the initial assessment and prioritisation of these risks. There already exist quite a large number of climate change adaptation guidelines and frameworks for different organisations ranging from small islands to municipalities, local governments and businesses, and Preston *et al*. (2009) provide a good overview of these frameworks and evaluate them according to a number of different criteria.

According to **AGO (2006)**, uncertainties still exist about the magnitude, rate and direction of changes to specific climate variables, especially at the regional and local levels. In relation to this need, CSIRO has also undertaken an analysis of the probability of exceeding sea level thresholds, and has produced probability distributions (single variable) and probability density plots (multiple variables) for temperature and rainfall changes in specific regions (see http://www.cmar.csiro.au). Probability distributions such as these do not remove uncertainty but they do provide an assessment of the realistically likely ranges of outcomes and the likelihood of particular outcomes within each range. The CSIRO and other researchers in Australia have also undertaken studies which address projections of climate changes at the state and regional levels. A number of state climate change reports provide regional and even site-specific information on projected changes to the frequency of: very hot and very cold days and spells; droughts; extreme rainfall; extreme winds; and storm surges; with many of these studies available publicly (AGO, 2006).

A current research project commissioned by the **Australian Government Department of Climate Change** aims to explore the issue of climate change risk management, specifically focusing on adaptation measures for the Sydney Coastal Councils Group (SCCG) region (Preston *et al.*, 2008b). The project scope does not only include the challenges associated with access to financial capital, technology and information to facilitate adaptation, but perhaps more importantly, the institutional processes and barriers that influence the implementation of adaptive measures. Thus far the project finalised the vulnerability mapping for the SCCG but has not yet investigated adaptation measures. For many countries, particularly Australia, predictions about future rainfall patterns vary significantly across different regions making any vulnerability evaluation even more difficult (OECD, 2006; Vaze *et al.*, 2008).

The **Victorian Government** has been involved with work investigating climate change and associated impacts in Victoria (see www.greenhouse.vic.gov.au/index.htm). In addition to this, several Victorian water authorities have undertaken studies to investigate the impacts of climate change on their supply systems. The most detailed of these studies was undertaken by **Melbourne Water** in conjunction with **CSIRO**. The report *Implications of Potential Climate Change for Melbourne's Water Resources* (Howe *et al.*, 2005) examined the impacts of climate change on all aspects of Melbourne Water's functions, including water supply. The report contained information such as:

- The development of Melbourne region climate change scenarios for 2020 and 2050 based on the IPCC scenarios;
- An overview of the potential implications of climate change coupled with potential water demand scenarios for Melbourne's water, sewerage and drainage systems including identification of major risk areas;
- A detailed quantitative case study for Melbourne's water supply system and potential adaptation options;
- Semi-quantitative case studies of the potential for increased sewerage overflows and local flooding; and
- Identification of potential adaptation strategies to mitigate the impacts of climate change given the range of uncertainties identified during the study.

Regarding work in the area of groundwater–surfacewater interactions, the **eWater CRC** has funded projects to address the deficiency in modelling and field measurement capability in the area of groundwater–stream interaction for Australian situations. A series of three reports were published by eWater CRC in relation to this research area (Rassam and Werner, 2008; Reid *et al.*, 2009; Turner, 2009). The eWater CRC report series is intended to improve stakeholder awareness and understanding of the interconnectivity, and the physical and chemical interactions of groundwater–surfacewater systems. The report series is also intended to provide a framework to underpin the development of a toolkit for describing, measuring and modelling groundwater–stream interaction in stressed or threatened Australian catchments, and has the broader goal of supporting judicious, conjunctive water management to safeguard our major connected groundwater–stream systems and their associated ecosystems (Reid *et al*., 2009). The eWater CRC plans to delivered software models within the Catchment Modelling Toolkit (see http://www.toolkit.net.au) to address issues related to the conjunctive management of groundwater and surfacewater and groundwater-dependent ecosystems.

The **Water Research Foundation (WRF)** (previously the American Water Works Association Research Foundation (AwwaRF)) has a *Climate Change Strategic Initiative* research program (http://www.waterresearchfoundation.org/theFoundation/ourPrograms/ResearchProgramSIClimateChange.aspx) focused on exploring the impacts of climate change on water supplies. The initiative will be sustained until the objectives outlined below are achieved; the target timeframe for the initiative is 5–7 years. The *Climate Change Strategic Initiative* has the following four objectives:

1. Enhance and improve water industry awareness of climate change issues and impacts;
2. Provide water utilities with a set of tools to identify and assess their vulnerabilities, and develop effective adaptation strategies;
3. Provide water utilities with a set of tools to assess and minimise their carbon footprint;
4. Communicate information to internal/external stakeholders.

The **WRF** has also established a central data repository called *The Climate Change Clearinghouse* Web site (see www.theclimatechangeclearinghouse.org) to provide a single source of all information related to climate change and water.  The Web site offers the water community access to useful information on:

- Climate change science relevant to water utilities;
- Impacts climate change can have on water resources;
- Guidance on planning and adaptation strategies; and
- Water Research Foundation research relevant to climate change.

A $300,000 WRF research project of a similar theme was funded in 2008 "*Identifying and Developing Climate Change Resources for Water Utilities: Content for Central Knowledge Repository Website*".

In June 2009, the Australian Federal Government announced the development of an online **National Water Information System** (Australian Government, 2009b) to be commissioned some time during 2010.  On completion, it is expected that this system will provide freely available up-to-date information on water resource availability and use, water trading, and forecasts of water availability months ahead of time.  The project involves compiling water data from more than 240 organisations into a single national repository for water information. According to the media release (Australian Government, 2009b), this information will be an invaluable resource for water corporations, government agencies, irrigators and the wider community, and will inform much better decision-making about storing, allocating and using our water resources.

The **United States Environmental Protection Agency (USEPA)** has established a *Sustainable Infrastructure Initiative* (see http://www.epa.gov/waterinfrastructure/) to meet the challenge of providing sustainable infrastructure for water and wastewater (USEPA, 2006).  USEPA is collaborating with drinking water and wastewater utility managers, trade associations, local watershed protection organisations, and state and local officials to help ensure that water infrastructure is sustainable into the future.  In addition to supporting adoption of state-of-the-art management approaches by utilities, including management of decentralised facilities, USEPA is promoting research and development for promising new technologies and techniques to increase effectiveness and reduce drinking water distribution and wastewater conveyance system costs.  They will also explore new design concepts for future systems.  The activities of the *Sustainable Infrastructure Initiative* are centred around four priority areas; full details of what is involved for each of these four priority themes can be found in USEPA (2006):

1. *Better Management*—to shift the utility management model beyond compliance to sustainability and improved performance by focusing on utility management systems, such as environmental management systems (EMS) and asset management, capacity development for smaller utilities, and selection of innovative, cost-effective technologies;
2. *Full Cost Pricing*—to help utilities recognise their full costs for providing service over the long-term and to implement pricing structures that effectively recover costs and promote environmentally sound decisions by customers;
3. *Water Efficiency*—to promote water efficiency in the residential and commercial sector through *WaterSense*, a new market enhancement program for water efficient products and services.  Under this pillar, USEPA also is facilitating the establishment of an independent, national collaborative organisation committed to improving water efficiency, promoting

improved building and landscaping practices, and recognising leadership in water efficiency;
4. *The Watershed Approach*—to encourage the adoption of watershed management principles and tools into utility planning and management practices, so that key decision makers consider watershed-based, cost effective alternatives along with traditional treatment technology investment choices. Watershed management approaches include, but are not limited to, source water protection, water quality trading, centralised management of decentralised systems, and smart growth approaches to stormwater and wastewater management.

A paper by **Leary (1999)** developed a framework for cost–benefit analysis of adaptation measures to climate change and future climate variability; however, this framework assumes that future climate changes are known with certainty, making its current relevance limited. The reality is, however, that there are important uncertainties about how future climate will differ from present climate, and by extension, the benefits of adaptation to climate change are also uncertain. If an adaptation response also involves an irreversible investment, this can substantially change evaluation of the benefits and costs of the adaptation policy and the decision to implement the policy. This paper suggests that more work is needed in the area of certainty/uncertainty assessments of future climate change predictions, and although this work was published in 1999, there still remains considerable uncertainty associated with climate model predictions. Incidentally, the IPCC does provide values for the relative qualitative/semi-quantitative/quantitative uncertainty associated with future climate change predictions (IPCC, 2007b). Treatment of uncertainty by the IPCC involves characterisation and communication of two distinct concepts: uncertainty in terms of *likelihood* or in terms of *confidence* in the science. *Likelihood* is relevant when assessing the chance of a specific future occurrence or outcome, and is often quantified as a probability. *Confidence* is composed of two separate but related elements: the first element is the amount of evidence available to support the determination that the effectiveness of a given adaptation approach is well-studied and understood; the second element is the level of agreement or consensus within the scientific community about the different lines of evidence on the effectiveness of that adaptation approach (IPCC, 2007b; CCSP, 2008).

In the United States, the **Department of Water Resources (DWR)** recently released the United States' first state-level climate change adaptation strategy for water resources, and the first climate change adaptation strategy for any sector in California. The report by DWR (2008) details how climate change is already affecting the state's water supplies and sets forth ten adaptation strategies to help avoid or reduce climate change impacts to water resources. Because of the large role of local and regional water management, central to these adaptation efforts is the full implementation of Integrated Regional Water Management (IRWM) plans, which will address regionally appropriate management practices that incorporate climate change adaptation. Among the full list of ten adaptation strategies outlined, relevant adaptation strategies for Australia's water industry include:

1. *Provide sustainable funding for state-wide and integrated regional water management*.
    - Activities that demand certainty and continuity of funding include: regional water planning; inspection; maintenance and repair; rehabilitation of flood management facilities; observational networks; and water-related climate change adaptation research.
2. *Fully develop the potential of integrated regional water management (IRWM)*.

- Future IRWM plans should identify strategies that can improve the coordination of local groundwater and surface storage with other water supplies such as recycled wastewater, surface runoff and flood flows, urban stormwater, imported water, water transfers, and desalinated water.
- Future IRWM plans should include specific elements to adapt to a changing climate, including: an assessment of the region's vulnerability to the long-term increased risk and uncertainty associated with climate change (e.g., an integrated flood management component and a drought component); aggressive conservation and efficiency strategies; integration with land use policies that help restore the natural buffering and storage capacity of catchments, and encourage low-impact development to reduce water demand, capture and reuse stormwater and urban runoff, and increases water supply reliability; and a plan for entities within a region to share water supplies and infrastructure during emergencies such as droughts.

