Assessment of the impacts of climate change on water supplies

A Consultancy Report Prepared for Rous Water Regional Water Supply New South Wales Department of Commerce

Prepared by
Dewi Kirono
Geoff Podger
Cher Page
Roger Jones

Climate Change Impacts and Risk
CSIRO Marine and Atmospheric Research

6 October 2006

Assessment of the impacts of climate change on water supplies

A Consultancy Report Prepared for the Rous Water Regional Water Supply
New South Wales Department of Commerce

Prepared by
Dewi Kirono
Geoff Podger
Cher Page
Roger Jones

Climate Change Impacts and Risk
CSIRO Marine and Atmospheric Research

6 October 2006

Enquiries should be addressed to:
Dr. Dewi Kirono
CSIRO Marine and Atmospheric Research
PMB No 1, Aspendale, Victoria 3195
Telephone: (03) 9239 4651
Fax: (03) 9239 4444
E-mail: dewi.kirono@csiro.au

Important Notice

Use of this Report

ACKNOWLEDGMENTS

This work was produced by CSIRO under contract to the Rous Water Regional Water Supply, NSW Department of Commerce.

Rob Siebert (NSW Department of Commerce) and Wayne Franklin (Rous Water Regional Supply) are gratefully thanked for their assistances during the study and their invaluable inputs during the 7th April and 29th August 2006 workshops and the regular communications.

NSW DIPNR is acknowledged for the agreement regarding the use of Wilson River IQQM. Chris Ribbons and Richard Cooke are thanked for providing the required files and assistance in running them.

Jim Ricketts is thanked for his help in setting up the OzClim program for the analysis.

Useful comments on the manuscript from Dr. Benjamin Preston are greatly acknowledged.

EXECUTIVE SUMMARY

Scope of the project

This project investigates the implications that climate change may have on secure yields of Rous Water's regional water supplies. The quantitative assessments were conducted with the aid of the Wilson River Integrated Quantity and Quality Model (IQQM). An alternative, i.e. to scope changes in secure yields based on simple hydrological sensitivity models, has also been made available. The aim of the assessment is to generate information on climate risk that can help identify the most appropriate time horizon for making new investments in infrastructure. After assessing the best- and worst-case outcomes to 2030, a ten-year time horizon is considered the minimum required to commission a new water source.

Climate change impact assessment framework

Figure A presents the assessment framework for this study. It follows the following main steps:

- Select six Global Climate Model (GCM) simulations through the use of the CSIRO Climate Scenario generator, OzClim;
- Prepare three climate scenarios (one wet, one medium, one dry) expressed as a function of global warming (percent change per ^{o}C of global warming) for potential evaporation (*Ep*) and precipitation (*P*) for specified times in the future (2010, 2020, 2030) for each of the six GCMS. This results in a total of 18 climate scenarios;
- Apply these climate scenarios in the IQQM model to generate climate change flow sequences. Rainfall and evaporation inputs to IQQM are modified to simulate climate change;
- Analyse the sensitivity of secure yields to changes in inflow to Rocky Creek Dam, Emigrant Creek Dam, and the downstream tributary via a large number of IQQM simulations. This generates sensitivity models which can be used to estimate yields based on evaporation and rainfall changes;
- Analysis the risks to Lismore's future water supply yield and secure yield by using Monte Carlo methods (repeated random sampling);
- Evaluate risk and identify feedbacks likely to result in autonomous adaptations; and
- Consult with stakeholders, analyse proposed adaptations and recommend planned adaptation options.

Results: Impact assessment, adaptation, and recommendation

Climate change probabilities in Rous Water region

- Increases in evaporation are virtually certain (i.e. >99% likely). The 95th and 5th outcomes range from about 2% to 4% in 2010, 4% to 12% in 2020, and 10% to 26% in 2030.
- The chances of decreasing rainfall are slightly higher than the chances of increase, particularly in the downstream tributary area. The lowest and highest (5th and 95th) changes in *P* range from about 2% to -4% in 2010, 7% to -11% in 2020, and 17% to -21% in 2030.

Risk of changes in supply

- Decreases in Rous Water's secure yields are likely in the future. The likely (>50% probability) changes in supply are -3.4 %, -5.7%, and -7.4% in 2010, 2020, and 2030 respectively.
- There is a less than 9% possibility that Lismore's supply will increase by about 2% in 2030. However, the driest and the medium outcomes are much more likely. The likely (>50% probability) reduction is about -0.5%, -1.5%, and -2.5% in 2010, 2020, and 2030, respectively. Figure B shows the annual average of water which can be pumped out from Lismore source in the future in comparison to the baseline.
- Figure C presents the projections of the secure yield and the demand. The actual demand and its trend are also plotted. It is suggested that the earliest time for a new source is in 2018, while the medium time for a new source is in 2023 (see section 4.3. for detail).

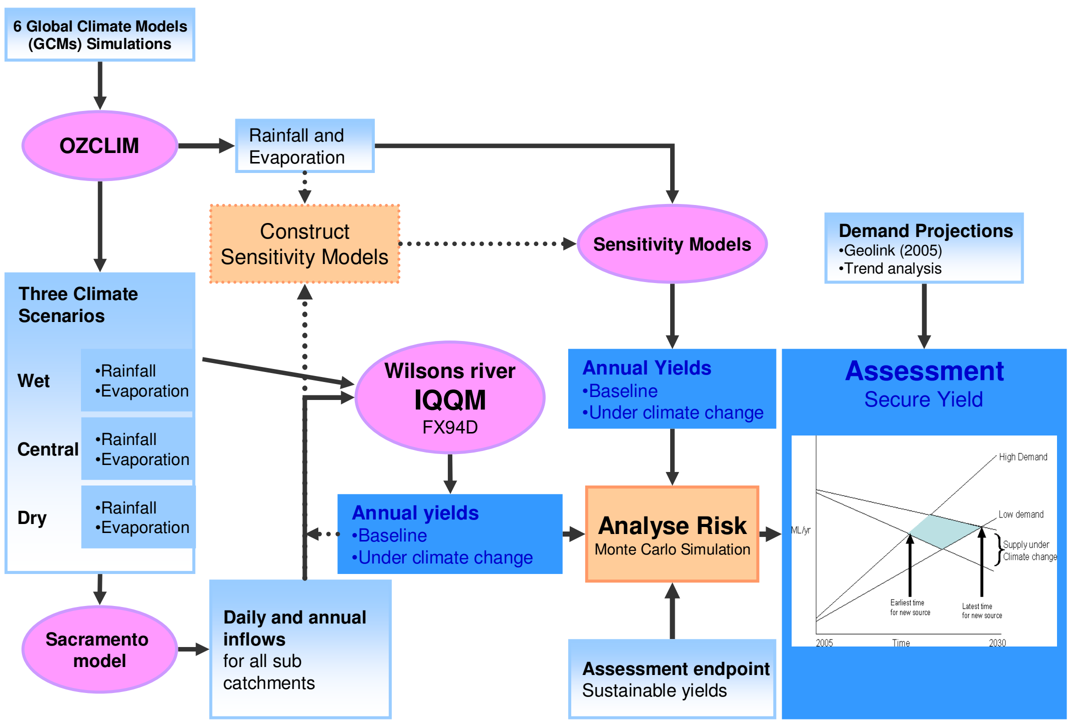

Figure A. General framework for risk assessment for Rous Water Scheme.

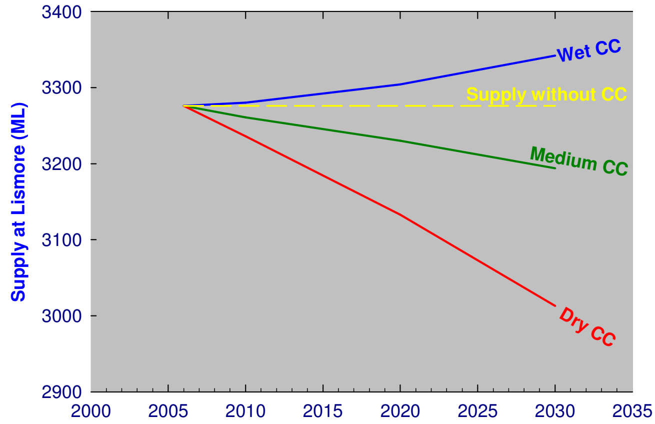

Figure B. Projected supplies at Lismore source due to climate change (CC).

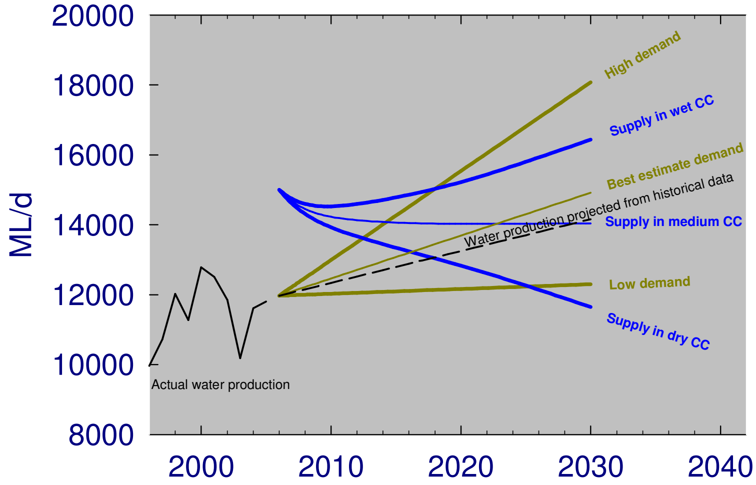

Figure C. Supply projections due to climate change (CC) versus demand projection. Note: the high demand, best estimate demand, and low demand curves are taken and modified from GeoLink (2005).

Adaptation and recommendations

The assessment indicates that, due to global warming, the need for a new source for the Rous Water system is very likely after 2018. If the medium supply scenario and best estimate demand are taken into account, the need for a new source would be expected to occur after 2023. Given that a ten years minimum is required to commission a new water source, the plan has to be started in 2008 for the worst scenario and/or in 2013 for the medium climate change scenario, meaning there is two to seven years time before the new source has to be really commissioned.

Within this window, it is recommended that demand is closely monitored as it dictates the time when a new source is required. Up-to-date information on changes in demand will be important in informing as to when the new source has to be commissioned.

To effectively manage risk, the demand should not be more than the driest supply projection (i.e., 13,000 ML in around 2018). This means that the maximum tolerable increase of demand by 2018 is only 10% of the current demand, if the driest supply projection is taken into account. If the wet supply scenario is taken into account, the maximum tolerable increase of demand by 2018 is about 25% of the current demand. Therefore, ongoing monitoring of rainfall patterns is also recommended.

To interpret the results appropriately, the fact that climate variability not represented by the historical record or model simulations could also affect water supply within the time horizon in question is need to be taken into account.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

1.1 Purpose of the project

Climate change poses significant risks to the availability and quality of water resources in many parts of Australia (Allen Consulting, 2005). This project investigates the implications that climate change may have on Rous Water's regional water supplies so that future supplies and water management activities can be adequately planned. This report presents the results of an assessment that was conducted to estimate the risk of changes in climate and the secure yields of the Rous Water system.

The project has been divided into two stages. The first, which was documented in a mid-term report submitted to the Rous Water in late June 2006, summarised current knowledge of climate changes likely to affect water resources and determined the detail to be included in the main stage of the project.

The second stage of the project, reported here, is the quantitative risk assessment. The assessment was conducted with the aid of the Wilson River Integrated Quantity and Quality Model (IQQM)s that provided a means of assessing possible changes in supply. An alternative, i.e. to scope changes in secure yields based on simple hydrological sensitivity models, has also been made available.

1.2 Outline of the report

The structure of this report is as follows:

Chapter 2 provides additional background regarding this project. It starts with a description of the Rous Water Regional supply and demand. Subsequently, it presents the information regarding climate change and the potential impacts of climate change on Rous Water supply.

Chapter 3 presents the description of the framework that was developed to assess the climate change impacts on Rous Water supply. This includes the description of the development of climate change scenarios and the secure yield estimation using both IQQM and the hydrological sensitivity model.

Chapter 4 discuss the assessment. This includes the climate change probability, risk of changes in secure yields of the whole system and of the Lismore source, as well as recommendations relevant to the design and implementation of adaptation strategies.

Chapter 5 provides the main conclusions of the project.

2. BACKGROUND

2.1 Rous Water Regional Supply

Rous Water is the regional water supply authority providing water in bulk to the Council areas of Lismore (excluding Nimbin), Ballina (excluding Wardell), Byron (excluding Mullumbimby) and Richmond Valley (excluding land to the west of Coraki) (Figure 1). It also supplies approximately 1,900 retail costumers. Rous County area is part of the Wilsons River catchment, from Lofts Pinnacle in the west, along Nightcap and Koonyum ranges near the coast. The major tributaries of the Wilson River are the Back, Leycester, Goolmangar, Terrania and Coopers Creeks. The large upland areas are heavily vegetated and fairly undisturbed, whilst the lower areas have commonly been cleared for pastoral land uses.

Approximately 3,000 hectares of land are currently irrigated each year in the Wilsons River Catchment. Access to stream flows is facilitated and managed through a licensing system which specifies limits on the amount of water that can be abstracted and the conditions under which irrigators can access river flows (*Water Act 1912* and *Water Management Act 2000*). Others that utilise the Wilsons River include commercial fisheries (at Richmond River estuary) and recreational fisheries.

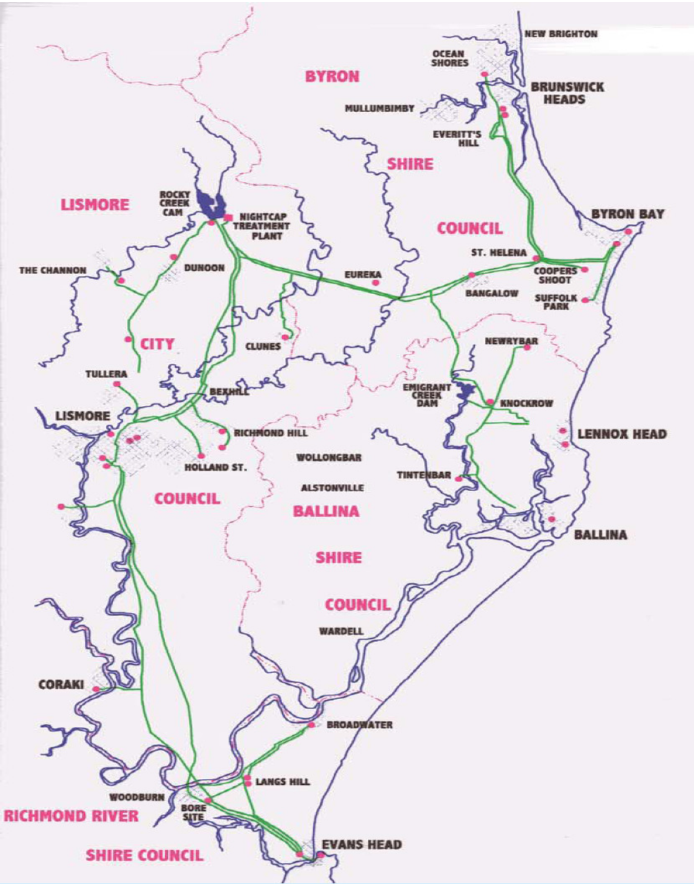

Figure 1 Rous Water scheme (Rous Water, 2006).

2.1.1 Current demand and supply

Current demands

Currently, a population of approximately 93,000 is serviced by Rous Water's supply system. This is comprised of approximately:

- 4,000 rural customers supplied directly from trunk water mains;
- 34,000 in the Ballina council area;
- 21,000 in the Byron council area;
- 29,000 in the Lismore council area; and
- 5,000 in the Richmond Valley council area.

Current bulk water usage for the supply area is ~12,600 ML per year. The current per capita consumption is approximately 120 kL/person/year (330 L/person/day) for the constituent councils (this figure also accounts for industrial, commercial and other non-residential users and losses within the system between the reservoir supply and the user meters).

