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EXECUTIVE SUMMARY

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

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
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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

The predicted sea level rise of 3–17 cm by 2030 and 7–52 cm by 2070 (Amitrano *et al.*, 2007)

Improved water use efficiency can also effectively reduce the strain on ageing water and

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; educ 6(s byd le)7duc

(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 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 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.

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
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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

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.

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 w 0 -1.15 TD [(l)13(nfY404)]TJ 0duu.82 1 0.o1.2641C.04k008 bc 0.0023 T5r21h0.8 re f 162htw 3i0011w

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 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

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 planning, particularly for large infrastructure projects that are vulnerable to under or over 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 thinb[Td [6(s)f)-3(4s)-6(,)80s)f4agshedthr-bot6(d(ha)-6d(haglob)-9(yt)8(e)-5(ch9(l)3( )e-relg 0 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 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 stan65(lop w)m,.302 0 Td re ien

13 REFERENCE MATERIAL

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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 inventori

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

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

The **Victorian Government** has been involved with work investigating climate change and associated impacts in Victoria (see www.greenhouse.vic.gov.au/index.htm

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

- o 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.
- o 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*.
    - o 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*.
    - o 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*.
    - o 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.*

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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

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

- 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.
- There are challenges and opportunities posed by the advent of probabilistic climate change scenarios for water resources management.
- Despite its significance, groundwater has received little attention from climate change impact assessments, compared to surface water resources.
- 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

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

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 eD8or In o chaater1-6( )6(c)-4( )6(re)-6at (f)3(.00es)-5ce b( )]

overview of the consideration of the water–energy nexus in Australian and international water

There is an absence of systematic monitoring and evaluation of climate change 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 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.

A paper by **Mukheibir and Ziervogel (2007)** discusses how the previous international focus

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,

What are the data and information requirements for conducting a vulnerability assessment? How much information is required to achieve different goals and what are

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"

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 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

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.

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

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* 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 aa< [(2tify)i6(tif A)-4(Wds)aa< [ates

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).

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

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
(J ET 231.78 19.4 252160 00.7620.00 213 g /TT0 1 Tf -0.0015 Tc 10.6779 0 0 10.6779 522.6 3103.153521620.

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.