3. *Aggressively increase water use efficiency*.
   - Within this overall strategic objective, local and regional water use efficiency programs (agricultural, residential, commercial, industrial and institutional) should also emphasise those measures that reduce both water and energy consumption. Agricultural entities should aim to reduce water demand and improve the quality of drainage and return flows, and report on implementation in their water management plans. Recycled water is also proposed as an energy efficient, drought-proofing option for some regions and local water agencies should be encouraged to adopt policies that promote the use of recycled water for appropriate, cost-effective uses while ensuring public health protection.
4. *Practice and promote integrated flood management*.
   - Flood management should be integrated with watershed management on open space, agricultural, wildlife areas, and other low density lands to lessen flood peaks, reduce sedimentation, temporarily store floodwaters and recharge aquifers, and restore environmental flows. There is a need for improved performance of existing water infrastructure for effective flood management through enhanced cooperation between relevant bodies (stakeholders, local, state and federal agencies). State and federal agencies collaboratively established a Joint Operations Center (JOC) to assist with this task. A detailed Flood Protection Plan is also being developed to provide strategies for greater flood protection and environmental resilience under anticipated future climate change (see www.water.ca.gov/floodsafe).
5. *Enhance and sustain ecosystems*.
   - IRWM and regional flood management plans should incorporate corridor connectivity and restoration of native aquatic and terrestrial habitats to support increased biodiversity and resilience for adapting to a changing climate. Flood management systems should also seek to re-establish natural hydrologic connectivity between rivers and their historic floodplains.
6. *Expand water storage and conjunctive management of surface and groundwater resources.*
   - State, federal, and local agencies should develop conjunctive use management plans that integrate floodplain management, groundwater banking and surface storage. Such plans could help facilitate system reoperation and provide a framework for the development of local projects that are beneficial across regions. Local agencies should also develop and implement groundwater management plans as a fundamental component of IRWM plans to: effectively use aquifers as water banks; protect and improve water quality; prevent seawater

intrusion of coastal aquifers caused by sea level rise; monitor withdrawals and levels; coordinate with other regional planning efforts to identify and pursue opportunities for inter-regional conjunctive management; avert otherwise inevitable conflicts in water supply; and provide for sustainable groundwater use.

7. *Preserve, upgrade and increase monitoring, data analysis and management.*
   - Extend and upgrade monitoring programs for critical variables such as temperature, precipitation, evapotranspiration, wind, snow level, vegetative cover, soil moisture and stream flow. Similarly, improved observations of atmospheric conditions are also needed to help define and better understand the mechanisms of the underlying atmospheric processes that drive seasonal and geographical distribution of rainfall. This will help climate modellers to better project future rain and snow patterns on a regional scale. More detailed information on water (type and quantity) is also needed in order to facilitate better water planning and management.
8. *Plan for and adapt to sea Level rise.*
   - Develop an interim range of sea level rise projections for short-term planning purposes for use by local, regional and state-wide projects and activities. Also develop long-range sea level rise scenarios and response strategies to be included in future state-level water management plans.
9. *Identify and fund focused climate change impacts and adaptation research and analysis.*
   - Water supply and flood management agencies need to perform sensitivity analyses of preliminary planning studies, and risk-based analyses for more advanced planning studies. For flooding, sensitivity and risk-based analyses, local agencies should consider an appropriate risk tolerance and planning horizon for individual situations. Science-based, watershed adaptation research pilot projects should also be funded to address water management and ecosystem needs. It is suggested that funding should only be granted in those regions that have adopted approved IRWM plans.

The **California Energy Commission** has a *Public Interest Energy Research (PIER)* Program that has funded and is continuing to fund in-depth climate-related research linked to climate change mitigation and adaptation (Vine, 2008). Some of this research includes:

- The development and exploration of probabilistic California climate projections for impact and adaptation studies;
- The development of higher resolution regional model tools to explore effects of climate change and land use change;
- The demonstration of probabilistic seasonal forecasts to improve the management of water reservoirs in the state;
- The installation of climate reference stations to track and, if possible, detect climatic changes in the state; and
- Enhancements to the CALVIN water system model to investigate potential adaptation measures under a wide variety of scenarios.

Still in California, a special division of the *California Climate Change Centre* is focused on how climate change could affect the state's economy through impacts on natural and engineered water systems. Broadly, planned work for this Centre includes: constructing a California water supply database; assessing water available to various users (especially agriculture) and characterising the water rights and claims of these groups; developing water supply reliability indices; analysing the relationship between water price, availability, and agricultural production and developing marginal benefit functions for water reliability (OECD 2006).

Again in the United States, the **National Center for Atmospheric Research (NCAR)** is partnering with the **Water Research Foundation** (WRF; formerly the American Water Works Association Research Foundation (AwwaRF)) to work with water utilities to develop decision tools to facilitate assessments of water utility vulnerabilities to climate change and adaptation options. This project builds upon a previous NCAR-AwwaRF partnership project that produced an educational primer for the drinking water industry on global climate change and its potential impacts on municipal water utilities. The current project will take the next step in this collaboration by engaging a select set of municipal water providers and related regional coordinating bodies, in the development of decision support tools that will facilitate assessments of water utility vulnerabilities and response options to prospective climate changes. The project will focus, in particular, on the problem of planning in the context of uncertainties surrounding the local-scale hydrologic changes that will result from global climate change. A structured assessment process will be developed that includes decision support tools and decision analytic techniques such as risk and uncertainty analysis to help the drinking water industry conduct scientifically sound and cost-effective assessments of utility vulnerabilities and adaptation options in the context of climate variability and change. More information can be found at http://www.isse.ucar.edu/awwarf/.

## 15 APPENDIX B. IDENTIFIED ADAPTATION RESEARCH NEEDS

According to Chapter 18 of the IPCC's *Climate Change 2007: Impacts, Adaptation and Vulnerability* report (Klein *et al.*, 2007), there are a number of research needs regarding the inter-relationships between adaptation and mitigation. These include:

- Monitoring progress on adaptation and assess its direct and ancillary effects.
- A need to document which stakeholders link adaptation and mitigation. Decisions oriented towards either adaptation or mitigation might be extended to evaluate unintended consequences, to take advantage of synergies or explicitly evaluate trade-offs (e.g., between adaptation and other development priorities). Trade-offs may involve ecological benefits and consequences, as well as social and economic benefits and consequences.
- The relationship between development paths and adaptation–mitigation inter-relationships requires further research. Unintended consequences, synergies and trade-offs might be unique to some development paths; equally, they might be possible in many different paths. Existing scenarios of development paths are particularly inadequate in framing some of the major determinants of vulnerability and adaptation.
- The effect of human intervention to manage the process of adaptation in natural systems.
- Economic and social costs and benefits of adaptation, in particular non-market costs and benefits. More comprehensive and realistic cost estimates are needed for impacts and adaptation options that use up-to-date scenarios and take account of human behaviour. Both negative and positive side-effects and externalities of adaptation measures also need to be accounted for, as does the issue of discount rates and their uncertainty in considering delayed effects and inter-generational equity. According to the latest IPCC Working Group II report, information on the adaptation costs and benefits is limited and fragmented (Parry *et al.*, 2007). Better understanding of the relative costs of climate change impacts and adaptation options will allow policy-makers to consider optimal strategies for implementation of adaptation policies, especially the amount and the timing (Parry *et al*., 2007).
- Implications of adaptation on economic growth and employment.
- Development of a consistent analytical framework to analyse inter-relationships between adaptation and mitigation, including their potential and limitations.
- Empirical analysis of each of the four types of inter-relationships, in particular at the regional and sectoral levels, and for specific social and economic groups.
- The effect of development pathways on adaptation and mitigation, and vice versa.
- Requirements on national and international policy in facilitating decisions on adaptation and mitigation at the relevant institutional levels.

Chapter 11 of the IPCC's ***Climate Change 2007: Impacts, Adaptation and Vulnerability*** report (Hennessy *et al.*, 2007) highlights a number of key uncertainties and future research priorities in relation to water resources and infrastructure:

- Research into impacts and optimum adaptation strategies for projected changes in drought and floods, and implications for water security within an integrated catchment framework is required. This includes impacts on long-term groundwater levels, water quality, environmental flows and future requirements for hydro-electricity generation, irrigation and urban supply.

- A re-evaluation is required of probable maximum precipitation and design floods for dams, bridges, river protection and major urban infrastructure.
- More research is required as to how local communities can shape adaptation and of adaptation options for Indigenous Australian communities, especially for those on traditional lands. Priority should be given to reducing the vulnerability of 'hotspot' areas through:
    - identification of mechanisms that governments might use to reduce vulnerability;
    - better understanding of societal preparedness and of the limitations and barriers to adaptation;
    - better definition of costs and benefits of adaptation options, including benefits of impacts avoided, co-benefits, side effects, limits and better modelling;
    - analysis of various options for social equity and fairness, the impacts of different discount rates, price incentives, delayed effects and inter-generational equity.

Chapter 3 of the IPCC's ***Climate Change 2007: Impacts, Adaptation and Vulnerability*** report (Kundzewicz *et al.*, 2007) outlines a number of key uncertainties and future research priorities in relation to freshwater resources and their management. Although the stated research needs arguably relate more directly to the *Water Resources and Freshwater Biodiversity* adaptation network within NCCARF, some of these also inherently relate to water supply infrastructure:

- **Research into the water–climate interface** is required to improve understanding and estimation, in quantitative terms, of climate change impacts on freshwater resources and their management, and to fulfil the pragmatic information needs of water managers who are responsible for adaptation. Among the research issues related to the climate–water interface, developments are needed in the following areas:
    - It is necessary to improve the understanding of sources of uncertainty in order to improve the credibility of projections.
    - There is a scale mismatch between the large-scale climatic models and the catchment scale, which needs further resolution. Water is managed at the catchment scale and adaptation is local, while global climate models work on large spatial grids. Increasing the resolution of adequately validated regional climate models and statistical downscaling can produce information of more relevance to water management.
    - Impacts of changes in climate variability need to be integrated into impact modelling efforts.
    - Improvements in coupling climate models with land-use change, including vegetation change and anthropogenic activity such as irrigation, are necessary.
    - Climate change impacts on water quality are poorly understood. There is a strong need for enhancing research in this area, with particular reference to the impacts of extreme events, and covering the needs of both developed and developing countries.
    - Relatively few results are available on the economic aspects of climate change impacts and adaptation options related to water resources, which are of great practical importance.
    - Research into human-dimension indicators of climate change impacts on freshwater is in its infancy and vigorous expansion is necessary.

- o Detection and attribution of observed changes in freshwater resources, with particular reference to characteristics of extremes, is a challenging research priority, and methods for attribution of causes of changes in water systems need refinement.
- o There are challenges and opportunities posed by the advent of probabilistic climate change scenarios for water resources management.
- o Despite its significance, groundwater has received little attention from climate change impact assessments, compared to surface water resources.
- o Water resources management clearly impacts on many other policy areas (e.g., energy projections, nature conservation). Hence there is an opportunity to align adaptation measures across different sectors. There is also a need to identify what additional tools are required to facilitate the appraisal of adaptation options across multiple water-dependent sectors.

- **Greater data availability is required**. Progress in research depends on improvements in data availability, calling for enhancement of monitoring endeavours worldwide, addressing the challenges posed by projected climate change to freshwater resources, and reversing the tendency of shrinking observation networks. Broadening access to available observation data is a prerequisite to improving understanding of the ongoing changes. Data on water use, water quality, and sediment transport are also urgently needed.