There are two types of water demand in typical households: internal water demand which is relatively constant throughout the year and does not normally change with climatic conditions; and outdoor demand which is strongly dependent upon weather and climatic conditions. For example, households may water gardens more often during periods of low rainfall and/or hot conditions, whilst they rarely do this in periods of high rainfall. The typical household in Australia uses 60% of the demand for outdoor activities (gardening) and only 40% of the demand for indoor activity (DEH, 2005). In the Rous Water region, the outdoor water demand (31%) is much less than the indoor water demand (69%) (Figure 2). This deviation from the Australian average may be due to the warm temperate sub-tropical climate, characterized by relatively high rainfall (up to 2000 mm per year) in the region.

The monthly and annual demand patterns for the Rous Scheme are presented in Table 1 and Table 2. The tables indicate that demand is relatively high during December and January, and that Ballina and Lismore demand centres have the highest annual demand patterns. Ballina and Lismore account for more than 25% of the total annual demand for the Rous Water scheme.

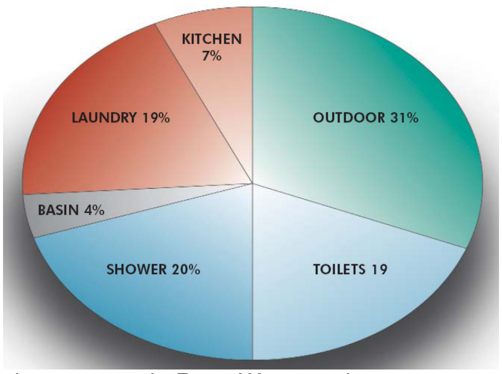

Figure 2 Domestic water use in Rous Water region.

Table 1 Monthly demand patterns for the Rous Water Scheme (NSW DIPNR, 2004).

Demand Centre	Jul %	Aug %	Sep %	Oct %	Nov %	Dec %	Jan %	Feb %	Mar %	Apr %	May %	Jun %	Total %
Ocean Shores	7.0	7.4	7.8	9.2	7.9	10.1	11.6	8.3	7.9	7.5	7.8	7.4	100
Byron Bay + Rural	7.2	7.3	8.1	9.6	8.9	10.4	11.8	7.9	8.1	7.1	7.1	6.5	100
Ballina Total + Rural	7.3	7.3	8.2	9.2	8.1	10.2	12.1	8.0	8.1	7.2	7.4	7.0	100
Bangalow	6.8	7.2	8.5	10.0	8.7	10.3	11.0	7.3	8.2	7.4	7.5	7.1	100
Clunes + Rural	7.1	5.1	6.6	6.9	5.9	6.4	11.4	10.9	12.7	9.8	8.4	8.8	100
Dunoon	7.9	8.3	8.7	10.6	8.3	10.4	11.0	7.7	7.2	6.6	7.0	6.1	100
Lismore Holland St.	8.0	7.8	8.8	9.4	8.5	10.0	11.1	7.7	7.8	6.8	7.3	6.8	100
Alstonville / Wollongbar	8.2	8.8	8.6	9.3	8.1	9.6	10.8	6.6	7.2	6.4	8.0	8.4	100
Lismore Urban	7.5	8.2	8.9	9.7	8.6	10.0	9.3	7.7	8.2	7.0	7.3	7.6	100
Coraki + Rural	7.0	7.9	8.3	9.5	8.1	10.1	10.7	9.2	8.5	7.3	7.2	6.2	100
Lower River	7.3	6.8	8.1	9.6	7.8	11.0	13.1	7.7	7.9	7.1	6.8	6.9	100

Table 2 Annual demand patterns for the Rous Water Scheme (NSW DIPNR, 2004).

Demand Centre	Annual Demand (%)
Ocean Shores	6.3
Byron Bay + Rural	15.8
Ballina Total + Rural	26.7
Bangalow	1.2
Clunes + Rural	6.7
Dunoon	1.6
Lismore: Holland St.	4.1
Alstonville / Wollongbar	5.0
Lismore: Urban	25.4
Coraki + Rural	3.1
Lower River	4.3
Total	100.0

Current supply

The Rous Water supply network includes over 30,000 connections within the reticulation areas of the constituent Councils, and around 1,823 rural connections to the Rous Water trunk main system. The system has adopted the former NSW Department of Public Works and Services definition of 'safe yield' as the level of service to be provided by the Rous Water scheme. Under this scheme the safe yield is defined as the annual demand that can be supplied from the headworks over the period of record used in the analysis (i.e. 100-year duration) and which satisfies the 5/10/20 rule (see Chapter 3 for detail).

Water presently comes from two main sources: Rocky Creek Dam and Emigrant Creek Dam. The Rocky Creek Dam, which is situated 25 kilometres north of Lismore near the village of Dunoon, has a storage capacity of 13,956 ML and a safe yield of about 9,600 ML/annum (DIPNR, 2004). Emigrant Creek Dam was constructed in 1967–68 to provide a water supply to Lennox Head and Ballina and is currently used to supplement the supply from Rocky Creek Dam. Its capacity is 820 ML with a safe yield of about 1,100 ML/annum.

Other available sources under Council control include Convery's Lane, Lumley Park and Prospect Bores in the Ballina area, as well as three bores near Woodburn in the Richmond Valley Shire. The combined safe yield is about 900 ML/annum.

The annual water production provided by the Rous Water Scheme from 1988 to 2004 is presented in Figure 3. Production ranges from approximately 10,000 to 13,000 ML/year with a long term average of 11,300 ML. The long-term trend is increasing, even though there were times when the production was very low compared to the long-term average. For example, low production periods occurred in 1988 due to mains restrictions; in 1996 as an impact of a demand management and user-pay system; and in 2003 due to water restrictions imposed to manage a drought (Franklin, *pers. comm*., 2006). Through several consultations with the Rous Water authority, it was decided that the historical data of 1996–2005 should be used in a trend analysis, to construct a realistic projection of demand (see Figure 31). Based on these data, the trend in the annual water production (which represents the actual demand) was estimated to increase at a rate of approximately 91 ML per year.

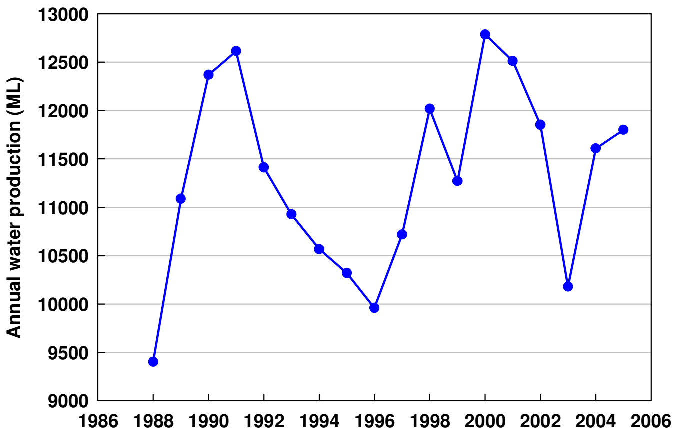

Figure 3 Annual water production of Rous Water Scheme from 1988 to 2005.

2.1.2 Future demand and supply

Future demands

In 2005, GeoLink (2005) estimated future population and the expected water demand to be served by the Rous Water supply system in the year 2050. The total projected populations in 2050 are as follows:

- High growth scenario: 180,000
- Medium growth scenario: 148,000
- Low growth scenario: 121,000

GeoLink (2005) estimated that the probability of the growth scenarios is skewed towards the high and medium scenarios. This estimation is close to the projection of the Australian Bureau of Statistics (ABS) and the Land Use Planning (Figure 4). In addition, the annual peak tourist population in the Rous Water supply district is estimated at approximately 43,600 individuals.

Based on these population projections and other considerations (see section 3.2.3), GeoLink (2005) estimated that the potential low to high demand scenarios for the year 2050 ranged from 13,200 to 23,800 ML/year which equates to a 23% to 84% increase in water demand from the current status (Figure 5). The best estimate of the likely future demand in the year 2050 is 18,000 ML/year. This equates to an increase of 43% over the current demand of 12,600 ML/year.

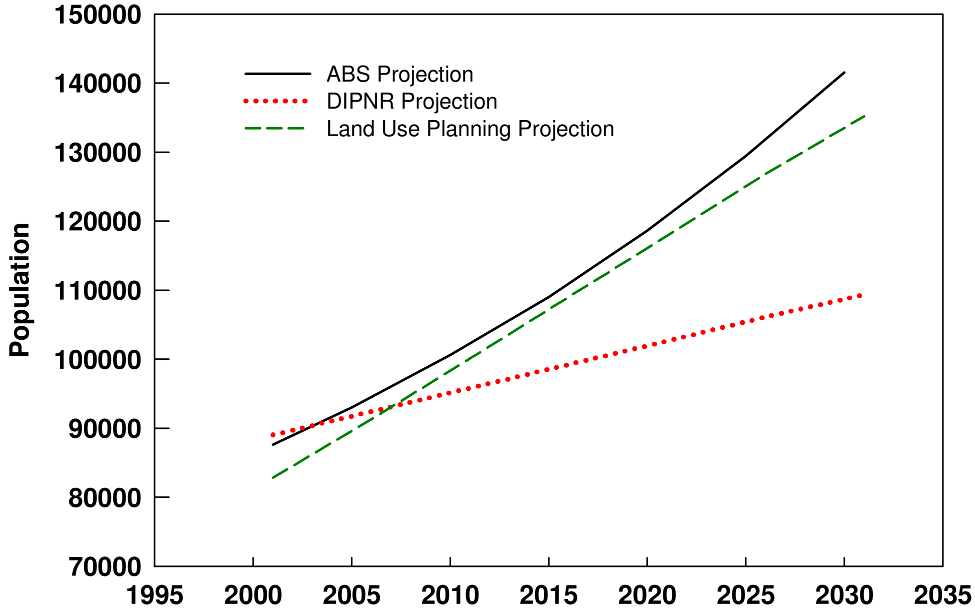

Figure 4 Population projection in Rous Water Scheme (Data are available in GeoLink, 2005).

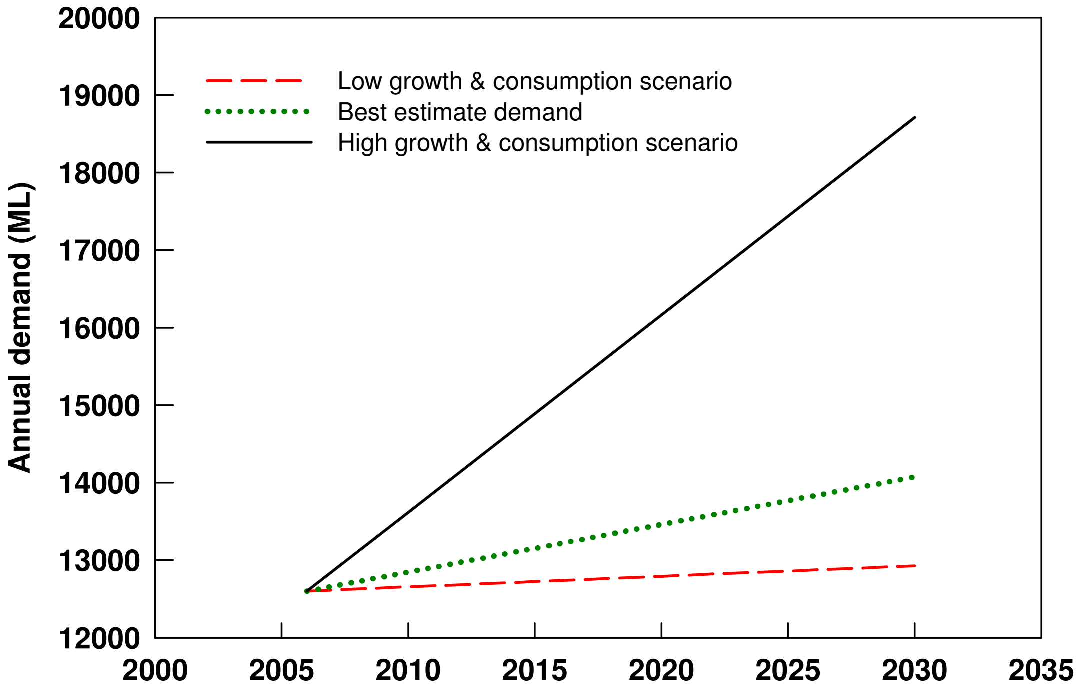

Figure 5 Annual demand projections for Rous Water Scheme (Data are taken from GeoLink, 2005).

Future supply

Rous Water's strategy, which was adopted in 1995 and amended in 2004, provides a range of options to meet water requirements. These options include:

- investigate and develop alternative water resources such as reuse, where appropriate;
- implement demand management measures;
- develop the Lismore source; and
- develop Dunoon dam.

A key objective of Rous Water's management plan is to implement effective demand management principles under best practice guidelines. The performance target for this objective is a minimum 10% reduction in the demand for water by the year 2011, relative to 1995 consumption levels (Rous Water, 2004). To achieve this objective, Rous Water has actively promoted a variety of demand management initiatives. These include the Residential House Tune-up Program, the Every Drop Counts–Primary School Education Program, the Rainwater Tank Rebate Program, and the Washing Machine Rebate Program. These initiatives were successful by several measures, but demand management alone may not solve the increasing needs for water as the population grows (Rous Water, 2004).

The Lismore source and the Dunoon Dam were identified by the strategy as being essential in expanding the capacity to meet future demand. The Lismore source is a medium-term solution which is able to assist in meeting the high demand projection up to year 2024. This will consist of a pump station abstracting up to 30 ML/day of water from the upper reaches of the tidal pool in the Wilson River, which would only occur when Rocky Creek Dam is below 95% capacity. The point of abstraction will be about 5km upstream of Lismore (Howard's Grass). The Lismore Source is expected to increase the secure yield to 14,900 ML/year (Siebert and Franklin, *pers. comm.*, 2006).

The Dunoon Dam would store inflows from its catchment up to the existing Rocky Creek Dam and from spills over the Rocky Creek Dam spillway (CMPS&F, 1995). Water drawn from Dunoon Dam will be treated by a process similar to the process to be used at Nightcap Water Treatment Plant after the present process improvement works are complete. Treated water will be pumped to the existing distribution system near Dorroughby where it will flow by gravity to Lismore. Alternatively, flow will be released into Rocky Creek to be abstracted from the Wilson River at the Lismore Source for treatment and pumping to the existing distribution system (CMPS&F, 1995).

These strategies were developed with an assumption that the climate remains unchanged. As the following section describes, there is increasing evidence that the climate has changed, and that the change may have an impact on future water availability. Therefore, it is necessary to take this into account in the water management plan.

2.2 Climate Change

The climate of New South Wales (NSW) is generally mild and temperate. However, extremely high daytime temperatures occur in the west during summer and extremely cold overnight temperatures occur in the tablelands and dry western slopes of NSW during winter (Hennessy et al, 2004). In the North-east, where the Rous Water area is located, average annual temperatures are around 15–18°C, while the average annual rainfall is around 1,200 to 2,000 mm. Regional annual rainfall, measured as the annual 10th percentile, median and 90th percentile values, exceeds 800 mm, 1200 mm, and 2000 mm respectively (Hennessy, et al, 2004).

The present CO_2 concentration of about 375 ppm is now higher than at any time in the past 740,000 years (EPICA, 2004). According to WMO (2003), the global average surface temperature has risen by about 0.6°C since 1990, with the warmest year being 1998, followed by 2002 and 2003. Computer models of the climate system have been used to estimate the relative contributions of various factors such as changes in solar radiation, aerosols from volcanic eruptions, increased greenhouse gas and aerosol emissions, stratospheric ozone depletion, and internal climate variability from events like El Niño (Hennessy et al, 2004). Most studies agree that global warming in the early 20th century can be explained by a combination of natural and human-induced factors (IPCC, 2001a). IPCC (2001a, b) concluded that:

- an increasing body of observations gives picture of a warming world and other changes in the climate system;
- emissions of greenhouse gases and aerosols due to human activities continue to alter the atmosphere in ways that affect the climate system;

- there is new and stronger evidence that most of the warming observed over the last 50 years is attributable to human activities;
- recent climate changes have already affected many physical and biological systems; and
- some human systems have been affected by recent increases in floods and droughts.

2.2.1 Historical climate patterns

Figure 7 and Figure 8 show that the temperature across NSW has steadily increased over the last fifty years. Over the North-east of NSW, the temperatures have increased at the rate of approximately 0.4°C per decade. Figure 9 indicates that in North-east, rainfall has been declining, except in summer, at a rate of roughly -20 to -50 mm per decade. In summer, the rainfall has been increasing at a rate of approximately +10 to +20 mm per decade. This contributes to a decreasing trend in annual rainfall of -30 mm per decade.

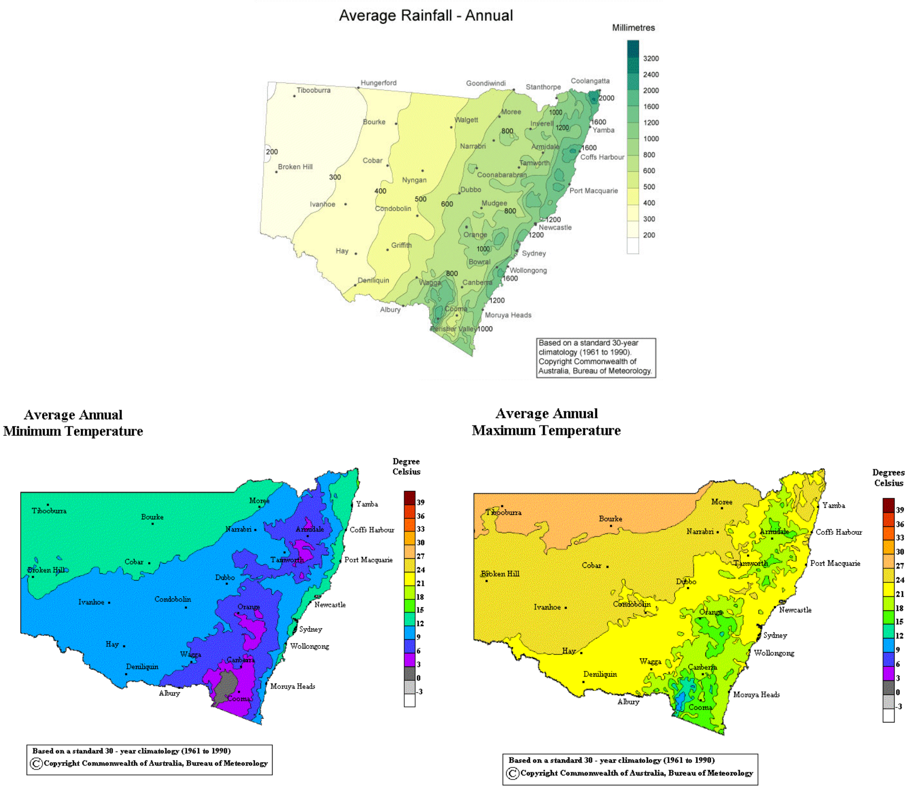

Figure 6 Average climate in New South Wales (BoM, 2006).

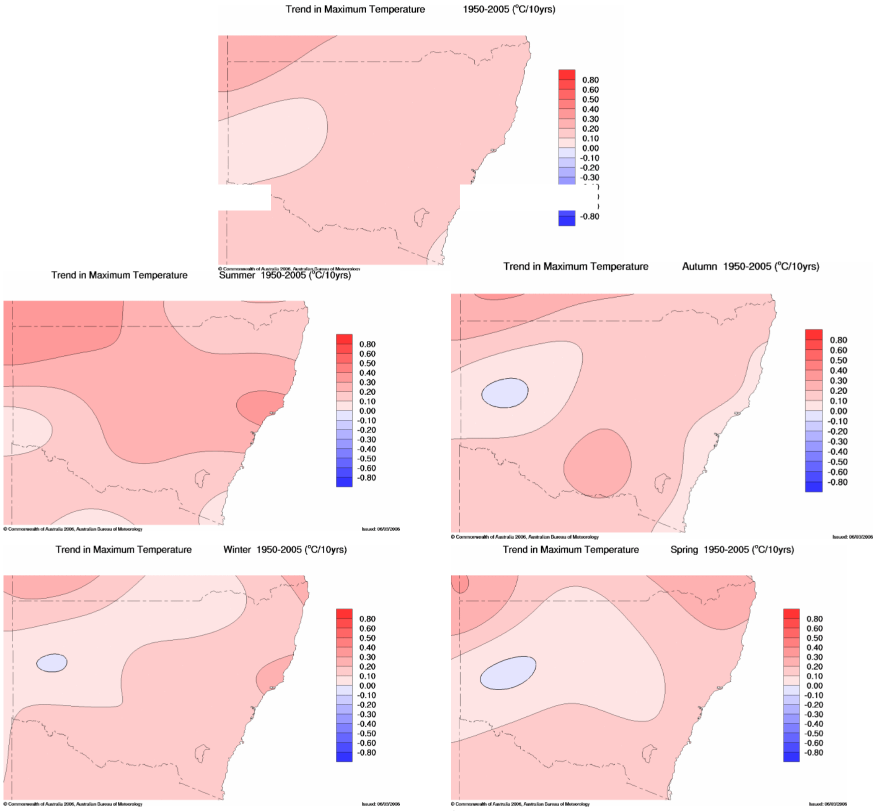

Figure 7 Trend in maximum temperature from 1950 to 2005 (BoM, 2006).

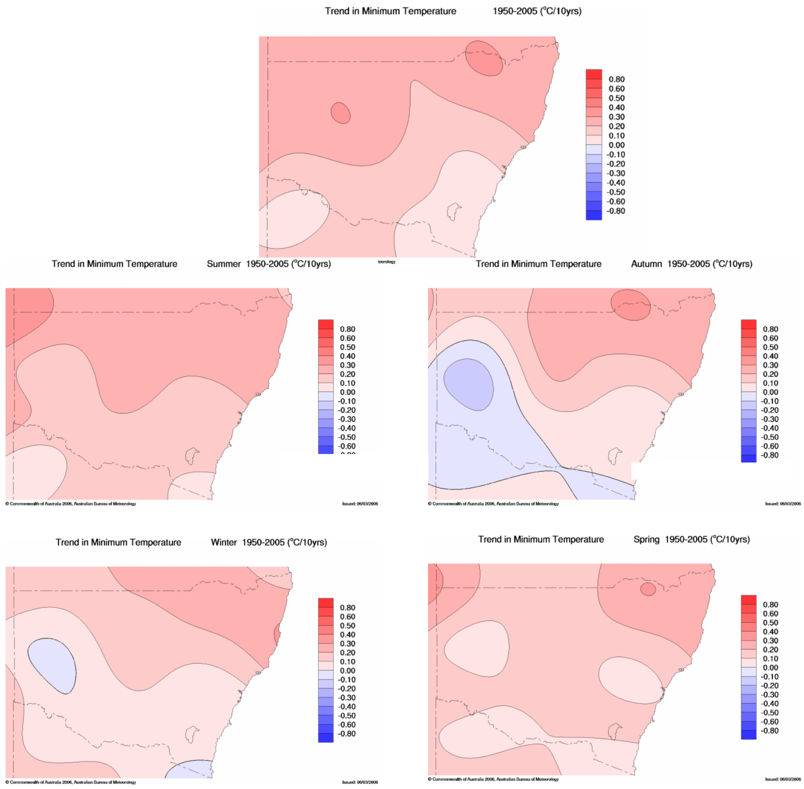

Figure 8 Trend in minimum temperature from 1950 to 2005 (BoM, 2006).

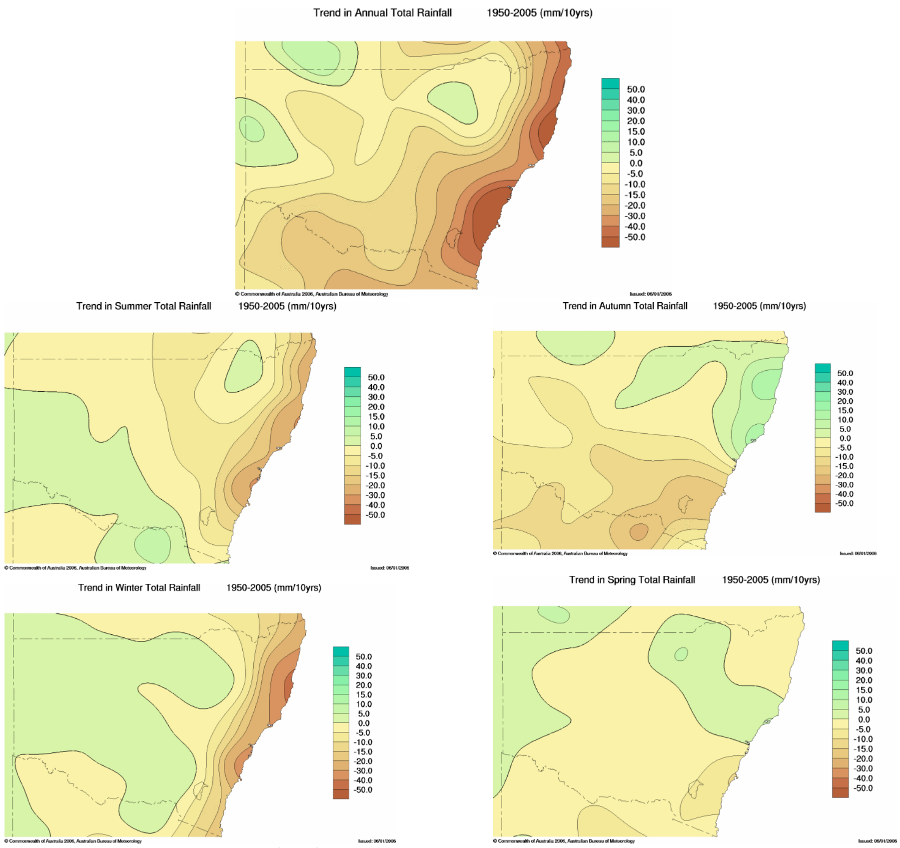

Figure 9 Trend in rainfall from 1950 to 2005 (BoM, 2006).

Figure 10 shows the trend in rainfall measured at Lismore station from the late 1880s to present. Annual rainfall is decreasing slightly at a rate of -0.6 mm per year. Winter rainfall is decreasing at a rate of -0.5 mm per year and summer rainfall is increasing at a rate of +0.1 mm per year. None of these trends are statistically significant at the p=0.05 level. Figure 11 maps the trends in annual frequency (days/year) of extreme daily rainfall events. Decreases are evident over the Rous Water region. Similar decreases are also revealed in extreme rainfall intensity (average daily totals equal to and above the $95^{th}/99^{th}$ percentile levels) (Figure 12).

Using the available data for air temperature, air humidity, and sunshine hours at Alstonville station, we can calculate the potential evaporation using Morton's (1983) method, which is also used to construct projections of future potential evaporation. The inter-annual variability of potential evaporation along with rainfall at this station is presented in Figure 13. It is clear that potential evaporation is lower than rainfall, except in spring, and rainfall at Alstonville is slightly decreasing while the potential evaporation is moderately increasing.

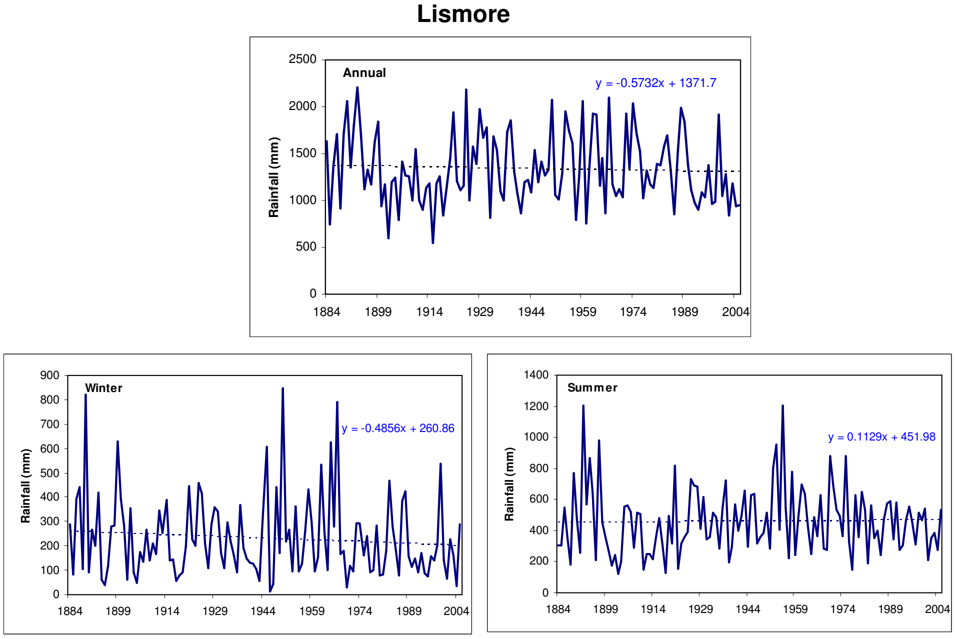

Figure 10 Rainfall in Lismore from the 1880s (source: current study).

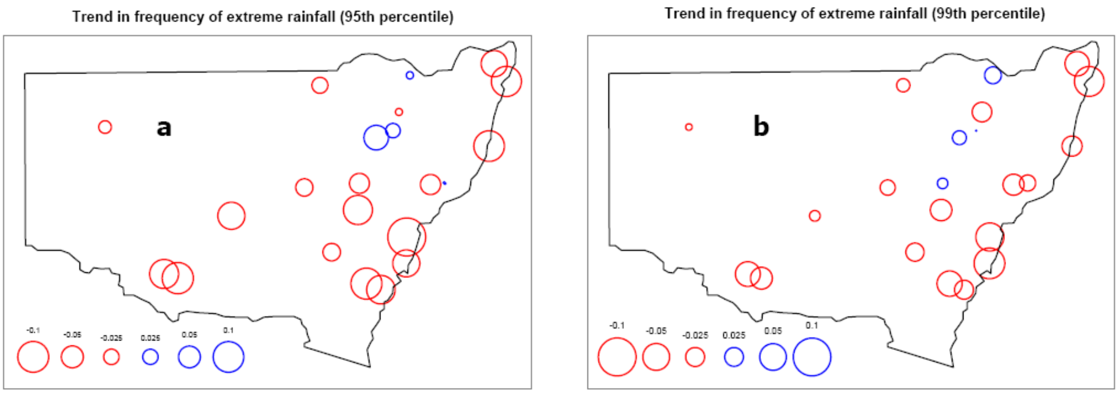

Figure 11 Trend in frequency of extreme rainfall (Hennessy et al., 2004).