Kenway *et al*. (2008) in ***Water–energy futures for Melbourne: the effect of water strategies, water use and urban form*** make a number of future research recommendations to progress the understanding and management of water–energy interactions in the urban water cycle planning and policy, including:

- Improved characterisation of energy use through the urban water system. This should include improved spatial representation in water and wastewater treatment and transport to improve analysis of water strategies including alternative options such as rainwater tanks. Initial focus on water and energy savings should be on picking the 'low hanging fruit' first (e.g., demand management measures, optimising energy efficiency of current water and wastewater treatment operations and developing new industry concepts);
- Evaluate long-term plans which govern the urban form of Melbourne (i.e. Regional Plans or strategies of 30 year plus time-frames) in detail for their projected flows of water, energy and system-wide influences. Such analysis could help identify solutions which simultaneously reduce water and energy use. Supporting social and economic analysis would also be warranted to evaluate the overall costs and benefits of alternative future urban form for Melbourne.
- Include energy implications as well as the energy of water use and total urban systems energy use when water management strategies are prepared. This is important to ensure true energy-neutrality (and in future carbon-neutrality) of water supply strategies. It will also help establish the relative contribution to energy and greenhouse conservation that is being progressed by the water sector.
- Collaborative development of more detailed and far-reaching scenarios with input from government, industry and the community to identify the potential influence of policy considerations on future water and associated energy needs. By developing more detailed analyses of key drivers (including urban form, demographics, life-style and end-use water and energy demand, technology adoption, climate and energy and water supply), there is an opportunity to greatly improve our knowledge of these complex interactions and inform policy accordingly. Consideration of wider-scale reuse including potable substitution would be warranted.

- Undertake analysis to separate the water and energy savings of scenarios involving solar hot water systems and water demand management – in combination with water supply options (e.g., reuse, desalination and water conservation). This would enable improved understanding of the relative magnitude of policy choices in these domains.
- Clarify the "relative environmental benefit" of water and energy savings. As an example, current policy enables new developers to choose between "water" options such as rainwater tanks and "energy options" such as solar hot water systems. Each of these strategies will have a different (water or energy) outcome; however, it is not yet clear which achieves the "best" overall outcome (or how much energy outcome is worth how much water outcome).
- Analyse industrial and commercial water and related energy use. Preliminary information suggests that consumption of energy by industry associated with the "industrial" use of water is at least as large as residential energy use for water, yet relatively little information exists at present in the public domain.
- Review virtual water accounting methodologies to inform their application in an Australian context. Particular issues to address include water abstraction versus rain-fed systems, international trade and water reuse. Future simulations to inform projections of virtual water flows through Melbourne are also recommended.
- Characterise greenhouse gas emissions (including methane, nitrous oxide) through the urban water cycle from water storages, through use and downstream to wastewater treatment and discharge. No detailed analysis was possible in this study due to limitations in underlying data sets.
- Develop reporting mechanisms and indicators to help improve the base-level understanding of urban water and energy interactions. Research and consultation is necessary to develop suitable reporting approaches. An example would be that our guides for reporting by water utilities (e.g., WSAA 2005; National Water Commission, 2007) could be expanded to include energy use associated with water use. Similarly, performance indicators for Melbourne's total energy budgets could be developed together with allocations for its components.
- A challenge for future analysis of urban water–energy–greenhouse interactions is to bring together information and skill sets which have traditionally been managed separately including water and energy supply, use and conservation. Investigations which integrate across these boundaries will help progress our understanding of these inter-relations in our complex urban systems.

More recently, Kenway (2009) in a presentation to Engineers Australia suggested an expansion of this water–energy inter-relationship to *water–energy–nutrients* and the food cycle. Interestingly, this linkage to food was also highlighted in a 2008 World Economic Forum publication (WEF, 2008). According to WEF (2008), the debate has traditionally focused on the interaction between water and energy from both a supply and a demand perspective. Developing truly effective solutions, however, depends on adding a third dimension to that debate—the challenges to food production. Not only are many food crops today also being used as feedstock for energy production, but regardless of the end use, food production requires enormous amounts of water. WEF (2008) suggests that future research effort should, therefore, explore the concept of expanding the 'water–energy' nexus to *water–energy–food* in order to address and evaluate future challenges on all three dimensions.

Recognising the intrinsic links between the water and energy sectors, and in a similar vein to the suggestions of Kenway *et al*. (2008) above, the UK water industry has recently emphasised the need for greater collaboration and partnership between the water and energy sectors.

According to a recent December 2008 briefing (Water UK, 2008), **the biggest risk to water service providers is loss of power**, such that the water industry needs to work with power suppliers to foster new alliances and develop innovative solutions to improve cross-sector resilience (particularly in the face of increasing future energy demands). The link between climatic variables and residential and commercial sector energy use has been widely documented for some time (e.g. Sailor, 2001; Pardo *et al*., 2002; Amato *et al*., 2005). The effect of higher temperatures is likely to be an increase in peak energy demand, suggesting that there will be a need to install additional generating capacity over and above that needed to cater for underlying economic growth (Pittock, 2003). Considering that the capacity of energy supply networks to meet peak electricity demands is challenging for some major Australian cities (e.g., Adelaide), especially on hot summer days, this will continue to be a major concern for energy suppliers into the future (Pittock, 2003). Considering also the large-scale dependence of the water sector on centralised reticulated electricity, the potential for water utilities to be exposed to failures in power supply is significant and is understandably a major concern for water service providers; emphasising the need for joint action and solutions with the energy sector.

Vine (2008), in relation to future research needs for California's electricity sector, suggested that more research is needed to develop detailed relationships between changes in temperature (including temperature extremes) and patterns of electricity consumption and demand, and following on from this, research into the implications of changing regional patterns of energy use for regional supply institutions and consumers (including water suppliers and operators). Vine (2008) also highlighted possible future adaptation measures such as the development of technologies that minimise the impact of increases in ambient temperatures on power plant equipment and technologies that conserve water use during water-intensive thermoelectric power plant cooling processes. Among the predicted impacts of climate change is an increased demand for peak electricity to power air conditioning units. During 2004 in California, for example, 30% of peak demand was attributable to residential and commercial air conditioning use alone. In order to meet the increased future energy demand for air conditioning, onsite or locally-based renewable energy systems (e.g., as part of a "microgrid") may become particularly interesting (e.g., the installation of a small wind generator next to a building or the placement of photovoltaic arrays on exterior structures). The state of California has been particularly progressive in recognising the need for co-management of water and energy efficiency measures for climate change adaptation in the context of water resources management. A recent report by the State's Department of Water Resources (2008) details a suite of ten adaptation strategies to help avoid or reduce climate change impacts on water resources, one of which includes an emphasis on water use efficiency measures that reduce both water and energy consumption.

Another option currently under consideration is the upgrading or replacement of existing 'water hungry' power stations with less water intensive plants. Such a project is currently proposed for Humboldt Bay in Eureka, California, with the replacement of the existing power plant recently receiving regulatory approval (WEF, 2008). The current Humboldt Bay power plant uses a once-through cooling system that draws water from the ocean, whereas the proposed replacement plant will use an air radiator cooling system on a recirculating closed loop (similar to an automobile radiator). The current plant's water demand is approximately 197,000 L $min^{-1}$, while the proposed replacement facility would require only 6.3 L $min^{-1}$ (WEF, 2008). So-called "dry cooling" alternatives such as air-cooled power generation systems are another alternative that warrants future consideration, particularly for Australia. Incidentally, Origin Energy Australia in 2007 commissioned the construction of a gas-fired air-cooled power station at Darling Downs, QLD. Once operational in 2010, the power station will emit about half the GHG emissions of a coal-fired power station, saving some 2.5 million tonnes of GHGs $year^{-1}$. Since the power station is air-cooled, it will also use less than three per cent of the water a conventional water-cooled coal-fired power station would use, equivalent to a water saving of about 7800 ML $year^{-1}$ (Origin Energy Australia, 2009). Wurtz and Peltier (2008) suggest that air-cooled power generation systems are becoming increasingly popular in many regions around the world and for reasons other than water availability. Given the water intensive nature of thermoelectric power generation (each kWh of electricity generated requires around 95 litres of water) (Vine, 2008), the potential for water savings through energy demand-management is clear.

Proust *et al*. (2007) also echo the needs highlighted above in calling for:

- Investment in energy and water data with good spatial discrimination to allow the past century to be described adequately and the next century projected;
- Institutional analysis of the, currently largely unconnected, water and energy policy and management systems, (i) to accurately describe these systems, and (ii) to identify means of enhancing trade-offs and synergies across water and energy technology, management and policy;
- Investigation of the scope for development of overarching strategies, frameworks and guidelines to drive innovation for decoupling physical throughput from economic return, with two dimensions: (i) decoupling energy use from water use, and vice versa; and (ii) decoupling economic growth from both energy and water use (with reference to trade-balance implications of both). In focusing on such decoupling, particular attention should be paid to the development of low carbon and water-use production systems in export-oriented industries, in the light of future shifts in market demands toward low-impact products and services;
- Using scenarios of long-term population and affluence trends, compare and contrast the options available to meet water demands in larger and smaller urban areas, and in rural households (e.g., efficiency, water tanks, desalination, inter-basin transfers, new dams, recycling) and the energy demands of different options;
- Development of nationally consistent protocols for gathering and analysing energy and water-consumption data in towns and cities, to enable effective linkage with demographic, socioeconomic and behavioural variables and to inform understanding of varying consumption patterns that underpin the selection of management strategies;
- Assessment of the move toward 'energy service companies', and of the degree to which this commercial and institutional model could be extended to the water sector, to deliver water-efficiency-focused planning and technology packages across diverse regional applications.

Across all of the above areas, Proust *et al*. (2007) suggest that R&D will need to factor-in projected climate change and increased variability in analysis of energy and water production and use.

In line with the above, an April 2009 IWA position paper on Climate Change submitted to the UNFCCC (IWA, 2009) highlighted the need for a future focus on synergetic adaptation action (e.g., water efficiency versus energy efficiency, energy savings/recovery by water utilities, water savings by consumers). The water sector is dependent on the availability of energy, but it also has the potential to partner with others to more effectively extract the energy from water and wastewater processes—reducing energy use and GHG emissions. The *water–energy* nexus means a completely new paradigm for the industry and one where overlaps need to be identified. According to IWA (2009), this 'water–energy' overlap calls for working toward solutions together on joint key issues rather than in individual sectors, and requires collaborations reaching "outside the water box". Marsh and Sharma (2006) provided a brief overview of the consideration of the water–energy nexus in Australian and international water and energy sector policy. The authors reported that consideration of the impacts of the water–energy nexus on policies and decisions appeared lacking, and although several water–energy models did exist internationally across both the energy and water sectors, limitations of current models (in terms of scope and a failure to consider the role of the wider economy in nexus issues) reduced their effectiveness for policy analysis. Marsh and Sharma (2006) suggest that a more integrated model that links water and energy industries with the economy at large (e.g., based on input–output analysis) may be better suited to assist policy makers in making more informed decisions on issues affecting these industries.

The Victorian State Government's report *Melbourne 2030: Planning for Sustainable Growth* Report (DSE, 2003) identifies the shift towards a more compact urban form as a primary objective for ensuring future sustainable growth (i.e. shifting away from the current situation of low density suburban developments). Kenway *et al*. (2008) predicted that this situation would result in a 50% reduction in total water use (due to loss of gardens); although Troy *et al*. (2005) showed that the patterns of water use in Sydney were the same for people living in separate houses as they were for those in high density dwellings suggesting a degree of spatial variability in water use profiles that need to be considered. Urbanisation alters the hydrology of catchments leading to the degradation of river ecosystems. Urban form can also impact on stormwater runoff as it can influence both the area and density of impervious surfaces that generate runoff. Predicted climate change impacts will alter future stormwater flows (they may increase them due to more predicted rainfall in some regions of Australia, or may decrease stormwater flows due to decreased future rainfall and increased rates of evaporation). Reductions in generated stormwater will also impact on inflows to urban waterways. There is a recognised general need for more engineering research on urban stormwater management (Mehdi *et al.*, 2004).

**Role of Local Government in climate change adaptation**: It is widely recognised that Local Governments play an increasingly critical role in managing the implications of climate change in the coastal zone (Withycombe *et al*., 2008). Consequently, local Governments require increased information and greater understanding of the effects of climate change and additional tools to assist and support their future management decisions in adapting to climate change, yet education and understanding of adaptation issues at the Local Government level remains a major barrier to implementation. Results from a survey of 15 Sydney Coastal Council members (Withycombe *et al*., 2008), showed a number of findings:

- Climate change adaptation is an emerging issue facing Councils (past focus was on mitigation);
- There was clear evidence that climate change is generally, but not universally, accepted as an issue for infrastructure, planning, and communities;
- Climate change tended to be considered as one of many environmental issues and was usually left to the environmental divisions within Councils for planning and action;
- The role of councils in addressing climate change is poorly defined;
- Climate change is mostly ignored in the process of regulating development;
- Local governments currently have responsibility for a wide range of infrastructure that may be impacted on by climate change, yet there is little understanding within councils about their level of vulnerability to climate change impacts;

- There is an absence of systematic monitoring and evaluation of climate change adaptation initiatives;
- Councils are well placed to play an important role in future community engagement activities to facilitate climate change adaptation; and
- Councils would prefer to lead by example; engage with communities on climate change issues; manage climate change risks; and also provide stewardship for their local environments.

Local government has a major responsibility to plan for the long-term sustainability of local communities. Local communities will be required to plan for the anticipated impacts of change in the climate system and flow-through consequences on infrastructure, agriculture, health and general wellbeing (NGA, 2009). Local Government has demonstrated an existing commitment to addressing its role in climate change and the impacts of climatic change, through programs such as the Cities for Climate Protection (CCP) Australia campaign (see http://www.environment.gov.au/settlements/local/ccp/). Local Government is considered to be well placed to lead communities by example in mitigating and adapting to climatic change (LGSA NSW, 2006). Implementation of climate change and adaptation plans will require resources, and while the cost of some initiatives and changes to existing practices might be expected to be met within councils' normal operating budgets, it is expected that there will be a number of urgent and capital intensive adaptations that will be required. For example, recent coastal storm activity has demonstrated the vulnerability of urban and rural lands along the coastline. Improving the resilience of infrastructure, land use planning and introducing long-term strategies such as the re-location of assets at risk, will be required (NGA, 2009). According to a National Local Government Association report (NGA, 2009), local government believes that high priority should be given to water saving and recycling initiatives particularly in urban and regional centres. Given the effects of climate change, drought and heightened awareness of the need for water conservation at the community level, improved security of supply, and associated water infrastructure, local government recognises the need for increased water recycling and water sensitive urban design (WSUD) initiatives.

In September 2006, a survey (coordinated by the Local Government and Shires Associations of NSW (LGSA) in conjunction with the NSW Greenhouse Office) was issued to all 152 NSW councils in order to specifically assess their current and future needs with respect to mitigation and/or adaptation measures implemented at the Local Government level (LGSA NSW, 2006). Results from the survey showed that Local Government in NSW is generally keen to be provided with the capacity and necessary tools to effectively assist in addressing the varied challenges that climate change may bring to their local region. In particular, councils are very interested in:

- Obtaining information to assist them in both risk assessment and insurance related matters and their potential exposure as a result of climate change;
- The provision of a web-based "Climate Change Action Pack" containing information that includes (but is not limited to): scientific facts; model policies; best practice examples; checklists to address climate change; educational material and programs; and a list of key contacts and web links. This *Climate Change Action Pack* would ideally be supplied in a multimedia format that is constantly updated, relevant and interactive.

A number of wider issues and recommendations also arose from this survey, including:

- A need for councils to have up-to-date information and assistance on how to best manage particular climate change impacts in their bio-region (e.g., the likelihood of reduced rainfall, more frequent and severe periods of drought, storm events increasing in severity and the likelihood of a rise in average temperatures);

- A recognition that councils generally appear to be doing little in terms of measuring or monitoring the effects of climate change over time or undertaking research or commissioning reports from experts on its local impacts. It was suggested that some formal discussion between all three tiers of government should take place to ascertain whether these activities are being undertaken by other governments (or agencies) and exploring the advantages/disadvantages in undertaking these activities on a bio-regional basis for use by Local Government;
- An urgent need for councils to be provided with advice relating to risk assessment and potential liability issues as they apply to climate change and its associated impacts. The NSW LGSA was considered the best vehicle to engage appropriate legal and insurance related advice for eventual dissemination to all member councils;
- A need to consolidate and re-evaluate previous climate change adaptation and/or mitigation education initiatives implemented by councils, with a view to developing case study examples for a limited number of highly effective initiatives so that they can then be more widely communicated to Local Government (e.g., via inclusion in the proposed *Climate Change Action Pack*);
- The need for a clearly articulated consultative program in order to ensure that the *Climate Change Action Pack* encourages regular feedback from relevant stakeholders (e.g., council officers, state and federal government agencies, NGOs etc.) during its development phase. The benefits of wider engagement with these stakeholders will be a greater likelihood of council adoption and/or implementation of measures included in the Pack;

Local Government adaptation measures outlined by the **Department of the Environment and Water Resources** (SMEC Australia, 2007) in relation to planning suggest a need for:

- Polices that ensure that the water resource implications of new developments are assessed;
- The promotion of water sensitive urban design (WSUD) at the plan-making and development-assessment stages of the planning process;
- Policies that incorporate demand management strategies such as roof water harvesting in residential areas.

The above findings demonstrate a clear recognition of the need for adaptation measures and an understanding of the prominent role that local government should play in implementing these measures, but a lack of knowledge regarding how to go about educating the relevant people and instigating the adaptation process. This ties into the need for improved education and awareness of climate change science and climate change adaptation approaches by water sector employees. As highlighted by the US Climate Change Science Program (CCSP, 2008), developing adaptation options to climate change may require that relevant staff have a more technical understanding of climate change as well as the adaptive capacity of social and economic environments. The challenge in implementing such education programs is that climate change science itself is rapidly changing, and so this emphasises the need for good relationships between climate change scientists and water industry staff as well as highlighting the importance of effective means of communication between the two key groups.

Urgent need exists to inform policy makers, managers, stakeholders, and the public about the specific evidence of climate change and its predicted consequences on important water resources (Peterson *et al.*, 2008). According to Peterson *et al*. (2008), education on the scale necessary is challenging and will require new initiatives that make use of a variety of existing media tools and evolving platforms (such as the internet and cell phones) to provide the public with accurate and unbiased information. The information cannot reach far enough or rapidly enough if restricted to traditional delivery in school curricula. In parallel to adaptation via water pricing and policy/legislation, there is also a need for greater understanding of the environmental justice and social equity consequences of such adaptation measures (Mitchell *et al.*, 2007; Wilbanks *et al.*, 2007; Peterson *et al.*, 2008). Such factors are considered by adopting an interdisciplinary approach to water resources management such as that of the US Water Environment Research Foundation's 'sustainable water resources management' (SWRM) framework (WERF, 2006). Future research priorities also include studies that assess the socioeconomic impacts of adaptation options, as well as research into methods of reducing ecosystem vulnerability to disturbances that will be brought about or exacerbated by climate change (e.g., distribution of invasive species, altered water source ecology and toxic cyanobacterial blooms) (CCSP, 2008).

The **American Water Research Foundation (WRF)** (previously AwwaRF) has outlined a range of research projects for consideration in relation to climate change and the water industry, one of which is a project investigating the impact of climate change on the ecology of algal blooms (with focus on algal toxins and taste and odour problems) (AwwaRF, 2008). Similarly, a project entitled '*Cyanosurvey: A National Update on Toxic Cyanobacteria and their Distribution*' (see http://www.wqra.com.au/temp/Cyanobacteria_2009.htm) is currently being put forward by Water Quality Research Australia, with the project to be coordinated by the Australian Water Quality Centre in Adelaide. The project will aim to source cyanobacteria samples from as many habitats in Australia as possible, with the anticipated outcomes of the *Cyanosurvey* project being:

1. An up to date understanding of geographic and habitat distribution of toxic cyanobacteria in Australia;
2. A better understanding of genetic differences between similar strains which can be used to refine our risk assessments;
3. Predicting possible changes in cyanobacterial distribution under a changing climate; and
4. Cross-validation of a range of toxin/toxicity detection methods, with recommendations for usefulness in terms of operation requirements.

According to **Hennessy *et al*. (2007)**, toxic (freshwater) algal blooms are likely to become more frequent in Australia and last longer due to climate change. Current thinking suggests that regional and global climatic change may benefit various species of harmful cyanobacteria by increasing their growth rates, ecological dominance, temporal persistence, geographic distributions and activity (Wiedner *et al.*, 2007; Paerl and Huisman, 2009). Future climate change scenarios predict rising temperatures, enhanced thermal stratification of aquatic environments, and alterations in seasonal and inter-annual weather patterns (including droughts, storms, floods); changes that would favour harmful cyanobacterial blooms in eutrophic waters (Paerl and Huisman, 2009).

A paper by **Mukheibir and Ziervogel (2007)** discusses how the previous international focus (United Nations Framework Convention on Climate Change, UNFCCC), has been mainly centred around mitigation of greenhouse gas emissions, and how recently there has been a shift in focus, where policy makers and academics have begun to debate the issues surrounding adaptation to future climate impacts and to consider the implications for the future. Mukheibir and Ziervogel (2007) suggest that previous climate change adaptation frameworks have had a regional or national focus and that it is necessary, therefore, to **develop frameworks for adaptation to climate change at the municipal level** in order to prioritise the most urgent local adaptation activities and identify the required **local** human and financial resources. If climate variability is to increase, it is necessary to understand how climate impacts on the different sectors and their resultant vulnerabilities. This will focus attention on where priority intervention might reduce the impacts of climate change, and help cities to adapt rather than react when the damage has already been done. In terms of urban water supply management, some of the adaptation initiatives outlined by Mukheibir and Ziervogel (2007) included reducing water leaks from distribution networks. Research on acoustic leak detection systems in the US (Connellsville, PA) resulted in a reduction in leakage losses of 12% over a one year period (AwwaRF, 2008), demonstrating the value of this avenue. In Australia, recent initiatives by Sydney Water have seen the installation of more that 80 new pressure regulating valves installed across greater Sydney. The new valve technology works by regulating water pressure in distribution networks, significantly reducing the risk of leaks and breaks. The initiative is currently benefiting some 106 suburbs across the Sydney basin and is already leading to around 10 ML of water savings per day, with this daily saving predicted to increase to 30 ML by 2012 (NSW Government, 2009). In terms of stormwater and flood risk management infrastructure, some of the climate change adaptation initiatives outlined by Mukheibir and Ziervogel (2007) included reducing the impacts of these natural hazards through infrastructural means, such as flood detention ponds and weirs, and the ongoing maintenance of stormwater drains to clear them of sand build-up and rubbish. Mukheibir and Ziervogel (2007) also suggested water policy reform options as a means of adaptation (incentives, regulations) as was also suggested by UNFCCC (2008) in terms of pricing and irrigation policy reform.