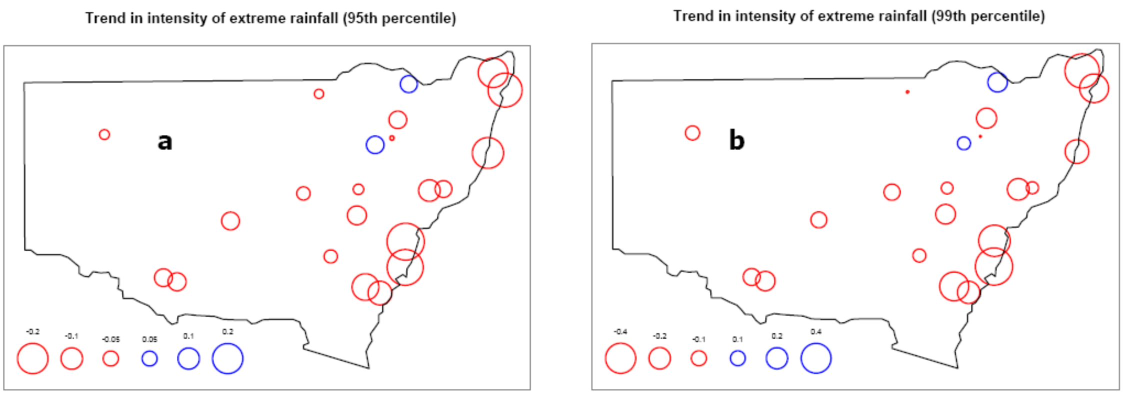

Figure 12 Trend in intensity of extreme rainfall (Hennessy et al., 2004).

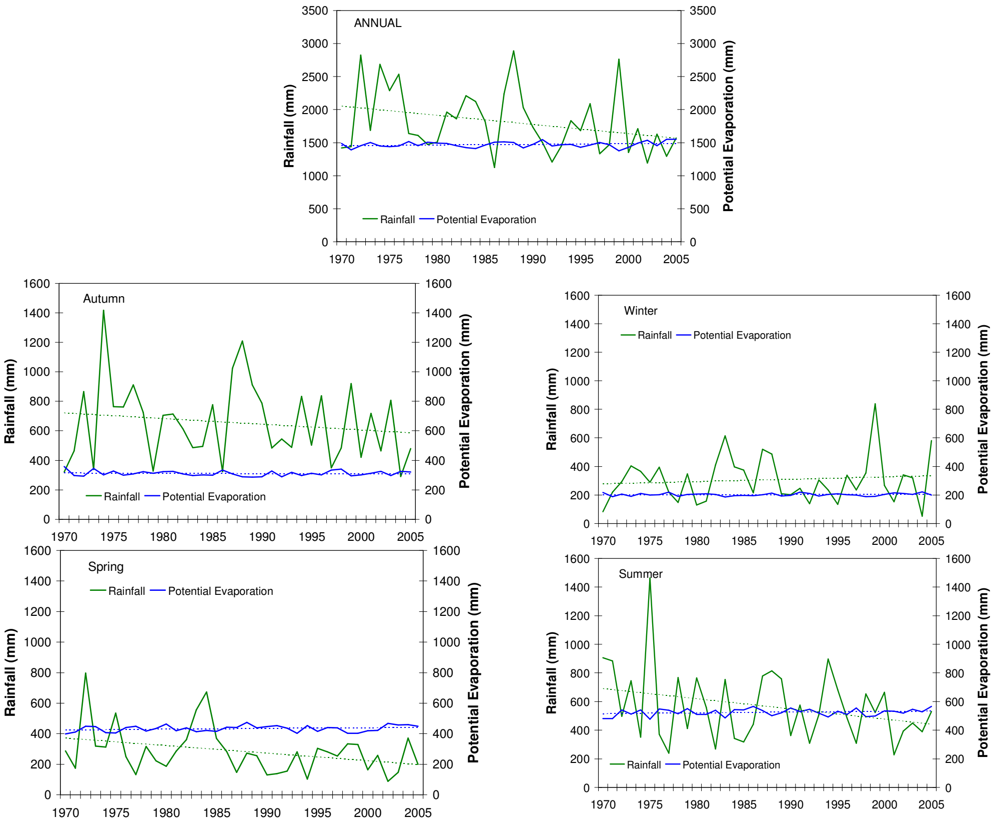

Figure 13 Rainfall and potential evaporation in Alstonville along with their linear trend lines (Source: current study).

2.2.2 Projected climate change

The climate system is highly complex, and therefore it is inappropriate to simply extrapolate past trends to predict future conditions. To estimate future climate change, scientists have developed scenarios. Scenarios are alternative pictures of how the future might unfold, with no statement of probability. They are used to assess consequences, and thus to provide some basis for policies that might influence future developments, or enable business or governments to cope with the new situation when it occurs (Pittock, 2003). Such scenarios enable scientists to set projections of future conditions derived on the basis of explicit assumptions. The IPCC commissioned a range of scenarios of greenhouse gas and sulphate aerosols emissions up to the year 2100. The scenarios were reported in the *Special Report on Emissions Scenarios* (SRES). The 40 SRES scenarios were based on four different 'storylines' of mutually consistent development across different driving forces (Figure 14).

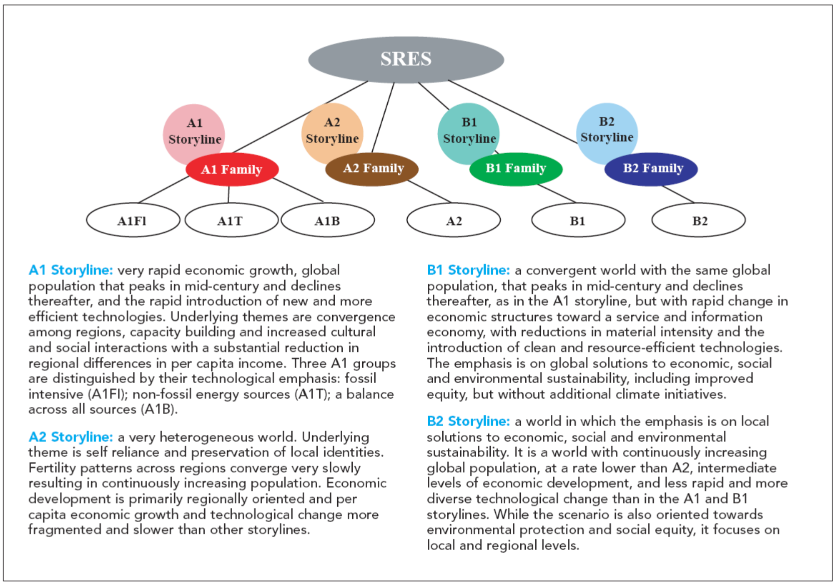

Figure 14 The family of SRES scenarios and their storylines developed on the IPCC Special Report on Emissions Scenario (Nakicenovic, 2000).

Temperature change projections based on the above emission scenarios are shown in Figure 15. Global mean warming is expected to increase by 0.4°C to 0.9°C from 1990 to 2020 and 0.9°C to 2.2°C by 2050. There is a range of uncertainty in these scenarios due to uncertainty in future global CO_2 emissions and in the global climate models used to assess temperature increases.

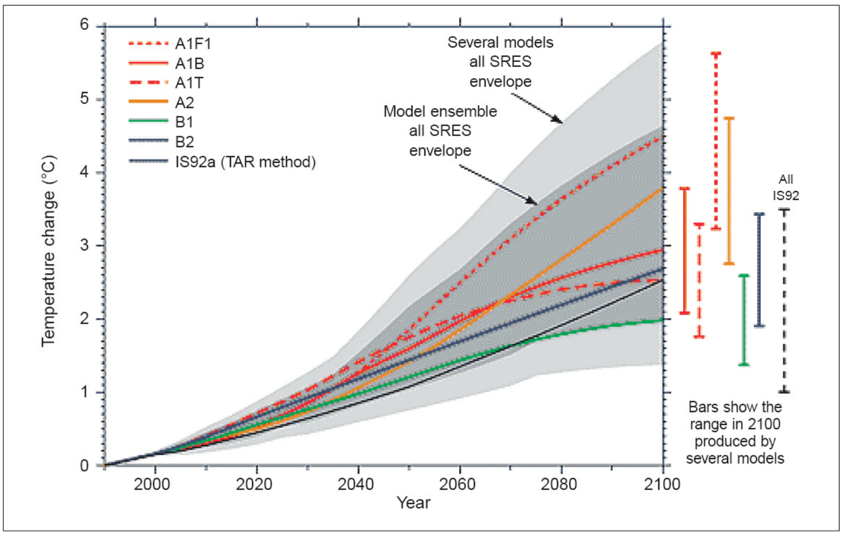

Figure 15 Temperature change projection (IPCC, 2001a).

CSIRO uses both global and regional models in the development of regional climate change projections. As discussed in Hennessy et al (2004), the models tend to simulate decreasing annual-average rainfall over NSW (Figure 16), particularly in winter and spring. In autumn the direction of the change is uncertain, while in summer there is a tendency for increases in the north-east.

Annual-average potential evaporation is projected to increase across NSW (Figure 17). The largest changes are projected in winter with the smallest changes in summer, because baseline potential evaporation rates are low in winter and high in summer. Compared to changes in the other areas of NSW, projected changes in the north-east are relatively small.

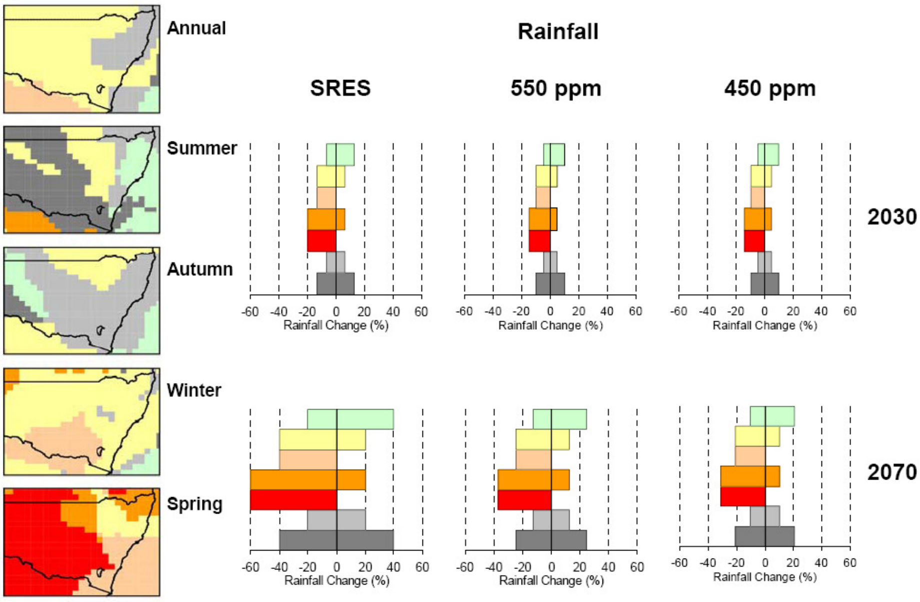

Figure 16 Ranges of change in average rainfall (%) for the years 2030 and 2070 relative to 1990. The coloured bars show ranges of change for areas with corresponding colours in the maps. The reduction in the range is also shown for the IPCC's 550 ppm and 450 ppm CO_2 stabilisation scenarios (Hennessy et al., 2004).

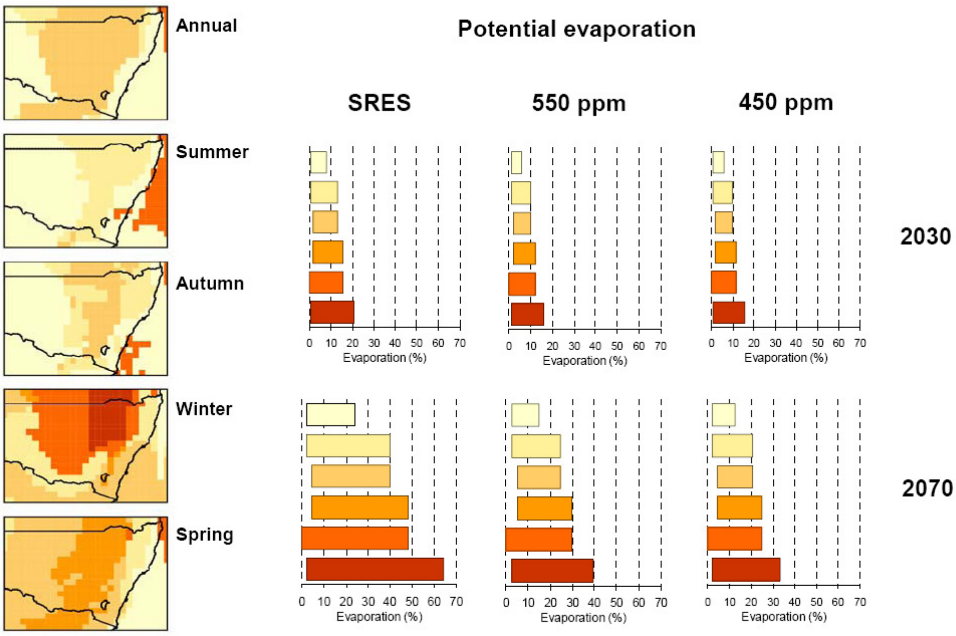

Figure 17 Ranges of change in point potential evaporation (%) for the years 2030 and 2070 relative to 1990. The coloured bars show ranges of change for areas with corresponding colours in the maps. The reduction in the range is also shown for the IPCC's 550 ppm and 450 ppm CO_2 stabilisation scenarios (Hennessy et al., 2004).

2.2.3 Potential impact on water supply and demand

Impacts on water supply

The relationship between climate, water supply and demand is relatively complex. Therefore, estimating the impact of climate change on water demand and water supply is not a simple task. Some estimates of changes in runoff due to climatic change have been produced using hydrologic models and a variety of climate scenarios in Australia. In general, these studies indicate that climate change may reduce runoff, streamflow and water supply.

CSIRO and Melbourne Water, for instance, recently completed a joint study of climate change risks to Melbourne's water supply (Howe *et al.* 2005). The risks that were identified include:

- Water Supply
  - reduced water supply due to lower streamflow;
  - bushfires in catchment areas;
  - pipe failure and collapse;
- Sewerage
  - reduced environmental condition of streams;
  - the potential for corrosion and odours in the sewerage network;
  - sewer overflows during storms;
- Stormwater
  - increased flooding risk and damage to stormwater infrastructure and facilities; and
  - the potential for negative water quality impacts due to increased concentration of pollutants entering the bay together with higher ambient bay water temperatures.

The study indicated that average inflow to Melbourne dams may decline 3–11% by 2020, and 7–35% by 2050 (Figure 18). The mid-range scenario indicated an 8% reduction in average annual volume of water supplied to the system by 2020 rising to 20% by 2050. Another study in Stirling Dam, Western Australia indicated that the current annual inflow of about 53.9 GL is projected to decrease as much as 24% to 41.1 GL in 2042–2062 due to climate change (The Department of Environment, 2004). In Adelaide, climate change may result in a reduction of flows into reservoirs of as much as 17 GL per year (Water Proofing Adelaide, 2004).

Potential impacts of climate change on Rous Water Supply infrastructure are summarised in Table 3. Decreasing yield from major sources and increasing competition with irrigators have been expected. Climate change may also cause water quality problem, therefore water treatment will be more expensive. In Emigrant Creek Dam, for instance, outbreaks of blue algae are already common, and these may become worse in a warming world (Rous Water, 2006).

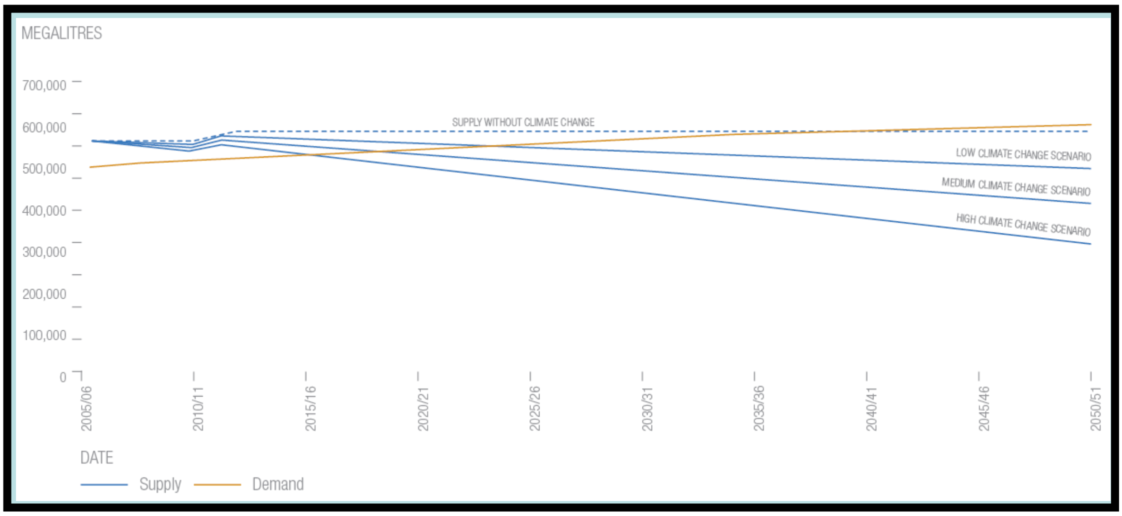

Figure 18 Projected changes in water supply due to climate change in Greater Melbourne (Our Water Our Future, 2005).

Table 3 Potential impacts of climate change on Rous Water Supply Infrastructures (Summarised from Rous Water, 2006).

Changes in climate	**Potential impacts**			
	Rocky Creek Dam	**Emigrant Creek Dam**	**Lismore Source**	**Dunoon Dam**
Longer dry periods	Yield to drop as dam is small relative to annual extraction	Emptying dam needs to be done on a regular basis. Yield to drop due to a longer period between replenishment	Pumping will cease earlier in the year to maintain environmental flows. Longer period of time without extraction from source	Possibly some loss of yield compared from previous estimates but larger capacity dam should fare better
Increased evaporation	Yield to drop as more water is lost to the atmosphere and longer periods transpire without inflow	Yield to drop as more water is lost to the atmosphere and longer periods transpire without inflows. Very high surface area to volume ratio	Irrigation demand rises, increasing competition with irrigators	Expected loss of yield compared to previous estimates
Higher water temperature	Greater water quality problems	Greater water quality problems	Higher incidence of algae. Not a current problem	Expect similar water quality problems in Rocky Creek Dam
Intensity of rainfall		High treatment cost due to turbid inflow and perhaps some loss of throughput	Higher turbidity but not necessarily for longer periods of time	

Impacts on water demand

Unlike the impacts of climate change on water supply, studies of the impact of climate change on water demand are rather limited. Most of the available demand analysis is focused on the impact of demand management and population growth (e.g. Figure 5). The estimation of the impact of climate change on water demand is rather complicated since the demand is not only influenced by climatic factors but also by socioeconomic factors (e.g. demography, economy, land use, culture, and infrastructure); policy (e.g. regulation, and investment); and stakeholder decision-making (e.g. business strategy, responds to risk, and planning guidelines). In addition, water demand can be divided into several sectors such as domestic, agriculture, leisure, and industry. Each sector has different sensitivities to climate change. For example, in the domestic sector, people generally spend more time in their garden and have fountains to cool patios by evaporation in warmer weather. However, in the Rous Water region, outdoor water demand (31%) is much less compared to that of the typical households in Australia (60%), therefore the outdoor water demand in this region will be less affected by climate change.

Empirical information on the impact of climate change on Rous Water's water demand was limited at the time of this project. However, some relevant knowledge of other regions close to the Rous Water can be used as surrogates. For instance, a water-demand analysis in Queensland's urban community has indicated that it is the frequency of rainfall, not the amount that significantly affects the external use of water in Maroochy, Mackay, and Ingham, whereas the amount of rainfall and the monthly air temperature are the most significant variables affecting water demand in the inland communities of Toowoomba and Emerald (Montgomery Watson, 2000).

3. FRAMEWORK FOR IMPACT ASSESSMENT

3.1 Introduction

Most research on the hydrologic impact of climate change uses a predictive approach. It begins with generating climate change scenarios. Climate information is then fed into hydrologic models and/or water-management systems to evaluate the differences in system performance under different climate scenarios. Adaptations can then be designed to manage those changes.

There are large uncertainties in these scenarios, arising from estimates of global greenhouse emissions, global climate sensitivity, regional changes, and climate variability. Hydrologic models also contain modelling uncertainty. In addition, climate change is just one of a number of factors putting pressure on the hydrological system and water resources. Population growth, changes in land use, water policies, prices, and adaptation are just a few examples of other factors affecting the water supply and demand. Therefore, the above predictive approach is limited by scenario uncertainty and often neglects the relationship between current climate risk, vulnerability to that risk and adaptations developed to manage risk. To deal with uncertainty, it is suggested that climate change and its consequences should be expressed in units of probability or likelihood. This enables one to pursue risk-based impact assessment and management, whereby thresholds for climatic changes and/or specific impacts are integrated with probability distributions for climate, environmental, and socioeconomic variables that influence system outcomes (Jones, 2001). Also, to deal with the dynamics of the system, assessing the impacts of climate change cannot be a static activity. Hence, new information is constantly being made available, new methods and models are being developed and tested, and policies related to water management and planning are dynamic and changing (Gleick and Adams, 2000).

Impact and risk assessment is only one stage in a larger risk management framework (Kirono et al., 2006). Ideally, risk management involves all related stakeholders. The decision-making process is commonly circular to allow the performance of decisions taken to be reviewed and revisited as new information on climate change and its impacts are available. It is also iterative to allow the problem, decision-making criteria, risk assessment and adaptation options to be refined.

Through consultation with stakeholders at the workshop on the 7th of April 2006 and regular fortnightly communications, the following key issues were identified for the risk analysis and adaptation assessment:

- Rous Water needs to know when to make infrastructure investments;
- a minimum of ten years is required to commission a new water source;
- it is agreed to use Wilson River IQQM FX94D as the baseline (see section 3.2.4 for information about model);
- the assessment endpoint is the secure yield. The secure yield is defined as the annual demand that can be supplied over the period of record used in the analysis (i.e. 100 year

duration) and which satisfies the 5/10/20 rule which is commonly applied by the NSW Public Works to determine the safe yield from a dam (Rous Water, 1995):

- restrictions of any kind should not be applied for more than 5% of the time (i.e. 5% days);
- restrictions of any kind should not be imposed more than one year in ten on average (i.e. 10% years); and
- the system should be able to supply 80% of normal demand (i.e. 20% reduction in consumption) through a repeat of the worst drought on record. The system should start with the storage drawn down to a level at which restrictions should be applied in-order to satisfy the above 5% and 10% rules (this known as the 20% part of the rule). Note that this was modelled by changing dam capacity to 80% and imposing permanent restrictions and ensuring the demand was met through the worst drought in the 100 year record.

3.2 Risk assessment

Figure 19 presents the assessment framework for climate change impacts and adaptation. The framework follows the following main steps:

- Select six Global Climate Model (GCM) simulations through the use of the CSIRO Climate Scenario generator, OzClim;
- Prepare three climate scenarios (one wet, one medium, one dry) expressed as a function of global warming (percent change per ^{o}C of global warming) for potential evaporation (*Ep*) and precipitation (*P*) for specified times in the future (2010, 2020, 2030) for each of the six GCMS. This results in a total of 18 climate scenarios;
- Apply these climate scenarios in the IQQM model to generate climate change flow sequences. Rainfall and evaporation inputs to IQQM are modified to simulate climate change;
- Analyse the sensitivity of secure yields to changes in inflow to Rocky Creek dam, Emigrant Creek dam, and the downstream tributary via a large number of IQQM simulations. This generates sensitivity models which can be used to estimate yields based on evaporation and rainfall changes;
- Analysis the risks to Lismore’s future water supply yield and secure yield by using Monte Carlo methods (repeated random sampling);
- Evaluate risk and identify feedbacks likely to result in autonomous adaptations; and
- Consult with stakeholders, analyse proposed adaptations and recommend planned adaptation options.

Details about how these tasks were performed are provided in section 3.2.1 to section 3.2.4.

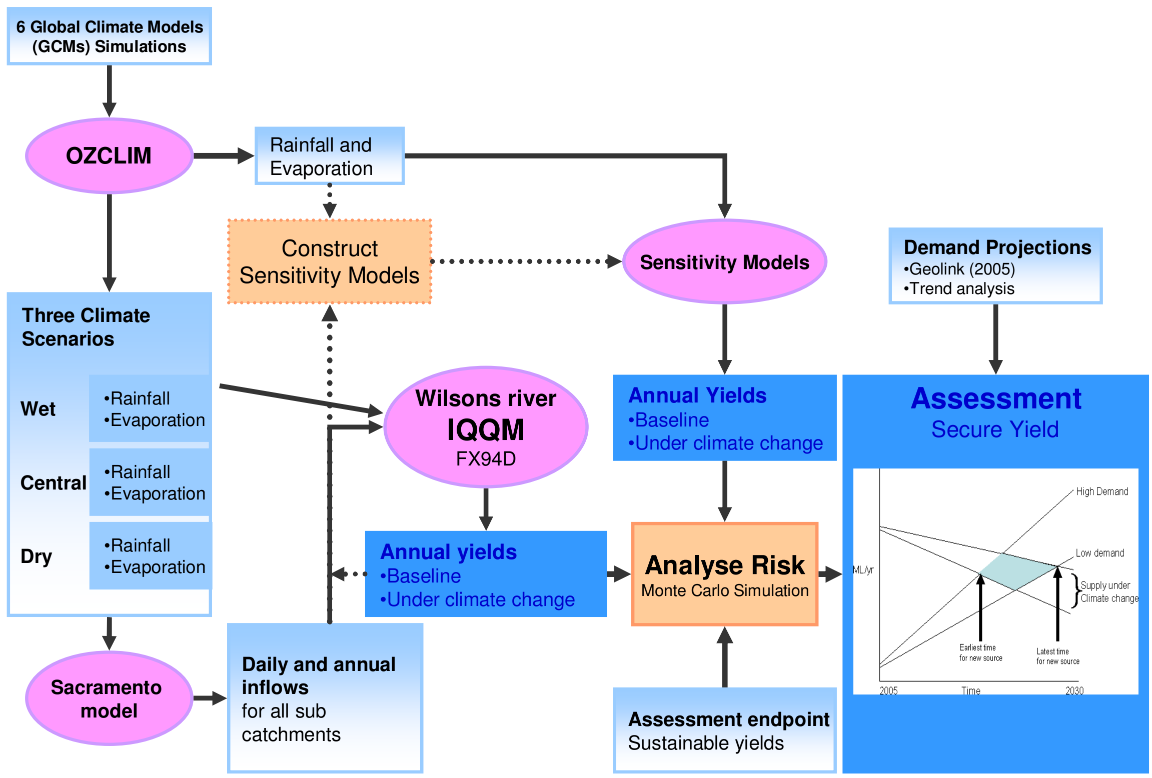

Figure 19 General framework for risk assessment for Rous Water Scheme.

3.2.1 Climate change scenarios

The climate change scenarios were generated from CSIRO's climate scenario generator, OzClim (Page and Jones, 2001). This PC-based climate scenario generator simplifies the process of calculating scenarios from climate change model output, applies scenarios to impact models and manages uncertainty. A range of GCMs, emission scenarios and climate sensitivities can be harnessed using this system.

For this assessment, multiple climate change simulations were conducted for year 2010, 2020, and 2030. These were based on six climate models at low, medium and high climate sensitivity and the SRES marker scenario B1, A1B, and A1F. This process produced a total of 18 simulations for every station used in the Wilson River IQQM. Details regarding the model simulations are provided in Table 4.

Table 4 Global Climate Models, climate sensitivity and emissions scenarios which were used to generate climate change scenarios for Wilson River.

Institution	Model symbol	Climate Sensitivity	Emission
CSIRO, Australia	CSIRO_Mk2	Low	SRES B1
		Medium	SRES A1B
		High	SRES A1F
CSIRO, Australia	CSIRO_Mk3	Low	SRES B1
		Medium	SRES A1B
		High	SRES A1F
CSIRO, Australia	CSIRO_CC	Low	SRES B1
		Medium	SRES A1B
		High	SRES A1F
Canadian Climate Centre, Canada	CCCM2	Low	SRES B1
		Medium	SRES A1B
		High	SRES A1F
DKRZ, Germany	ECHAM4	Low	SRES B1
		Medium	SRES A1B
		High	SRES A1F
Hadley Centre, United Kingdom	HadCM3	Low	SRES B1
		Medium	SRES A1B
		High	SRES A1F

3.2.2 Demand projection

Demand projections were presented in section 2.1.2 and are taken from the results of GeoLink (2005) study. In that study, the population projections have been derived from the following three different methods and/or data sources:

- Australian Bureau of Statistics (ABS) data;
- NSW Statistical Local Area Population Projections 2001-2031 (DIPNR, 2004); and
- Land use and strategic planning data supplied by each of the Councils (Ballina, Byron, Lismore, and Richmond Valley).

GeoLink (2005) acknowledges that some factors (e.g. changes in social policy, behaviour, and economics) may have a significant effect on future population change. Nonetheless, these projections are the current best estimate since they are derived not only from population records but also from land use and strategic planning data, including:

- consumption patterns within each local government area (including monthly consumption, monthly bulk water supply, and annual consumption data which were categorized into residential, commercial and industrial for each demand centre) and projections of future consumption from these historical patterns;
- the impact of demand management initiatives, e.g. the Residential House Tune-Up Program, the 'Every Drop Counts' Primary School Education Program, the Rainwater Tank Rebate Program, etc.;
- the introduction of the BASIX (Building Sustainability Index) system. For example, a typical single dwelling design will meet the BASIX target for water conservation if it includes: (a) showerheads, tap fittings and toilets with at least a 3A rating; and (b) a

rainwater tank or alternative water supply for outdoor water use and toilet flushing and/or laundry (DIPNR, 2005); and

- the implementation of dual reticulation schemes within the supply area. Dual reticulation refers to the use of highly treated effluent (recycled water) for non-potable uses at households.

In addition, a simple trend analysis was performed using the 1996–2005 historical data. This analysis produced a tool to project future demand based upon available demand data (see also section 2.1.1).

3.2.3 Yield estimation using IQQM

This study used the Integrated Quantity and Quality Model of the Wilsons River which is described in detail in DIPNR (2004). The IQQM is a hydrologic, river system simulation package for water resources planning purposes at the river basin scale (DLWC, 1998). IQQM consists of the Sacramento rainfall-runoff model and river routing, water demand and allocation routines to simulate river flow and regulation. This software has been implemented in most regulated and a large number of unregulated river systems in NSW and Queensland.

The Wilsons River catchment is shown in Figure 20 along with the climatic and hydrological stations which are used in IQQM. The number of observed rainfall, evaporation, and stream flow stations used in the model are 8, 1, and 14, respectively. Rainfall data is used to account for soil moisture (which governs the crop water demands of irrigators) and to apply rainfall onto the water surfaces of reservoirs and river reaches. Rainfall data is also required for calculating catchment inflows. The evaporation data is used to estimate potential evapotranspiration from crops, evaporation from reservoirs and river reaches, and to synthesize streamflow.

The model incorporates existing irrigation development (3,000 ha); system demands (11 urban/rural demand centres); sources of supply (Rocky Creek Dam, Emigrant Creek Dam, and Borefields); scheme operating rules and access to streamflows at Lismore.

The published results for the Wilsons River model (DIPNR, 2004) are based on a model scenario known as FX04D. The Lismore source access rules have been investigated further, resulting in a revised scenario known as FX94D, which is as yet unpublished. Based on a discussion with Rous Water, this study has adopted the FX94D model run as the baseline from which to assess the impacts of climate changes. The differences between the FX94D model and the published FX04D model are presented in Table 5.

To assess the 20% rule a variation of the FX94D model has been created for this study (FX94Dr). In this scenario the storages are configured to 55% capacity, which imposes permanent water restrictions within the model. This is used to establish the baseline for the 5/10/20 rule.