A report by **Amitrano (2007)** identified a number of research needs for adaptation in relation to preparing buildings for climate change, and although the specific focus is on commercial and residential infrastructure, some of the future research needs may also apply to water infrastructure:

1. The climate change scenarios used in this scoping study were based on readily available material. If further research is to be conducted on the potential impacts of climate change on buildings, then more specific scenarios are needed. More information is needed on potential changes in extreme events such as heavy rainfall, flooding, hail, tropical cyclones, wind gusts, storm surges and bushfire that may affect decisions about regional building standards. For example, do buildings need to be built to higher standards for extreme winds and bushfires. Since some impacts depend on combinations of changes in multiple climate variables (e.g., temperature and rainfall), it is important to assess links between changes in temperature and rainfall, rather than broad ranges of change based on many climate models. The recommended approach is to provide climate-model-specific scenarios for as many climate variables as possible, using at least two climate models that perform well in the regions of interest. This was the approach used by McMichael *et al*. (2003), who considered health impacts in 2020 and 2050. More information is also needed on potential changes in extreme events such as heavy rainfall, flooding, hail, tropical cyclones, wind gusts, storm surges and bushfire.

2. Further investigation is necessary into a framework that allows climate change to be harmoniously incorporated into both land-use planning and building standards, so they work effectively together ensuring no 'gaps' in the building process. This is particularly important for both urban water use and flooding. Developing a framework will allow localised areas e.g., councils to concentrate of the specific issues in their area but use the framework guidelines to ensure consistency with other councils.

3. Future-proofing and protecting Australian buildings against climate change may require incorporation of adaptation options into the building code. The inclusion of sustainability as a goal in the Building Code of Australia provides an opportunity for doing this (by incorporating separate, new clauses – or worked in as part of existing clauses).

4. Encourage and support initiatives that are aimed at mainstreaming sustainable design and construction e.g., use of the Your Home manual, the Housing Industry Association's Greensmart programme, etc. This will by default improve the resilience of new buildings to the impacts of climate change.

5. Encourage and support research into novel systems and technologies for the adaptation of residential and commercial buildings to climate change.

6. There is also a need to research prospective homeowner aspirations and needs in terms of home design versus the expectations and strategies of home designers and builders, and the extent to which either/both are in alignment or conflict with home design which is appropriate to deal with the challenges of climate change.

7. Develop a risk and condition-assessment methodology to determine benchmark levels for retrofitting and/ or accelerating retirement of Australian residential and commercial building stock.

8. It is recommended that a methodology for assessing the costs and benefits of taking retrofit action (based on the assessment of risk / determination of the benchmark level) be developed.

9. The costs of adaptation options will be a critical consideration in any analysis of their viability. At this stage it is not possible to do more than provide a rough estimate of the likely costs of selected adaptation options using some fairly crude assumptions. Therefore, more work is needed to develop more accurate climate change adaptation costs to both governments and communities.

**Preston *et al*. (2008b)** in the ***Mapping Climate Change Vulnerability in the Sydney Coastal Councils Group*** report identified several key research questions relating to vulnerability assessments and adaptive capacity assessment in coastal councils:

- What is an appropriate framework for assessing and communicating vulnerability? Should researchers continue to rely upon constructs such as exposure, sensitivity and adaptive capacity in participatory environments, or should these concepts be translated and incorporated into more traditional hazard models to ease stakeholder communication?

- What are the data and information requirements for conducting a vulnerability assessment? How much information is required to achieve different goals and what are appropriate/relevant indicators that can be used for vulnerability assessment?
- What is the relative importance of different components or individual indicators of vulnerability (i.e., significance of climate versus landscape characteristics versus adaptive capacity) and to what extent can more rigorous statistical treatment of vulnerability indicators aid in their prioritisation and integration?
- How do researchers and stakeholders quantify and manage the uncertainties inherent in vulnerability assessment in using assessment outcomes for prioritisation and decision-making? To what extent can vulnerability assessments be validated to build confidence in their representations of future states?
- At what scale should vulnerability assessments be conducted to provide useful information to stakeholders? Is the tendency to pursue increasingly high-resolution data and assessment outputs warranted or necessary to inform stakeholders about vulnerability and risk?
- What is the relationship between climate change vulnerability and the risk of adverse consequences? Is there utility for stakeholders in the identification of spatial areas associated with greater susceptibility to adverse impacts, or are efforts better invested in developing tools fore more predictive analyses of specific outcomes (natural hazards, economic damages, or social consequences) and their probabilities?

Vulnerability assessment is key, since "*the degree of vulnerability indicates the amount of adaptation that is required within the context of our history, infrastructure, and technologies*" (Wheaton and Maciver, 1999). Climate change vulnerability assessment also has a high degree of spatial variability associated with it (Preston *et al.*, 2007)—further complicating the already difficult task. This suggests that vulnerability assessments have to be done on small scales or regionalised

A report by Kinrade and Justus (2008) based on interactions with five member Councils of the **Western Port Greenhouse Alliance (Victoria)** identified the critical importance (in terms of resources and efficiency) of prioritising the large number of climate change risks in order to direct adaptation response resources to where they are most needed. They also cited a number of generic issues that point to major factors for consideration when planning and carrying out adaptation responses; included:

- the need for a whole of government approach to climate change adaptation, with effective coordination between the three tiers of government;
- the need to deal with resource constraints likely to be encountered when implementing climate change adaptation policies and programs, especially at the local government level; and
- the importance of fully engaging communities in all aspects of the climate change issue.

The report by **Kinrade and Justus (2008)** also raised a number of issues and needs for local government in relation to flooding of low-lying areas (from both sea level rise and increased precipitation) and increased flash flooding from stormwater drainage system overloading. Firstly, local councils in the Western Port region face a great deal of uncertainty over the application of planning approval processes to developments in areas affected (or potentially affected) by coastal inundation and inland flooding. This uncertainty stems from a number of factors, notably:

- absence of clear directions in relevant legislation and planning schemes on how exposed areas should be treated in approval processes;
- lack of high resolution data enabling areas exposed to future inundation to be pinpointed (i.e. 'lines on maps'); and
- gaps in existing flood mapping and uncertainty over who bears responsibility for filling those gaps.

Based on workshop outcomes, group recommendations of the 'preferred adaptation measures' in relation uncertainty over or lack of planning controls in areas affected by coastal inundation or flooding were as follows:

1. **Climate change legislation should be developed** and enacted by the state government to provide clear directions on dealing with climate change in planning and approvals processes. Existing state planning legislation should also be reviewed and amended as necessary. The legislation reform package will require active participation of state government departments and agencies, as well as local government, federal government, water authorities, CMAs and the Central Coastal Board.
2. **Local planning schemes should be amended** to include specific provisions on the treatment of sea level rise and storm surge projections in relation to land protection, use, and development. Amendments are required to overlays and zones and 'buyer beware' conditions must also be added. Provisions need to be supported with robust science and tools (e.g., GIS).
3. **Extensive consultation with stakeholders and the community** is required before decisions are made on legislative and planning scheme changes.
4. **Multi-disciplinary research and data collection**, funded by federal and state governments, is required to support planning and infrastructure decision making in coastal areas. The 'Future Coasts' coastal vulnerability assessment currently being completed by DSE Victoria should fill some data gaps. Once it has been completed, councils in the Western Port region should compile and prioritise a list of further research needs.
5. **Capacity building measures** are needed to improve decision makers' understanding of regional climate changes (ranges and uncertainties) and to ensure a consistent and transparent approach to the treatment of climate change by local government, state government, VCAT and the judiciary.
6. **A communications strategy** should be developed by WPGA councils to educate local residents, developers and the media about climate change and coastal issues in the region. The strategy needs to draw upon best available data, provide information on what is known and uncertainties and be presented in a way that is consistent, whilst avoiding scaremongering.
7. **Responsibility for local stormwater management** needs to be clearly defined and established in legislation. At present, there is a lack of clarity on this question, with management responsibility being shared between local councils, Melbourne Water, other water authorities, CMAs and DSE. It is recommended that DSE become the 'champion' for driving this legislative reform, with strong input being provided by other stakeholder agencies.
8. **Local stormwater levels and inundation mapping** is required across the Western Port region and other parts of Victoria taking into account intense rainfall projections under climate change scenarios. Preference should be given to a single agency (e.g., DSE or Melbourne Water) having responsibility for the task and acting as custodian for all relevant inundation and property data. Revenue mechanisms to fund the inundation mapping may need to be sought.
9. **Research into drainage design, peak flows and runoff** should be undertaken, with drainage design guidelines being revised to take account of changes to extreme rainfall

intensity projected under climate change. A coordinating agency needs to take responsibility for the research at the state level (e.g., DSE).

According to a 2008 Peer Workshop on Adaptation to Climate Change Impacts, the **US Department of Transportation** (http://www.fhwa.dot.gov/planning/statewide/pwsacci.htm#ftn1) has identified a number of future needs (although they are transport infrastructure oriented, they may still apply to water infrastructure):

**Policy and Guidance Needs**

- Definition(s) of "critical infrastructure" and "strategic investments"
- Prioritisation frameworks for climate change adaptation needs in context of overall transportation investment, and between adaptation and mitigation-related investment
- Definition of "strategic disinvestment" and guidance on its application in context of climate change adaptation and diminishing revenues

**Information-sharing and Dissemination Needs**

- Establishment of a readily-accessible information database on climate change mitigation and adaptation in transportation
- Development of "manuals" on climate change adaptation for use in different situations and environments
- Active dissemination of information on research results, best practices, etc. through additional peer exchanges, the Internet and documents/reports

**Technical Assistance Needs**

- Guidance/technical assistance on vulnerable infrastructure inventorying, including data collection methods and management
- Development of flexible design guidelines appropriate for a climate change adaptation working environment
- Assistance and guidance on risk management approaches and methodologies
- Guidance on developing cost estimates for adaptation initiatives and programs

**Research Needs**

- Methods for translating global climate change trends research into local (or at least regional) forecasts that support development of appropriate adaptation strategies
- Cost-effective approaches to identifying, managing and bolstering critical infrastructure
- Improved forecasting models that specifically account for climate change scenarios and different geographies
- Development of transportation system performance measures that provide information relevant to prioritisation and decision-making on adaptation approaches and projects

The **Water Utility Climate Alliance** in the US released a *Water Sector Statement on Climate Change and Water Resources* in May 2008 (WUCA, 2008) detailing a number of future research needs relating to climate change adaptation in the water industry. They highlighted a need for:

- Predictive and decision-support tools, including necessary data resources, to help utilities plan for the future impacts of climate change. These tools and resources should include climate models that forecast precipitation changes and address other issues pertinent to water quantity and quality on a national, regional, and subregional scale; climate models that address sea level rise and its effect on coastal water supplies; and assessments to determine – on a national, regional, and subregional scale – the vulnerability of different regions to the anticipated impacts of climate change over different timeframes.