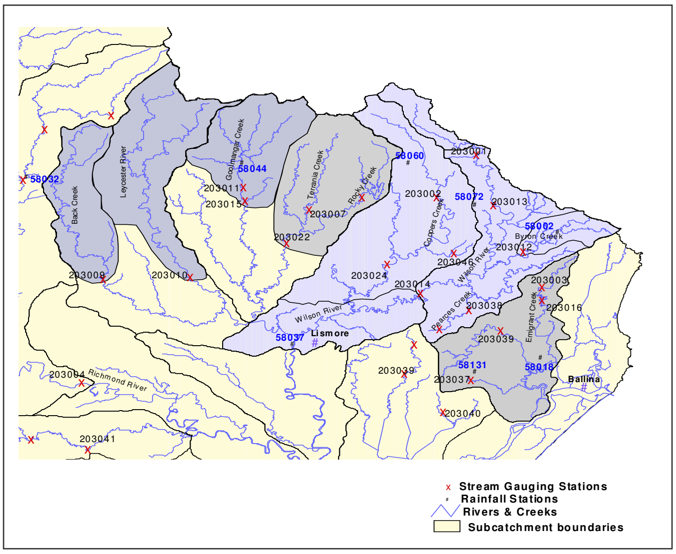

Figure 20 Wilsons River catchment as used by IQQM (DIPNR, 2004).

Table 5 Differences between published and adopted Wilson River models.

Description	FX04d	FX94D	FX94Dr
Sustainable yield	15,800 ML/a	14,900 ML/a	14,900 ML/a
Lismore source access rules	CTP 87 ML/day (Flow-87)*0.5 to 132 ML/day 22.5 ML/day to 181ML/day (Flow-181)*0.5 Pump limit of 30 ML/day	CTP 107 (Flow-87)*0.25 Pump limit 30 ML/day	CTP 107 (Flow-87)*0.25 Pump limit 30 ML/day
Lismore source Rostering constraint	0 up to 41 ML/day usage (Usage-41)*0.5	0 up to 61 ML/day usage (Usage-41)*0.25	0 up to 61 ML/day usage (Usage-41)*0.25
Emigrant Ck capacity	820 ML	820 ML	451 ML
Rocky Ck capacity	13,956 ML	13,956 ML	7,676 ML

Using simulated flows in IQQM

To be able to assess the impacts on flow due to changes in climate the time series inputs used in IQQM had to be changed. In the FX94D scenario IQQM uses a mixture of observed and predicted flows that vary between sites. The Sacramento rainfall runoff model was used to extend flows for most of the tributaries. Emigrant Creek Dam was based on the Australian Water Balance Model (AWBM) rainfall-runoff model while Rocky Creek dam was based on a monthly correlation with a nearby gauge and then disaggregated by a mixture of techniques. For this study all tributaries needed to be modelled using rainfall-runoff models and to be consistent the Sacramento model was used for all tributaries. DIPNR had already developed

Sacramento models for Rocky Creek Dam and Emigrant Creek Dam that had a good match with the short periods of observed data and these were adopted.

The Sacramento models generally matched well with observed flows at all sites. However, when the observed data were replaced with the simulated data, the result for secure yield was different to that from the original FX94D model. As the model is most sensitive to inflows from Rocky Creek Dam and Emigrant Creek Dam, the Sacramento models for these tributaries were adjusted until the original secure yield of 14,900 ML/year was achieved without significantly changing the mass balance from the 100-year time series of simulated streamflow. Unfortunately this was not quite possible due to very small differences (<2%) in critical events for the to 5% and 10% rules. The best that could be achieved was a secure yield of 15,000 ML/year while keeping the difference in overall volume at Emigrant Ck and Rocky Ck within 2%. Consequently, for this study, all secure yields are compared against a baseline secure yield of 15,000 ML/year rather than the 14,900 ML/year obtained in the DNR FX94D scenario.

Methodology for determining secure yield

Secure yield for the Rous Water supply was estimated based upon the minimum yield required to meet the 5/10/20 rule (Section 3.1). Figure 21 shows the combined Rocky Ck and Emigrant Creek storage volumes from 1892 to 2002 (110 years) for the FX04D scenario. The figure shows that the system is able to meet the secure yield for the 5% and 10% rules. According to the 5% rule, restrictions of any kind should not be applied for more than 5% of the time. During this time, restrictions had been applied for about 886 days, therefore less than 5% of the total time (i.e., 2,021 of 40,436 days total). The supply was also able to meet the 10% rule as the restrictions had been in place less than 11 years of the 110-year record.

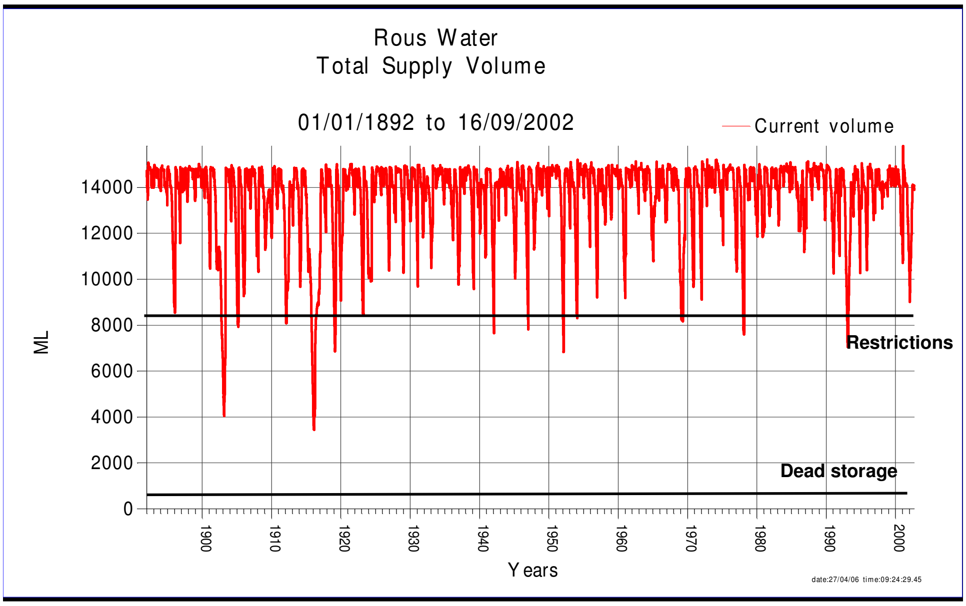

Figure 21 Rous water total supply generated from IQQM from 1890 to 2002.

The estimation of secure yield for each climate scenario required an iterative solution that successively modifies and runs IQQM until the demand is met in accordance with the 5/10/20 rule. The iterative solution is described in Appendix 1.

This process is carried out for each of the climate scenarios, for a total of 54 scenarios (i.e., 18 scenarios for each of the years 2010, 2020 and 2030). To solve each scenario, IQQM was run approximately 10 times, resulting in approximately 540 runs to cover all of the climate scenarios.

3.2.4 Yields under climate change

For impact assessment, the estimated yields under climate change were based on the IQQM output. In this case (referred to as IQQM), OzClim was used to generate daily records of rainfall (*P*) and evaporation (*Ep*) for each climate change scenario. These modified records were then input to the IQQM Sacramento model to generate climate change flow sequences. The rainfall, evaporation and flow records within IQQM were replaced with the modified climate change records. IQQM was run to apply multiple scenarios for 2010, 2020, and 2030. By doing so, we obtained multiple estimates of the yield at Lismore and the yield of the whole system for each of these years.

In addition, to explore the potential of having a very simple model which can provide a simple and quick estimate of change in yield to a given change in climate, this project developed simple model which enables one to estimate change in yield as a function of changes in rainfall and evaporation. The approach (here referred to as the sensitivity model) involves the use of two sets of transfer functions: one set relates precipitation and evaporation to inflows, the other relates inflows to yields. To do this, the relationships between climate and inflows of the main sources (i.e. Rocky Creek Dam, Emigrant Creek Dam, and downstream tributaries) were first examined. The results (not shown here) suggest that all inflows show the same sensitivity to changes in rainfall. For instance, approximately 10% change in rainfall results in about 15% change in inflow.

These actions produced a simple multivariate transfer function relating the inflow with *P* and *Ep* to estimate inflow of each main source using the input of *P* and *Ep*. The multi-linear function of the model is as follows:

$$\text{Flow} = (a \times P) + (b \times Ep) - c$$

Where *P* and *Ep* were measured in mm per year and inflow in ML per year, and *a*, *b*, and *c* are constants.

Figure 22 shows that the above transfer function is quite capable of estimating the inflow. Quantitatively, the standard errors of estimates from the model were 2%, 5%, and 8% for the Rocky Creek Dam, the Emigrant Creek Dam, and the downstream tributary, respectively. These model validations suggest that the sensitivity models can be confidently used to estimate flow as a function of *P* and *Ep*.

Sensitivity tests were subsequently conducted to assess the sensitivity of the secure yields to inflow of the main source (i.e. Rocky Creek Dam, Emigrant Creek Dam, and downstream tributary). To do this, the IQQM was run several times to assess the impact of the following assumptions on the secure yields:

- ±1%, ±2%, ±5%, and −10% changes in inflows; and
- +10% changes in irrigation demand (which is conducted by adjusting the area).

Figure 23 presents the changes in secure yields due to changes in inflow of each source. It suggests that the secure yields are mostly sensitive to flows downstream of the dams as they influence the amount of water abstracted at Lismore. These analyses also demonstrated that the secure yields are not sensitive to changes in the irrigation demand (not shown here).

The results of these sensitivity analyses were then utilised to develop the other transfer function that can provide estimates of secure yields as a function of inflow to the Rocky Creek dam, Emigrant Creek dam, and the downstream tributaries.

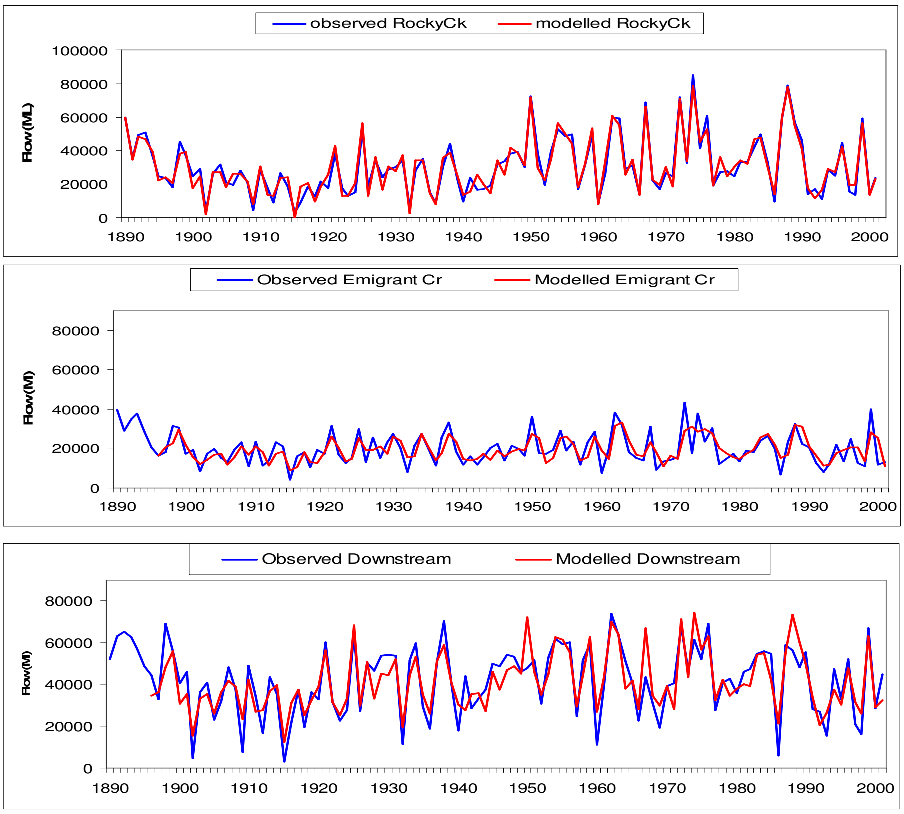

Figure 22 Comparison between the observed and the modelled inflow of each main source.

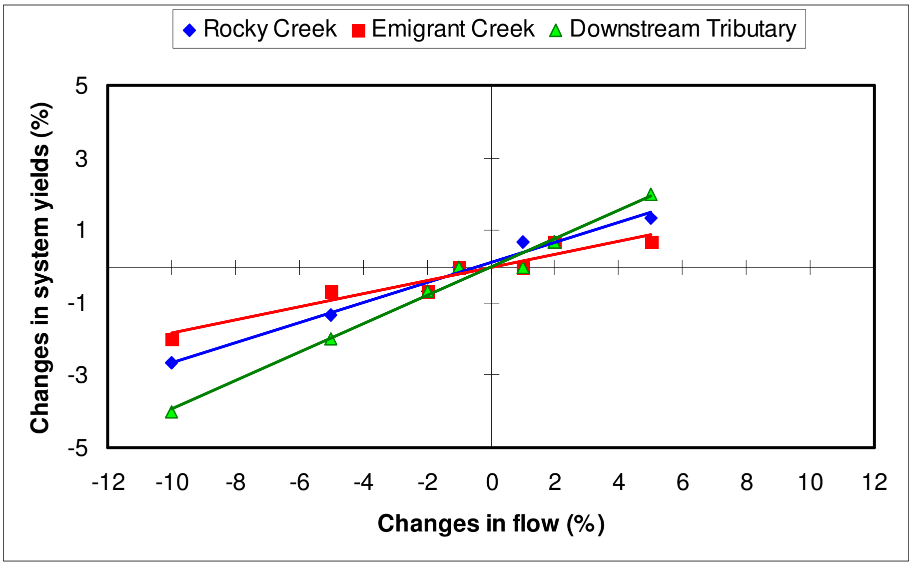

Figure 23 Changes in secure yields due to changes in inflow of each main source.

3.3 Risk Analysis

As mentioned previously, the issue of climate change is beset by uncertainties. These uncertainties include the magnitude of global warming, regional changes in rainfall and evaporation, and regional supply sensitivity and coping capacity. In the face of this problem, quantifying the uncertainties in climate change and its downstream consequences in units of probability or likelihood will help identify robust adaptation strategies.

There are two types of likelihood for future events that are both measured in terms of probability:

- event-based probability where the likelihood of recurring events is estimated (e.g. floods, droughts and temperature extremes).
- the probability of a specific outcome which is measured over a range of future uncertainty.

In this study, the second type of probability is used to describe the future state of climate change under the enhanced greenhouse effect. To do this, Monte Carlo methods (repeated random sampling) were employed to stochastically generate probabilistic estimates of future climate change and its impacts on Rous Water's secure yields.

To estimate the probability of climate change, three types of uncertainty are taken into account:

- future greenhouse gas and sulphate aerosol concentrations;
- the sensitivity of climate to these concentrations; and
- regional patterns of climate change from different climate models.

These uncertainties are quantified as ranges with an upper and lower limit and a known probability distribution. These ranges are then randomly sampled repeatedly and combined to determine a joint probability distribution relevant to the secure yields. The Monte Carlo sampling was conducted for 2010, 2020, and 2030 in the following manner:

Random local *P* change = Random global warming × Random local *P* change per ^{o}C global warming
Random local *Ep* change = Random global warming × Random local *Ep* change per ^{o}C global warming

This random sampling was repeated 2,500 times in year 2010, 2020, and 2030 to get an adequate sampling density over the projected range of uncertainty. Simulations samples were subsequently used to calculate cumulative probability distributions for future climates as shown in Chapter 4 (e.g. Figure 24 and Figure 25).

4. RISK ANALYSIS RESULTS

4.1 Climate Change Probabilities

The probability of the most to the least likely future climates is shown in Figure 24 and Figure 25. These cumulative probability graphs rank the data in the simulation from the highest to the lowest value, and graph each point with its corresponding percentile. This treats each outcome as being of equal likelihood. For example, in 2030 there is a 20% probability that the change in evaporation will be +23% or less (Figure 24) and there is a 50% probability that the change in Rocky Creek rainfall will be about -5% in 2030 (Figure 25). The downward sloping cumulative probability graphs indicate the proportion of data in the simulation predicted to exceed each value on the x-axis. The inspection of both figures suggests the following:

- Increases in potential evaporation are virtually certain (i.e. >99% probability of occurrence). The 95th and 5th outcomes range from about 2% to 4% in 2010, 4% to 12% in 2020, and 10% to 26% in 2030.