- Research focused on the impacts of climate change on water quality and quantity, stormwater and flood control management and wastewater treatment were put forward. Examples of areas where research is needed include methods to increase water conservation; energy efficiency management techniques that help water utilities reduce their own greenhouse gas emissions; the development of alternative water sources such as reuse, recycling, and desalination; and multiple benefit quantification analysis of such practices as urban tree cover and green roofs to both control stormwater runoff and help cities adapt to the consequences of climate change.
- More funding to assist with drinking water, stormwater, flood management, and help wastewater utilities to adapt to climate change and address environmental and public health risks that could result from changes to the hydrologic environment. For example, we anticipate that potential public health risks could result from higher water temperatures breeding higher concentrations of certain organisms, from changes in ambient water quality, or from more intense rainfall events. These factors could compromise treatment processes, restrict wastewater utilities' ability to discharge effluent and cause greater risk of sewage overflows. We also anticipate that drinking water, wastewater and stormwater infrastructure enhancements will be necessary to deal with regionalised impacts of these consequences.

A number of specific water industry knowledge gaps and research needs in relation to climate change adaptation were also identified during a 2002 two day workshop hosted by the ***Canadian Climate Impacts and Adaptation Research Network*** (C-CIARN) – Water Resources division **(Mehdi *et al.*, 2004)**. Although this is now some years ago, it is likely that the issues raised are still of relevance today. Issues included:

- Updated engineering design criteria based on more recent climate data. Infrastructure risk management needs to be re-thought using different recurrence data in respect of the increased occurrence of structural failures and flooding. Future work should also focus on engineering for shorter duration precipitation events.
- More data on continuous empirical observations at the national, regional and local spatial scales to address impacts and understand potential adaptations for communities and municipalities. The absence of water resources data represents a substantive knowledge gap that needs to be addressed to better understand and better cope with climate change impacts and adaptation. In particular, efforts should be made to prevent cuts in monitoring and data collection due to future budget constraints.
- Information is needed to determine likely probable changes in the source water quality and at the tap, especially as a result of extreme events, wastewater overflow, or structural failures. Developing new standards and approaches for water distribution and drainage in the face of climate change with updated information and data is needed. Implementing planning and water management at local levels in the case of structural failure or other damage is also required.
- Research on risk assessment, management and communication is an important aspect for municipalities when dealing with climate change. Information on climate change risk management is needed as a basis for informed decision making at the local level. Risk management tools for decision-makers and stakeholders need to be developed as part of a tool-kit. In addition, researchers need to develop practical tools for data capturing, monitoring, communication, modelling and for local governments to implement integrated catchment management. Part of the tool kit should include the development of

innovative tools for use by water managers to determine water allocations in the face of potential conflicts which may arise more frequently under climate change scenarios.

- Finally, research on municipal water conservation solutions, such as minimising the areas of impermeable surfaces, developing new technologies for water recycling, and investigating the different pricing structures (e.g., valuation of water resource based on fundamental uses and needs) is imperative to adapting.

A number of general interdisciplinary water-related knowledge gaps and research needs in relation to climate change adaptation were also identified during a 2002 two day workshop hosted by the ***Canadian Climate Impacts and Adaptation Research Network*** (C-CIARN) – Water Resources division **(Mehdi *et al.*, 2004)**. Although this is now some years ago, the issues raised are still relevant today and are still being seen in more recent publications. Issues included:

- **Downscaling of climate models**: there is a need for models to be downscaled from a global to a watershed or regional level, as this would enable more accurate decisions to be made with regards to managing water resources in light of climate change.
- **Improved data availability**: in order to allow decision makers to make the most accurate decisions, a greater access to climate change and water resources data was required.
- **Education and awareness**: education and awareness of potential climate change impacts and adaptation strategies for stakeholders, researchers and decision makers is considered to be lacking.
- **Communication and dissemination:** there is a need for better communication strategies and a more timely and targeted diffusion of results from the researchers to the stakeholders and to the general public was deemed necessary to adapt to climate change.
- **Price of adaptation:** Who will pay for adaptation measures implemented? Accurate pricing strategies are deemed necessary to be put in place so that the real cost of adaptations are accounted for. One means of better understanding the real cost of adaptation, is to better assess the impacts of extreme events on socio-economic factors.
- **Decisions in times of conflict & conflict resolution:** there is a need to develop appropriate decision making processes for dealing with conflicts related to water resources. The need for conflict resolution will come more and more into play, as water resources become sparser in certain regions.

A report by **Hanak and Lund (2008)** on the ***Adaptation of California's Water Management to Climate Change*** suggests a need for more integration of water-related sectors such as 'water supply' and 'flood management'; given that they are jointly reliant on many common reservoirs and channels. Other needs were also identified in the areas of *flood management* and *water quality management*.

***Flood management*** – According to Hanak and Lund (2008), further analysis is needed to explore the effects of different climate and precipitation scenarios and to examine how investments should change if the full range of policy levers were at work simultaneously, including levees, bypasses, and reservoir systems as well as land use decisions. Adaptive changes to reservoir operational policy will have significant consequences for the optimal use of reservoirs for flood protection, because it will probably be necessary to alter flood space requirements as the pattern of runoff changes. Needed reforms include forward-looking reservoir operation planning and floodplain mapping, less restrictive rules for raising local flood assessments, and improved public communication of flood risks. Given the long-term implications of today's decisions on future risk, the 'flood management–climate' connection is one of the greatest gaps in thinking and analysis regarding water system adaptation to climate change.

This is linked to the conclusions of the OECD (2006) report. According to OECD (2006), water infrastructure plays a critical role in water resources management, with dams, levees, reservoirs and drainage systems representing the key flood prevention techniques. If this infrastructure is at a high standard and its inherent resistance matches expected intensity of floods and droughts, it can perform well and will be better prepared to cope with future climate risks. This issue was also highlighted recently by Bobylev (2009) in that current estimation (and especially quantification) of urbanisation and climate change impacts on water infrastructure faces great uncertainty due to lack of data and research on the issue. Adequate preparedness of water infrastructure (including urban underground infrastructure) for climate change is critical, and more research is needed to provide policy and planning guidance for adapting urban infrastructure and growth in the context of future environmental change (Bobylev, 2009). The water industry in the United Kingdom (Water UK, 2008) has also defined a number of infrastructure-related research areas (assessments of strategic risks to infrastructure; dam and reservoir safety research; underground assets; regulatory and asset risks) as being key priorities for successful future adaptation to climate change. Furthermore, since infrastructure decisions have long-term implications, it is important that such decisions are made with all the relevant information at hand, including the most accurate regional projections of temperature and precipitation; again highlighting the need for greater meteorological data collection activities and improved regional climate models.

***Water quality management*** – Changes in water quality as a direct result of temperature increases and salinity incursion, as well as chemical interactions resulting from these processes, are likely to have significant implications for regulatory programs. According to Hanak and Lund (2008), we are at an embryonic stage of knowledge regarding the effects of climate change on water quality management. There is a need for water quality sampling networks designed to monitor for changes expected from climate change. More research is needed to investigate the likely effects of changing temperatures and runoff patterns on aquatic habitat, sedimentation and contaminant deposits, and chemical and biological processes. Modifications to water quality standards and guidelines will also be a likely necessity in response to climate change; however, this process raises the potential for significant conflicts with stakeholders and the potential for such conflicts need to be considered during the reform process. The report of Hanak and Lund (2008) recommended the commissioning of studies to understand the implications of climate change for both flood management and water quality management.

**WGA (2008)** in its report ***Water Needs and Strategies for a Sustainable Future*** identified a number of potential adaptation strategies:

- In relation to water infrastructure, more collaborative research and better methods are required to identify regional vulnerabilities and quantify related risks, acceptable levels of risk, and projected expenditures to reduce unacceptable risk.
- In relation to water infrastructure, better decision support tools are needed, as well as research into more efficient and cost effective construction and asset management techniques, processes and programs.
- Climate change scenarios need to be integrated with projections of long-term demands and the need for drought planning, more storage, water banking, water conservation, etc.

- Stormwater and other waters of impaired quality should be considered as supplemental water supplies.
- More data is needed to evaluate risks related to climate change and possible changes in operational project rule curves, etc.
- Forecasting models require more and better data to be robust and useful.
- Planning for climate changes should be undertaken at all levels, from the federal government to private and public water utilities, with participation from stakeholders.
- More focus should be on planning, while recognising the importance of preparing for emergency response.
- More water storage should be considered, accompanied by an extensive risk and cost-benefit analysis, together with an analysis of the potential for reducing demand and increasing water use efficiency.
- Greater water conservation should be encouraged, while recognising the net impact on recharge, return flows, wetlands, etc.
- Regional cooperation between water resources managers/purveyors should be encouraged.
- There is a continuing need for more dialogue and public education.

According to Smit and Wandel (2006), there is a vast body of research in the fields of resource management, community development, risk management, planning, food security, livelihood security, and sustainable development that deals with the actual practices and processes of adaptation; however, there is still comparatively little research that has focused on the implementation or 'practical application' processes for adaptation measures (at least not under the label of "adaptation" research and certainly not in the climate change field). In other words, there has been little research that investigates the adaptive capacity and adaptive needs in a particular region or community in order to identify means of implementing adaptation initiatives or enhancing adaptive capacity. Such research enables the identification and development of particular adaptive measures or practices tailored to the needs of that particular community. Smit and Wandel (2006) concluded that there has been considerable scholarship in the climate change context on calculating indices of vulnerability and adaptive capacities, and on evaluating hypothetical adaptations, yet the practical applications of this work (in reducing vulnerabilities of real people) are not yet readily apparent. This suggests a future need for case study research to 'road test' existing vulnerability assessment and adaptation tools.

The WRF held a ***Water Industry Climate Change Research Needs Workshop*** (AwwaRF, 2008) in Denver, Colorado during January of 2008 where an expert panel aided in the development of a Strategic Research Plan for the Climate Change Strategic Initiative. Various workgroups investigated and identified water, wastewater and stormwater knowledge gaps and adaptation research needs over five key thematic areas.

1. **Water Quality:**
    - Research on water quality modelling/monitoring for treatment planning and research into improved detection methodologies.
    - Research into management practices to minimise water quality variability resulting from: extreme events; the use of multiple water supply sources; and changes in demand.
    - Research into treatment processes to cater for future climate change-related changes (i.e. disinfection practices, management of aesthetic quality;

contaminant removal (e.g., disinfection by-product precursors, salinity management, microbiological contaminants).

**2. Water Resources:**

- Research into water resource modelling and decision support methods to enhance the capacity to plan a range of adaptation strategies in relation to water demand and water storage.
- Research in the area of groundwater modelling to assess the climate change impacts and compare various aquifer management approaches.
- Research into advanced treatment technologies (e.g., desalination) and water reuse in terms of: energy consumption; policy development; public perception; permitting; residual waste management.
- Research into managing the competing uses for water (e.g., water allocations, irrigation, environmental flows, drinking water supply) and into regional solutions.

**3. Infrastructure**

- Research into the effects of climate change on infrastructure rehabilitation, repair, or replacement and on associated asset management decisions.
- Adaptation of design standards or specifications, and changes in design criteria such as design storm frequency and intensity in the case of stormwater management.
- Research and development of new materials that can better withstand temperature fluctuations and direr or wetter conditions.
- Research and development of technologies that can help utilities better adapt to the effects of climate change, including the role of 'green infrastructure' and decentralised system technologies.

**4. Energy and Environment**

- Research into the impacts of changes in water resources and water availability on future energy demand (e.g., pumping from new water sources to treatment plants, treatment of closer water sources with lower quality).
- Research into the impacts of changes in water resources on energy production (i.e. availability of cooling water for thermoelectric power plants) and the subsequent effects on electricity price and availability.
- Research into the impacts of changes in temperature on water and electricity demand.
- Research into water utility operations and process optimisations.

**5. Management and Communications**

- Development and application of new risk models, priority setting and emergency response strategies that balance service levels and performance, risks, and costs.
- Enhancing the development and implementation of demand management strategies that involve the community.
- Development of new rate structures to allow for new patterns of water use, new sources of water, different levels of demand for different types of water, etc.

- Development of regional collaborative arrangements and other institutional arrangements to share and reduces climate change risk among water utilities, water users and other stakeholders.
- Encouraging the industry to take greater leadership roles in public discussion about water management and water allocation challenges and options.
- Research into ways of communicating and working with the public so utilities can better understand the overall climate change impacts (not just those relating to drinking water and wastewater) on households, businesses, environmental resources and the wider community.
- Development of community programs to effectively educate customers and partners in watershed and resource planning about climate change, and to encourage acceptance of new policies (conservation, demand management, alternative water sources) and higher costs associated with developing, operating and maintaining new infrastructure.

A set of around 25 detailed research project descriptions also came from this workshop (the reader is referred to AwwaRF (2008) for the full details of these projects). Briefly, they included:

- Impacts of underground geological $CO_2$ sequestration on the water quality of groundwater supplies (this research priority was also stated by USEPA (2008) as research that is "underway" by the EPA Office of Research and Development (report due in 2010). This USEPA research will assess and provide decision support related to the behaviour of injected $CO_2$ in the subsurface and the impacts to drinking water sources).
- Development of a Water Utility handbook or guide for navigating climate change information and data, to help water managers find the data that meets their specific needs.

A recent report by **Maunsell Australia and CSIRO Sustainable Ecosystems (2008)** suggests that more research and modelling of the impacts of carbon trading on operational expenditure for desalination and water recycling operations is required in order to better inform estimates of future operating and water supply costs.

The **USEPA (2008)** in their September 2008 *National Water Program Strategy: Response to Climate Change* report outlined a number of potential climate change/water related future research needs in the three key areas of Human Health, Ecosystems and Technological research:

**Human Health**

- **Better Predict Municipal Water Supply Impacts Associated with Temperature Increases, and where relevant, Snow to Rain Shifts**: Develop more complete estimates of water supply impacts of snow to rain shifts, the correlation of increased use of municipal water supplies, and water loss due to evapotranspiration.
- **Assess Population at Risk of Salt Water Intrusion to Drinking Water Wells**: Identify the population that relies on public and private drinking water wells that may be at risk to intrusion of salt water and the likely impacts on nearby community water systems. This issue was also highlighted by IEC (2008) as a potential issue for remote coastal communities in the Northern Territory.
- **Determine Climate Change Impacts on Ground Water and Surface Water Interactions**: Investigate the impacts from climate change on aquifer levels, aquifer

recharge, and surface water levels. In turn this should be related to stream flows and wetland health.

**Ecosystems**

- **Maintaining Water Retention Rates within Watersheds**: Develop methods to scale the rates of retention of watersheds and indices to compare retention rate impacts of land use shifts, including retention rates of various practices (e.g., green roofs, impervious surfaces, retention basins, wetlands).
- **Increasing Resilience of Aquatic Ecosystems**: Identify the elements of aquatic ecosystems that foster increased resilience of the ecosystem and identify ways to strengthen and expand these elements.
- **Estimate Hypoxia/Low Dissolved Oxygen Events**: Identify coastal and fresh waters most at risk to decreased levels of oxygen in the water as a result of warmer air and water temperatures, the extent of increase of such events, and the environmental costs and economic impacts of the events.
- **Non Point Source Pollution Management Models**: Develop models to forecast non point source pollution loadings under variable climate change scenarios including changes in velocity of flows and pollutant concentrations and describe how these models can be used in design of non point source pollution control plans and watershed plans.
- **Impacts of Salinity Changes on Health of Aquatic Systems**: Identify the waters most at risk of increasing levels of salinity and the likely impacts on fisheries and the health of aquatic systems.
- **Identify Flow Changes on Water Quality**: Identify the water pollutant increases and the hydrologic changes associated with flow changes, i.e., flooding of varying types (e.g., inland, coastal) and drought conditions.

**Technology**

- **Support Models to Determine Localised Impacts of Climate Change**: EPA will support and work with leading scientific agencies and, academic and research foundations which are working toward downscaling of climate change models. The goal is to provide regional climate data that states and local water resource managers can use to make local predictions of climate change impacts and trends on their water resources.
- **Stormwater Injection Wells**: Identify potential issues and benefits of injection of stormwater into underground geologic formations and recommend how this practice might best be managed in the future.
- **Biofuels Impacts on Water Quantity and Quality**: Evaluate the impact of increased biofuels production on water quality (e.g., increased land in crop production and increased use of fertiliser/pesticides) and use of water for production of biofuels.
- **Assess Drinking Water Treatment Complications Associated with Climate Change Impacts**: Assess the impacts of climate change (e.g., salt water intrusion, increased source water sediment and organic levels, and increased microorganism levels in water) for treatment of drinking water and for compliance with drinking water standards.
- **Energy Savings of Water Conservation**: Evaluate the potential for energy savings associated with different water conservation practices in areas of the country served by different power generation sources (e.g., coal-fired power plants vs. hydropower).
- **Alternative Water Supplies**: Assess issues associated with the development of alternative water sources as part of a suite of water supply management techniques (e.g., the best methods to evaluate the suitability of underground sites for the storage of water for future use; the water quality implications of desalination.)

- **Effects of Water Conservation on Treatment Plant Operations**: Evaluate the impact of water conservation practices that reengineer water conveyance and reuse on the efficiency of conventional sewage treatment plant operations (i.e., dewatering of influent).
- **Methane Cleaning Technology**: Identify technologies to more cost effectively and reliably clean methane from sewage treatment plant digesters to allow for combustion of power of fuel cells.
- **Identify Energy Efficient Treatment Technologies**: Identify energy efficient treatment technologies for drinking water treatment, wastewater treatment, and industrial wastewater treatment.
- **Investigate Energy Conservation Measures**: Topics include assessing less energy intensive treatment methods, identifying opportunities for on-site combined heat and power production efforts (such as utilising biogas from anaerobic digesters and/or low head small hydro-electric) identifying more efficient processing of biosolids, and assessing the potential benefits of co-location of power plants and water utilities.

According to Hamstead *et al*. (2008), there is an urgent need to better manage the interconnectivity between surface and groundwater resources in Australia and to more effectively factor in and adapt to the future impacts of climate change. This knowledge gap was also reflected in a recent publication by the Murray–Darling Basin Authority (MBDA) in that current information regarding the extent of connections between surface and groundwater is very limited and has a relatively high level of uncertainty attached to it (MDBA, 2009). This realisation of the need for more information on surface and groundwater interactions has also been emphasised in the United States (WGA, 2008).

Water quality depends on a wide range of variables, including water temperatures, flows, runoff rates and timing, and the ability of catchments to assimilate wastes and pollutants. Climate change could alter all of these variables. For example, increased winter flows could reduce pollutant concentrations or increase erosion of land surfaces and stream channels, leading to higher sediment, chemical, and nutrient loads in rivers. Changes in storm flows will also affect urban runoff, with may have follow-on water quality impacts. Reduced summer flows may also reduce dissolved oxygen concentrations, reduce the dilution of pollutants, and increase zones with high temperatures (Kiparsky and Gleick, 2003). More research to assist with drinking water, stormwater, flood management, and help wastewater utilities to adapt to climate change and address environmental and public health risks that could result from changes to the hydrologic environment. For example, we anticipate that potential public health risks could result from higher water temperatures breeding higher concentrations of certain organisms, from changes in ambient water quality, or from more intense rainfall events. These factors could compromise treatment processes, restrict wastewater utilities' ability to discharge effluent and cause greater risk of sewage overflows (USEPA, 2008).

In relation to hydro-electric power generation, the primary concern for operators of such schemes is to predict the future net availability of water in the catchment basin, and to determine the future seasonal variability of precipitation and its divergences from current normal ranges (Mehdi *et al.*, 2004). This information will allow adaptation of current hydro-electric operations and planning to cope with more severe extreme events (e.g., droughts and maximum precipitation) and may facilitate changes to reservoir operation policies during such events. Regional climate models capable of providing reliable local climate scenarios are, therefore, required for such small-scale climate change impact assessment and adaptation studies. Determining future electricity demands and consumption patterns (including under extreme climate event occurrences), as well as being able to predict future changes in dam levels, are also of primary importance for hydro-electric power schemes in order to ensure that adaptation strategies are appropriately tailored for optimum power generation capacity under future climate change (Mehdi *et al.*, 2004; Vine, 2008). If predicted future energy demands cannot be met, developing contingency plans to cope with shortfalls of electrical supply during these periods is important. Additionally, the development of new technologies that would operate under changing stream-flow conditions and new technologies that can cope with predicted water quality issues and saltwater intrusion are also of importance in order to safeguard hydro-electric infrastructure against climate change impacts and avoid costly repairs (Mehdi *et al.*, 2004). According to its website, the Snowy Mountains Hydro scheme currently provides over 70% of all renewable energy that is available to the eastern mainland grid of Australia (approx. 1,500 GWh), so such research and development into hydro-electric technologies is arguably of relevance for Australia.

Managing the potential impacts of climate change in the coastal environment requires access to the best scientific information, expert engineering interpretation and a range of methodologies and models (Harper, 2009). The basis for all climate change adaptation research should be plausible climate scenarios and associated impact scenarios for water resources which have to be fully quantitative (Pittcock, 2008). The development of adequate simulation methodologies remain a principal research challenge in the presence of uncertainty (Harper, 2009). Since impacts vary significantly for different regions, these analyses have to take a localised approach (ATSE, 2008). It is generally recognised that there is a need for models at the country, region, and provincial level (OECD, 2006). Equally, seasonal as well as medium term (Pearce and Le Page, 2008) and long term effects have to be distinguished (Pittcock, 2008) and more research is required to do this.

The OECD (2006) points out that there is often a gap between available scientific information and tools and their actual use by policy-makers and water managers. Very often scientific information rests within scientific circles and does not reach potential users. For effective adaptation to take place there needs to be mechanisms in place for scientific information to be translated into a form relevant to water managers and policy makers (OECD, 2006). A continuous dialogue between different stakeholders is, therefore, needed so that policy-makers can communicate their needs to scientists, and scientists can explain their findings to the policy-makers. One main question with regards to climate change adaptation policies and guidelines is: who is responsible for developing and implementing the respective documents? Many say that a national approach is necessary instead of leaving it to local governments and councils to come up with their own planning policies (ABC TV, 2008).