- The chances of decreasing rainfall are relatively even with the chances of increasing rainfall, particularly in the downstream tributary area. The lowest and highest (5th and 95th) changes in *P* range from about 2% to −4% in 2010, 7% to −11% in 2020, and 17% to −21% in 2030.

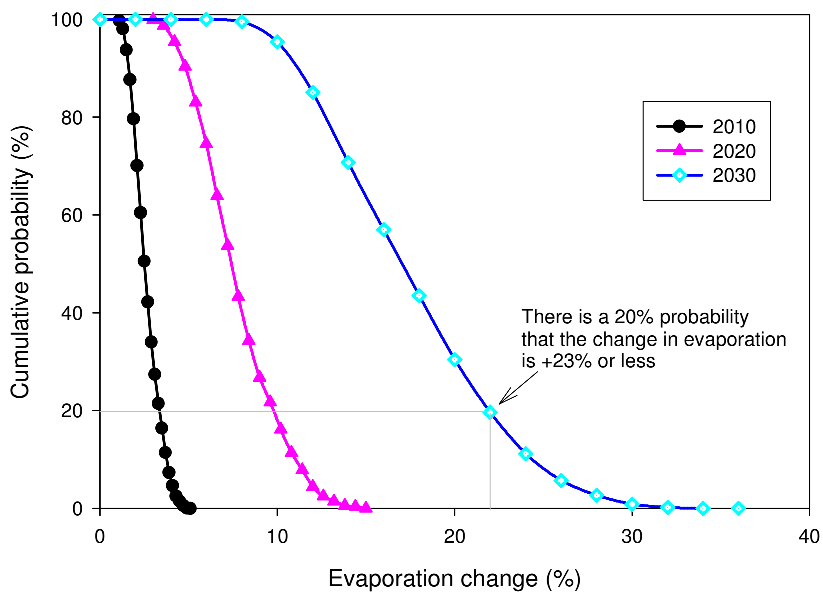

Figure 24 Probability distributions for evaporation changes in 2010, 2020, and 2030. An example about how to interpret this graph is provided for year 2030.

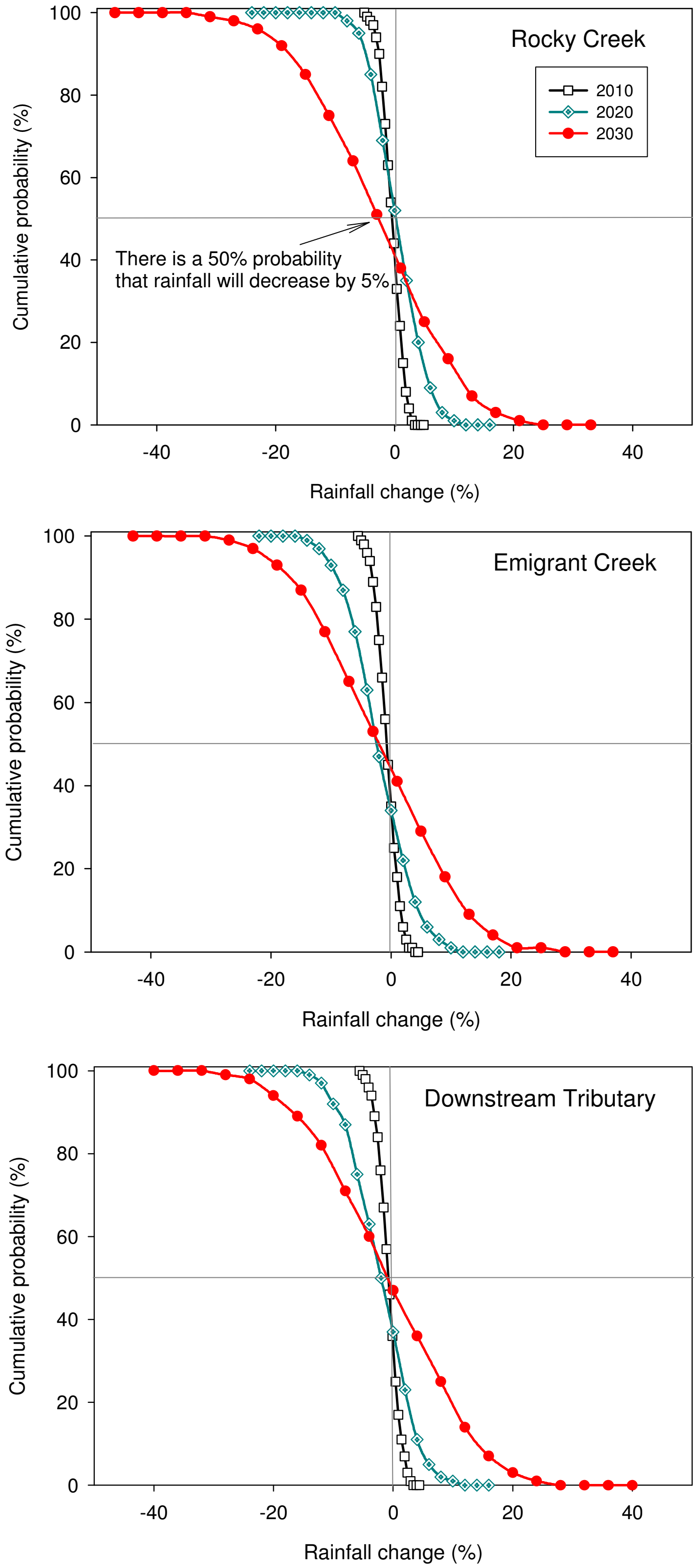

Figure 25 Probability distribution for rainfall changes in 2010, 2020, and 2030. Example about how to interpret this graph is provided for Rocky Creek dam rainfall in 2030.

4.2 Risk of Changes in Supply

As described previously in section 3.2.4., the assessment of change in supply due to climate change was based on the IQQM modelling. However, this study also offers an alternative to scope changes in secure yields based on simpler hydrological sensitivity models, if the more sophisticated hydrological such as IQQM is unavailable. The risk of changes in supply based on both the IQQM and simple hydrological model are described in the following.

4.2.1 Risk based on IQQM runs

The rainfall, evaporation and flow records within IQQM were replaced with the modified climate change records from the 18 climate scenarios to estimate future safe yields. Results of this analysis indicated a range (minimum and maximum) of change from about 0.7% to -3% in 2010, 1% to -7% in 2020, and 3% to -9% in 2030.

The cumulative probability distributions were generated based upon the output from these simulations as shown in Figure 26. For example, there is 50% chance that the yields will decrease by more than 8% in 2030. We can see that the wettest outcomes are very unlikely (<10% probability), whereas the driest and the central outcomes are likely (>66% probability). The most likely (>50% probability) changes in secure yields in 2010, 2020, and 2030 are -1.7%, -5.8%, and -8.1% respectively.

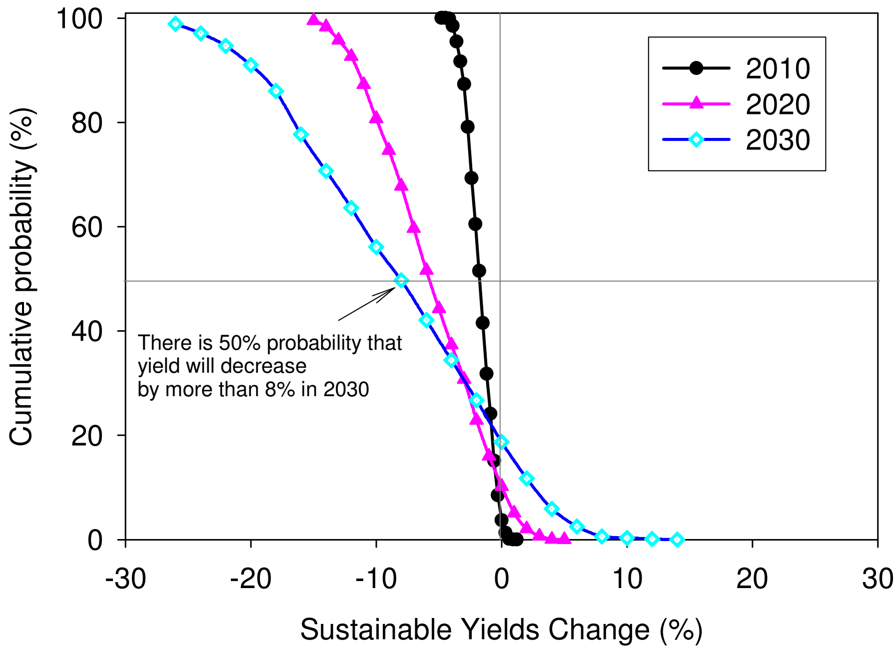

Figure 26 Probability distributions for climate change impacts on secure yields (calculated from IQQM). An example for interpreting the graph is provided for 2030.

4.2.2 Based on sensitivity models

The climate-inflows transfer functions obtained in section 3.2.4 were used to estimate changes in inflow to the main sources (Rocky Creek Dam, Emigrant Creek Dam, and downstream tributaries) due to changes in rainfall and evaporation based upon the 18 climate scenarios in 2010, 2020, and 2030. Subsequently, these estimated inflows are input to the inflow-yield transfer function to estimate changes in the yields in each future year.

Figure 27 presents cumulative probability distributions for changes in yields where the probability distribution is tallied from wettest (best) to driest (worst) outcomes. The figure suggests that increases in yields are unlikely (<33% probability), and that declines in yields are much more likely. The most likely (>50% probability) changes in secure yields in 2010, 2020, and 2030, are -5.0 %, -6.3%, and -6.7% respectively.

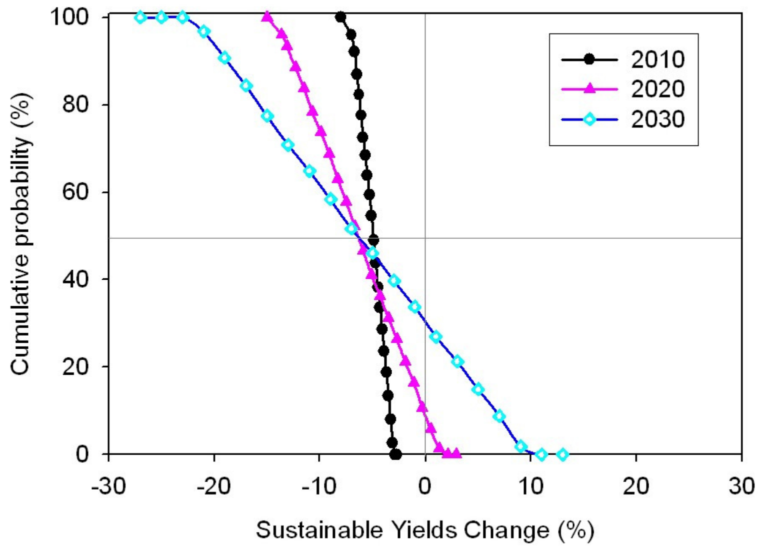

Figure 27 Probability distributions for climate change impacts in secure yields (calculated from the sensitivity model).

4.2.3 Conclusion: changes in supply

The descriptions above have shown that the IQQM and the sensitivity models offer similar results. This implies that the simple sensitivity models have a capacity to produce similar estimates to those produced by more complex models such as IQQM, therefore opens a possibility of employing a simpler hydrological sensitivity model to provide a simple and quick estimate of climate change impact on water supply, when a more complex hydrological model is unavailable (Jones et al., 2006). In conclusion:

Both results obtained from the IQQM and the sensitivity model suggests that the decreases in secure yields are likely (>66% probability) in the future. When the median estimates of the two approaches are averaged, it is found that the most likely changes in secure yields are -3.4 %, -5.7%, and -7.4% in 2010, 2020, and 2030 respectively.

4.3 Impact Assessment and Adaptation

4.3.1 Lismore's source

The Lismore source is a medium-term solution which is expected to assist in meeting the high demand projection up to year 2024 in a no-climate change situation. Using the IQQM we can simulate the yield at the Lismore source in a climate change situation. For this purpose, the IQQM daily baseline records of rainfall and evaporation were replaced with the daily records of rainfall and evaporation according to the climate change scenarios generated from OzClim.

There is a less than 9% possibility that Lismore's supply will increase by about 2% in 2030. The driest and the medium outcomes are much more likely. The most likely (median) reduction is about -0.5, -1.5%, and -2.5% in 2010, 2020, and 2030 respectively. Figure 28 shows the annual average of water which can be pumped out from the Lismore source in the future in comparison to the baseline. The wet, the medium, and the dry curves represent the 5th, 50th, and 95th percentiles of the probability distribution respectively.

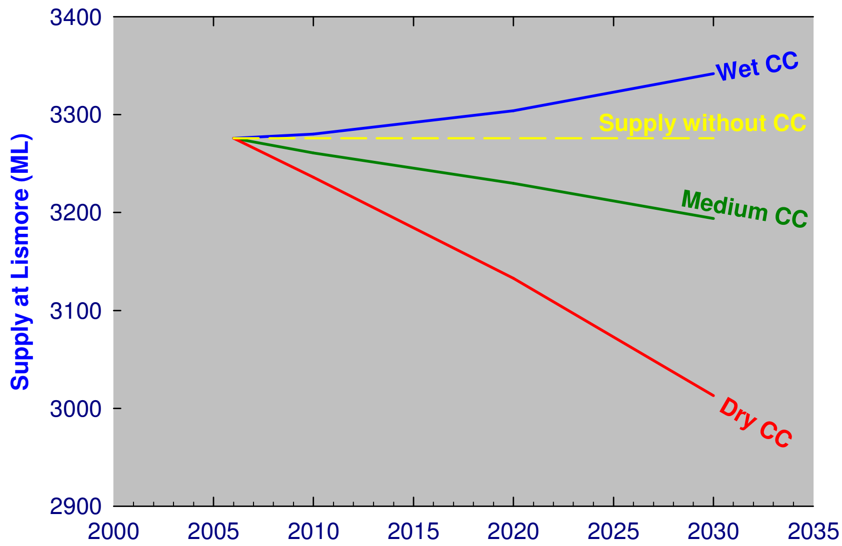

Figure 28 Projected supplies at Lismore source due to climate change (CC). The wet, the medium, and the dry curves represent the 5th, 50th, and 95th percentiles of the probability distribution respectively

4.3.2 Rous Water's supply

The projections of the secure yield (estimated by this study) and the demand (estimated by Geolink, 2005), are presented in Figure 29. To represent the actual demand and its trend, the historical water production from 1996 to 2005 and its trend projection (estimated in section 2.1.1) are also plotted. GeoLink's demand projections have been slightly modified so that they have the same starting point with the actual demand trend in 2006 (i.e., approximately 11,973 ML). The supply in wet, medium, and dry climate change (CC) curves represent the 5th, 50th, and 95th percentiles of the probability distribution, respectively.

The figure indicates that given the wet climate change scenarios, over the near term, the supply will fall in 2010 before increasing to the above present supply in 2020 and continuing to rise to more than 16,000 ML in 2030. In the wet scenarios, the rainfall and evaporation will increase at almost the same rate, i.e. 2% from the current figure, in 2010. Hence, the increase in evaporation offsets the rainfall gain, slightly decreasing the yield. Meanwhile, in 2020 and 2030, the increase in rainfall is much higher than the increase in evaporation, therefore the yield will increase. In the medium climate change scenarios, the supply will decline to around 14,042 ML while in the driest scenario it will decline to approximately 11,642 ML in 2030. It is noteworthy that according to the results presented in section 4.2., the decrease in secure yield is highly likely in the future.