Predictions for the short- and long-term future via simulation models heavily rely on good monitoring systems. There is a need for more powerful tools and a more widespread application of the tools in water related areas such as river flow, river level, reservoir level or groundwater level (OECD, 2006). Data obtained from the monitoring systems are essential for early detection of changing meteorological and hydrological conditions and therefore are of great importance for the development of short-term response measures as well as longer term adaptation strategies.

As a second step vulnerability assessments or mapping of local water sources and infrastructure based on the impact scenarios can deliver approaches for targeted adaptation action plans (Smith et al., 2008). First attempts to develop standards and frameworks which take into account climate change adaptation strategies have been developed, e.g., for agricultural systems (Benegas et al., 2008) or for coastal and ocean engineering (Harper, 2004) but are still not very widespread. The current lack of concrete climate change adaptation plans is also reflected in the still very sporadic uptake of future water supply plans by water service providers in Australia (Neal et al., 2007). Sydney Water has stipulated that one of the focus points for their climate change response strategy in the next few years will be vulnerability mapping of its assets exposed to climate risks, particularly extreme events and sea level rise (Allen *et al*., 2008). Vulnerability assessment is a complicated task, since the degree of vulnerability and experience of climate change will vary between households, and across communities, businesses, sectors and regions such that the appropriate adaptation response will always depend on a range of local circumstances (Garnaut, 2008a). Therefore, unlike the mitigation effort, adaptation is best seen as a local, bottom–up response whereby households, communities and businesses are best placed to make the decisions that will preserve their livelihoods and help to maintain the things they value (Garnaut, 2008a).

Many literature sources point out the need for guidelines which would represent appropriate national policy solutions to climate change adaptation. These guidelines should consider the respective expected consequences of climate change and be based on a risk assessment framework which could be applied to relevant planning and design codes in a nationally consistent manner (ATSE, 2008). With regards to future infrastructure projects these guidelines should include appropriate risk assessment and strategic planning approaches which consider the vulnerability to the effects of climate change. There is also literature which suggests that there is a need to evaluate existing adaptation decision-making frameworks in order to improve the outcomes from adaptation initiatives (Preston *et al.*, 2009).

One of the running themes throughout much of the surveyed literature was the importance of adequate information dissemination and stakeholder education regarding climate change science and subsequent adaptation needs. As discussed by Garnaut (2008a), "*the creation of information does not guarantee its optimal uptake*" such that "*Information must be prepared and released in a form that is usable by its intended beneficiary.*" Correcting gaps in the public knowledge base rests not just on the research effort itself, but also on the interpretation and presentation of scientific findings in a meaningful and relevant form that can be factored into local risk management and decision-making processes. Even when soundly researched information is widely communicated, it may be of limited value if end users have problems comprehending it or using it in making their decisions (Garnaut, 2008a). Recognising the need for effective communication of climate change science to non-scientists, a guide to the most recent IPCC reports has been produced (Kirby *et al.*, 2009) to help bridge the gap between science and policy, and to raise public awareness about the urgency of action to combat climate change and its impacts. This guidance report was targeted at readers who do not have the scientific background necessary to interpret the original IPCC synthesis report (IPCC, 2007a). Incidentally, a PhD thesis has also recently been published in this area (Baggett, 2007) Several research questions were highlighted from this work in relation to stakeholder engagement and communication in the context of water resources management, including research to investigate:

- How different sources of information are viewed by different stakeholders, as well as the content of the information they provide;
- Stakeholders opinions and expectations regarding different approaches to managing conflict to gain agreement; and

- Longitudinal studies of the variation in different stakeholders' opinions and expectations in relation to the issues within specific water resource management projects.

Water managers also need to have outputs of climate models in useful and interpretable formats amenable to incorporation into resource management models, and available at scales (regional and catchment scales) useful for resource management activities (WGA, 2008). To this end, there is a need for remote sensing and related analytical applications to be scaled to smaller catchment scales for local decision making (WGA, 2008).

A report by WGA (2008) also identified that there is a need for some form of information broker/translator utility to act as the intermediary between climate scientists and practitioners, and to facilitate discussion on practitioners' needs as well as involving practitioners in the development of relevant research questions. This issue was also raised by SMEC Australia (2007) in that there is a need to establish effective communication channels between scientists and local government officers. At the same time, WGA (2008) stipulated that water managers need to take the initiative to clearly communicate their needs for applied science to the climate research community, and must seek opportunities to guide this research in directions that will support real-life problem solving. One of the research needs identified by Vine (2008) in relation to the Californian Electricity Sector was a need for more effective integration of the investment, finance, and risk management communities into the climate change adaptation research and development process to help identify opportunities and barriers and evaluate the potential solutions for market success. This general theme of improved cross-disciplinary communication and collaboration was noted frequently throughout the literature review process.

## 16 APPENDIX C. ADDITIONAL INFORMATION RESOURCES

**CRC for Water Quality and Treatment/ WQRA occasional papers and research reports** – 1999–2009 (http://www.waterquality.crc.org.au/publication_occppr_resrpts.htm) (accessed 14/04/09)

**National Water Commission: Waterlines Publications** (http://www.nwc.gov.au/www/html/732-introduction---waterlines-publications.asp) (accessed 14/04/09)

**The Australian Water Data Infrastructure Project** (http://www.daff.gov.au/brs/water-sciences/ground-surface/awdi-project) (accessed 14/04/09)

The objective of the Australian Water Data Infrastructure Project (AWDIP) is to facilitate Australia-wide assessments of water resources through ongoing development of a comprehensive and accessible water information framework. The AWDIP is a framework for a network of distributed hydrological databases. The framework will enable on-line access to State and Territory agencies hydrographic data sets representing Australia's first distributed database of national natural resource management data.

**AGO Connected Water website – Identifying and managing inter-connectivity of Australia's water resources** (see Fullagar *et al*., 2006; Brodie *et al*., 2007). (See also connected water website: http://www.connectedwater.gov.au/) (accessed 14/04/09)

The key water issues in Australia—over-allocation, environmental flows, river salinity—are all influenced by the degree and nature of the connectivity between surface water and groundwater. The Bureau of Rural Sciences (BRS) Managing Connected Water Resources project focuses on the key information gap of how rivers and aquifers interact and how best to assess and manage these interactions. The project will provide a better understanding of the potential connectivity of surface water and groundwater and the management and policy implications of this connectivity (cut from: http://www.daff.gov.au/brs/water-sciences/ground-surface/managing-connected-water)

**Department of Agriculture, Fisheries and Forestry Water 2010** project (http://www.daff.gov.au/brs/climate-impact/water-2010). This provides national landscape water balance information for policy and planning purposes (more relevant to Alice's review) and is also more agriculturally focused, but could still be of relevance for regional settlements?

**CSIRO's Urban Water Program** (http://www.csiro.au/science/UrbanWater.html)

**CSIRO's Climate Adaptation Flagship**
(http://www.csiro.au/org/ClimateAdaptationFlagship.html)

- Includes a *Sustainable Cities and Coasts* Research Program

**CSIRO's Transport and Infrastructure Flagship**
**(http://www.csiro.au/science/TransportInfrastructure.html)**

- Includes a *Building and Construction* Research Program, an *Urban Planning* Program and a *Utilities* Program

The **Department for Planning and Infrastructure** (Western Australia) (http://www.dpi.wa.gov.au/)

**Sydney Coastal Councils:** System approach to regional climate change adaptation strategies in Melbourne (http://www.sydneycoastalcouncils.com.au/system-approach-to-regional-climate-change-adaptation-strategies-in-metropolises/project_publications.php)

**RMIT Climate Change Adaptation Program – Global Cities Institute**
(http://gc.nautilus.org/gci)
Part of the '*Climate Change Adaptation Program* (CCAP)' at RMIT exploring new solutions for infrastructure, methods of communication and transport – among other climate change adaptive responses. Their goal is to create a global framework for the infrastructural adaptation of cities to climate change. Their objectives are:

- to complete an assessment of the relative vulnerability of strategically-chosen cities in the Asia Pacific region;
- to design strategies to increase resilience of those cities in relation to climate-change impacts;
- to implement an initiative composed of specific urban-infrastructural adaptive responses based on RMIT's scientific and technological innovations that exemplify the general global principles that should frame urban climate-change adaptation.

**National Climate Change Adaptation Programme (NCCAP)**
(http://www.climatechange.gov.au/impacts/nccap/index.html) has adaptation themes for both *Settlements and Infrastructure* (http://www.climatechange.gov.au/impacts/settlements.html) and *Water Resources* (http://www.climatechange.gov.au/impacts/water.html).

The **Cities for Climate Protection (CCP)** Australia campaign, delivered in Australia in partnership with the Australian Government (through the Department of the Environment, Water, Heritage and the Arts) and ICLEI Oceania, provides a resource to assist Local Governments and their communities reduce greenhouse gas emissions (http://www.environment.gov.au/settlements/local/ccp/).

The **Water Research Foundation (WRF) (previously AwwaRF)** has developed a 'Climate Change Clearinghouse' web site (www.theclimatechangeclearinghouse.org) to provide a single source of all information related to climate change and water. The Web site offers the water community access to useful information on:

- Climate change science relevant to water utilities
- Impacts climate change can have on water resources
- Guidance on planning and adaptation strategies
- Water Research Foundation research relevant to climate change

The **WRF** has undertaken a Climate Change Strategic Initiative (http://www.waterresearchfoundation.org/theFoundation/ourPrograms/ResearchProgramSIClimateChange.aspx) to establish a research program focused on impacts of climate change on water supplies. The initiative will be sustained until the objectives outlined below are achieved; the target timeframe for the initiative is 5–7 years. The Climate Change Strategic Initiative has the following four objectives:

1. Enhance and improve water industry awareness of climate change issues and impacts;
2. Provide water utilities with a set of tools to identify and assess their vulnerabilities, and develop effective adaptation strategies;
3. Provide water utilities with a set of tools to assess and minimise their carbon footprint;
4. Communicate information to internal/external stakeholders.

The **USEPA** has established a ***Sustainable Infrastructure Initiative*** (http://www.epa.gov/waterinfrastructure/) as well as a ***Green Infrastructure Initiative*** (www.epa.gov/water/greeninfrastructure) to help meet the future challenge of providing sustainable infrastructure for water and wastewater (refer USEPA, 2006).

The **USEPA** also has a **Water Resource Adaptation Program** (http://www.epa.gov/nrmrl/wswrd/wqm/wrap/) to provide data, tools, and engineering solutions for adaptation to climate, land use, and socioeconomic changes. The research approach has three basic elements:

1. investigating hydrologic effects of climatic change and defining the water resource needs of future socioeconomic conditions using tools such as climate modelling, robust statistical analysis, and water availability forecasting;
2. developing adaptation methods, primarily focused on advanced and innovative engineering techniques and solutions; and
3. developing and providing end users with tools for water resource adaptation.

The **Water Environment Research Foundation (WERF)** has a Climate Change knowledge area (http://www.werf.org/AM/Template.cfm?Section=Climate_Change) aimed at evaluating the likely effects of climate change on wastewater services, and assessing processes and technologies to cost-effectively mitigate and adapt to the potential impacts.