The demand projections (either based on the Geolink, 2005, or based on the trend analysis of the actual demand) show an obvious increase. The slope of the actual demand trend is similar to the best-estimate demand provided by GeoLink (2005), suggesting that the two are relatively comparable. Demand is likely to increase to more than 14,150 ML (according to the trend analysis) or more than 14,900 ML (according to GeoLink, 2005) by 2030. This suggests that by 2030, the secure yield is unlikely to be able to meet the demand.

The point of concern, where the worst supply scenario encounters the best estimate demand projection, is around 2016. The other point (i.e., where the worst supply scenario encounters the demand projection based on trend analysis), is around 2018. In those years, both the supply and the demand will be close to 13,000 ML. After that, the demand will be larger than the supply, hence, a new source would be needed to enhance supply. With an approximate lead time of ten years to commission a new source, efforts should commence in 2008.

Given a medium climate change scenario point of view, the new source is expected to be needed by 2023 (if the best estimate of GeoLink's demand projection is used) and/or by 2028 (if the trend of the demand is considered). The year of 2023 generally coincides with the maximum time of usefulness of the Lismore source (i.e. the Lismore source is expected to help meet demand until 2024). This suggests that the commission of new source should be taking place by at least 2013.

In regard to the wet scenario, there is a chance that supply will keep pace with the best estimate demand and the low demand projection, therefore no further action would be required. However, the supply will not be able to meet the high demand projection in around 2018. In that case, a commission of new source by at least 2008 is recommended.

4.3.3 Adaptation and recommendations

The above assessment indicates that, due to global warming, the need for a new source for the Rous Water system is highly likely after 2018. If the medium supply scenario and best estimate demand are taken into account, the need for a new source would be expected to occur after 2023. Given that a ten years minimum is required to commission a new water source, the plan has to be started in 2008 for the worst scenario and/or in 2013 for the medium climate change scenario, meaning there is two to seven years time before the new source has to be really commissioned.

Within that time, it is recommended that the actual demand is closely monitored. This is because it governs the time when a new source is required. In the case of a dry climate change scenario, for instance, GeoLink's demand projection leads to a relatively similar suggestion with that of the actual trend of demand (i.e. only 2 years difference). In the case of medium climate change scenario, however, this differential becomes larger (i.e., 5 years). In addition, given a high demand and a low-supply, a crisis may occur in around 2012, since in that time the supply will be unable to meet the demand while the new source will unlikely to be ready even if the commission is started now. Thus, information regarding the demand is valuable in updating the plan as to when a new source has to be built.

One of the Rous Water's management measures is to reduce total demand for water by at least 10%, relative to 1995 consumption level, in the year 2011 (Rous Water, 2004). However, even if these initiatives were successful, demand would still increase due to population growth (Rous Water, 2004, and GeoLink, 2005). The results of the current study indicates that ideally, the demand will not be more than the driest supply projection (i.e., about 13,000 ML in around 2018). This means that the maximum tolerable increase of demand by 2018 is only approximately 10% of the current demand. If the wet supply scenario is taken into account, the maximum tolerable increase of demand by 2018 is about 25% of the current demand. Therefore, ongoing monitoring of rainfall patterns is also recommended.

To interpret the results appropriately, there is another factor need to be taken into account, i.e. the fact that climate variability not represented by the historical record or model simulations could also affect water supply within the time horizon in question. Changes in decadal mean rainfall may occur due to other factors other than the greenhouse effect (e.g. long term variations in natural climate), so they will be additional changes estimated here. This may be a factor if the current declining trend in rainfall continues and climate changes due to the enhanced greenhouse effect also intensify. If wetter condition occurs in the future, the impact of long-term rainfall reductions due to greenhouse effect will be less severe.

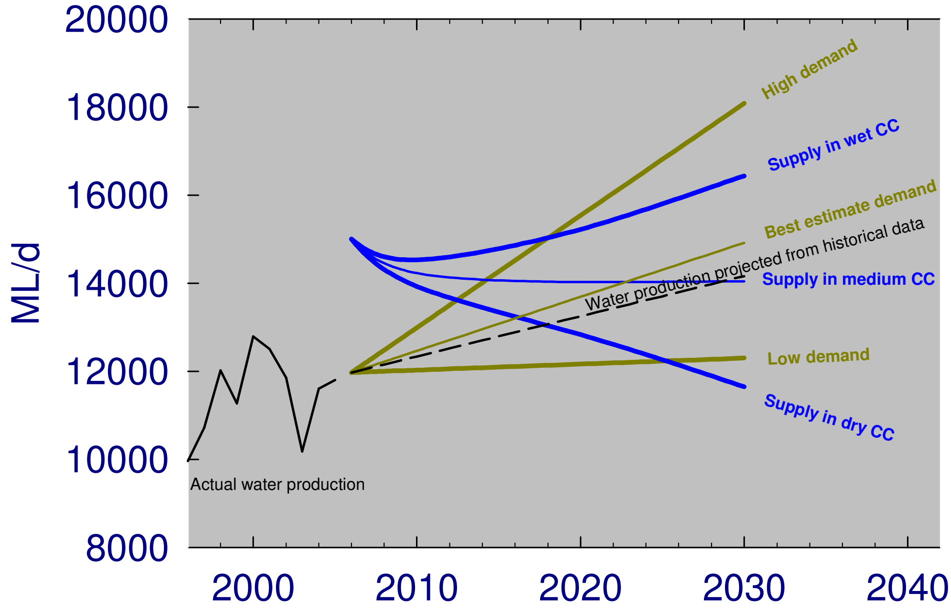

Figure 29 Supply projections due to climate change (CC) versus demand projection. Note: the high demand, best estimate demand, and low demand curves are taken and modified from GeoLink (2005).

5. CONCLUSIONS

This report has documented the framework and the results of the assessment of impacts of climate change on Rous Water's supplies. The quantitative assessments were conducted with the aid of the Wilson River Integrated Quantity and Quality Model (IQQM). An alternative, i.e. to scope changes in secure yields based on simple hydrological sensitivity models, has also been made available.

In terms of risk of climate change the following are found:

- the increases in evaporation are virtually certain (i.e. > 99% likely). The lowest and highest (5^{th} and 95^{th}) changes range from about 2% to 4% in 2020, 4% to 12% in 2020, and 10% to 26% in 2030.
- the chances of decreasing rainfall are relatively even with the chances of increasing rainfall, particularly in the downstream tributary area. The lowest and highest (5^{th} and 95^{th}) changes in rainfall range from about 2% to -4% in 2010, 7% to -11% in 2020, and 17% to -21% in 2030.

In terms of changes in the secure yield the results suggest that the decreases in secure yields are highly likely in the future.

- The most likely (>50% probability) changes in secure yields are -3.4 %, -5.7%, and -7.4% in 2010, 2020, and 2030 respectively.
- With regard to Lismore's supply, the most likely (>50% probability) reduction is about -0.5, -1.5%, and -2.5% in 2010, 2020, and 2030 respectively.

The results of the assessment suggest that:

- Given the best estimate demand and the driest supply scenario, the earliest time for a new source is in 2018. Considering the best estimate demand and the medium supply scenario, the medium time for a new source is in 2023.
- There is a two to seven year window of uncertainty regarding when the new source has to be commissioned.
- Within this time, it is very important to monitor the demand and update the assessment as to when to start building a new source. Ongoing monitoring of rainfall pattern is also recommended.

6. REFERENCES

Allen Consulting. 2005. *Climate Change Risk and Vulnerability*. Report to the Australian Greenhouse Office, Department of the Environment and Heritage, Canberra, Commonwealth of Australia, 159 pp.

BoM. 2006. Australian Bureau of Meteorology. *www.bom.gov.au*.

Chiew, F.H.S., Jones, R.N. and Boughton, W.R. 2005. Modelling hydrologic sensitivity to climate conditions. *Proceedings of the 29th Hydrology and Water Resources Symposium*, The Institution of Engineers Australia, Canberra. 9 pp.

CMPS&F. 1995. *Rous Regional Water Supply Strategy Planning Study*, Scheme Options, Final Report. May 1995.

Department of Environment. 2004. *Climate change, catchment runoff and risks to water supply in the south-west of western Australia*. Government of Western Australia, Department of Environment.

DEH. 2005. *Water conservation handbook for local government*. Water Conservation Partnership Project, South Australia. Department for Environment and Heritage.

DIPNR. 2004. *Rous Water – Augmentation of Regional Water Supply Scheme, Hydrologic modeling study using Wilsons River IQQM*. Issue 3. NSW Department of Infrastructure, Planning and Natural Resource

DLWC. 1998. *Hydrology unit technical practice notes*. NSW Department of Land an Water Conservation.

Downing, T.E., Butterfield, R.E., Edmonds, B., Knox, J.W., Moss, S., Piper, B.S. and Weatherhead, EK. 2003. *CCDeW: Climate Change and Demand for Water*. Defra.

EPICA. 2004. Eight glacial cycles from an Antarctic ice core. *Nature*, **429**, 623-628.

Geolink. 2005. Dunoon Dam, Population and demand projections. *Draft report*, 19-08-2005.

Gleick, P. and Adams, A. 2000. Water: The potential consequences of climate variability and change for the water resources of the United States. *The report of the Water sector assessment team of the national assessment of the potential consequences of climate variability and change, for the U.S. Global Change Research Program.*

Hennessy, K., Page, C., McInnes, K., Jones, R., Bathols, J., Collins, D. and Jones, D. 2004. *Climate change in New South Wales, Part 1: Past climate variability and projected changes in average climate*. Consultancy report for the New South Wales Greenhouse Office.

Howe, C., Jones, R.N., Maheepala, S. and Rhodes, B. 2005. *Melbourne water climate change study, Implications of potential climate change for Melbourne's water resources*. A collaborative project between Melbourne Water and CSIRO Urban Water and Climate Impact Groups. Doc: CMIT-2005-106.

IPCC. 2001a. Summary for policymakers. In Houghton, J.T., Ding, Y., Griggs., D.J., Noguer, M., Van Der Linden, P.J. and Xioaosu, D (eds) *Climate Change 2001: The scientific basis*. Contribution of working group I to the third assessment report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge.

IPCC. 2001b. *Climate Change 2001: Impacts, Adaptation and Vulnerability*. McCarthy, J., Canziani, O., Leary, N., Dokken, D. and White, K (eds). Contribution of working group II to the third assessment report of the Intergovernmental Panel on Climate Change, World Meteorological Organisation and United Nations Environment Programme. Cambridge University Press.

Jones, R.N. 2001. An environmental risk assessment/management framework for climate change impact assessments. *Natural Hazard*, 23, 197-230.

Jones, R.N. and Page, C.M. 2001. Assessing the risk of climate change on the water resources of the Macquarie River Catchment, in Ghassmi, F., Whetton, P. Little, R. and Littleboy, M. (Eds). Integrating *Models for Natural Resources Management across disciplines,* *issues and scales (Part 2).* Modsim 2001 International Congress on Modelling and Simulation, Modelling and Simulation Society of Australia and New Zealand, Canberra, 673-678.

Jones, R.N. and McInnes, K.L. 2004. *A scoping study on impact and adaptation strategies for climate change in Victoria*, A working paper produced as part of a three-year research program on: Assessment of climate change, impacts and possible adaptation strategies relevant to Victoria. April 2004.

Jones, R.N. and Preston, B.L. 2006. *Adaptation actions for local government*. A consultancy report for SMEC Australia Pty Ltd., Draft January 2006.

Jones, R.N., Chiew, F.H.S., Boughton, W.B. and Zhang, L. 2006. Estimating the sensitivity of mean annual runoff to climate change using selected hydrological models. *Advances in Water Resources*, **29**, 1419–1429.

Kirono, D.G.C., Page, C., Podger, G. and Jones, R. 2006. Assessment of the impacts of climate change on water supplies. *Mid-term report prepared for Rous Water New South Wales Department of Commerce*. June 2006.

Montgomery Watson. 2000. *Improving water use efficiency in Queensland's Urban Communities*, Quensland Department of Natural resources. Final report.

Morton, FI. 1983. Operational estimates of areal evapotranspiration and their significance to the science and practice of hydrology. *Journal of Hydrology,* **66,** 1-76.

Nakicenovic, N. (ed). 2000. Special Report on Emissions Scenarios. *A Special Report of Working Group III of the Intergovernmental Panel on Climate Change, Intergovernmental Panel on Climate Change*.

Our Water Our Future. 2005. *Draft for community comment secure water strategy central region*.

Page, C.M., and Jones, R.N. 2001. OzClim: the development of a climate scenario generator for Australia. In: *MODSIM 2001: International Congress on Modelling and Simulation: proceedings, Australian National University*, F. Ghassemi*, and others* (editors). Canberra, ACT: Modelling and Simulation Society of Australia and New Zealand. p. 667-671.

Pittock, A.B. and Jones, R.N. 2000. Adaptation to what, and why? *Environmental Monitoring and Assessment*, **61**, 9-35.

Pittock, A.B. 2003. *Climate change: an Australian guide to the science and potential impacts. The Australian Greenhouse Office*, Canberra.

Rous Water. 1995. Rous regional water supply strategy planning study. Scheme options. *Final Report May 1995*.

Rous Water. 2002. Ballina heights dual reticulation feasibility study. Rous Water Regional Authority. *Final report March 2002*.

Rous Water. 2004. *Demand management plan, 2004-2009*. Rous Water Regional Water Supply, Adopted Council Meeting March 2004.

Rous Water. 2006. A Presentation about Rous Water Regional Supply. www.scu.edu.au/schools/esm/dds. Downloaded in 02 June 2006.

Vivès, B. and Jones, R.N. 2005. Detection of abrupt changes in Australian decadal rainfall (1890-1989). *CSIRO Atmospheric Research Technical Paper 73*.

Water Proofing Adelaide. 2004. *Water proofing Adelaide*, Exploring the issues – a discussion paper. Government of South Australia, Action Salinity Australia, Water Care.

WMO. 2003. WMO statement on the status of the global climate in 2003. World Meteorological Organisation. http://www.mwo.ch/web/Press/index.html

APPENDIX

The iterative solution that successively modifies and runs IQQM until the demand is met such the 5/10/20 rule is just met is as follows:

1. Set initial upper and lower search limits (5,700 and 18,500 ML/a)
2. Determine current secure yield by taking average of the upper and lower search limit (initially 12,100 ML/a)
3. Create a new pattern file that proportionally adjusts Ballina demand for the current secure yield
4. Create an IQQM macro language file that:
   - Points to the new pattern file
   - Points to the appropriate climate scenario rainfall, evaporation and flow time series database
   - Adjusts the 10 other demand centres based on the current secure yield
   - Runs the FX94D scenario model from 1/1/1900 to 31/12/2001
   - Outputs the combined storage volume of Rocky Ck and Emigrant Ck dams to a CSV file
   - Outputs the daily volume extracted at the Lismore source
5. Runs IQQM via the macro language file
6. Reads the combined storage volume CSV file
7. Sums the number of days of restriction
8. Sums the number of years with restrictions based on a July water year
9. Reads the Lismore source file and determines the average annual extraction volume at Lismore source
10. Checks if the number of days of restriction are <= 1862 and number of years of restriction are <= 10
11. If either is not met and the number of iterations is less than 7 makes the upper secure yield equal to the current yield and repeats to step 2
12. If it is met continues to step 9
13. Creates a new macro language file similar to step 4 except
14. Runs FX94Dr scenario model that contains Rocky Ck Dam and Emigrant Ck dam at 55% capacity and permanent restrictions
15. Only outputs Rocky Ck dam volume to a CSV file
16. Runs IQQM via the macro language file
17. Reads the Rocky Ck storage volume
18. If it reaches 150 ML makes the upper secure yield equal to the current yield
19. If it does not reach 150 ML makes the lower secure yield equal to the current yield
20. If the number of iterations are less than 7 repeats to step 2
21. After 7 iterations the lower secure yield value represents the secure yield to an accuracy of 0.1 ML/a