THE UNIVERSITY OF ADELAIDE AUSTRALIA

The Environment Institute
University of Adelaide

# Strengthening Basin Communities Program
# Planning Component Consultancy SBC033A.1/2

## Climate Change Scenarios Information

MILESTONE 2 REPORT

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## EXECUTIVE SUMMARY

The South Australian Murray-Darling Basin is one of the state's most productive regional areas, sustaining major irrigation and dryland farming areas as well as industries like tourism and manufacturing. However, recent years have seen some of the lowest water availability on record for businesses and communities reliant on the Murray. This has combined with low rainfall years in surrounding dryland farming areas and caused major impacts on the wellbeing of people living in the region and impacts on the environment and economy.

These conditions may be a pre-cursor of what is to come. Climate change forecasts suggest that the region will trend toward hotter and drier conditions on average over the next 20-60 years and inflows to the state from the River Murray will be reduced. Recognition of the impact of low rainfall and hotter temperatures over the past decade on the SA MDB means that the time is right to consider how to adapt to the forecast impacts of climate change.

This consideration should not be delayed by the assumption that climate change is declining as drought pressure eases such as in the coming season. It will be important therefore to develop user friendly information that differentiates between climate change scenarios and short term drought.

Eleven Councils within the SA Murray-Darling Basin Natural Resources Management Region established two consortia and attracted Federal funding through the Strengthening Basin Communities (SBC) Program – Planning Component to deliver a series of plans to assess the impact anticipated climate change will have on communities, their local water dependant industries, urban water resources management, development plan policy and other strategic planning documents for local government. These plans will identify opportunities to adapt to the anticipated climate, and in particular, living with less water. The "Impact Assessment, Adaptation and Emerging Opportunities" Project is the overarching parent project for both consortia.

The Environment Institute at the University of Adelaide and its team was appointed to undertake the overarching project and has four deliverables:

- Climate change scenarios - Make recommendations on the scenario(s) and associated projected climatic conditions to be applied to the parent and broader projects.

- Climate Change Impact Assessment Report - The report will assess the impact of recently experienced (i.e. the extended drought) and predicted climate conditions on each Council, their communities, community assets and services.

- Adaptation and Emerging Opportunities Plan - Opportunities will be identified for each partner Council and their community to address the predicted impacts of climate change.

- Horticultural/Rural Lands Review – This will identify and describe the horticultural/rural land affected by the current drought that may be affected by forecast climate change impacts and then develop potential model statutory planning policy.

This report is a requirement of Milestone 2 of the parent project and presents the *climate change scenarios* required under the project brief.

The key messages arising from each of the three Milestone 2 reports are as follows:

1. Climate Change Scenarios :
    - The study region like the rest of Southern Australia is expected to be warmer (high confidence) and drier (lower confidence). By 2030 the region shows a warming of between 0.5 to 1.3 degrees C with the mid range model showing 0.8 degrees. At 2030 the range in warming is due to different models and is not very sensitive to the emission scenarios. By 2070 there is a greater influence of emission scenarios (whether greenhouse gases are greatly increased or stabilised). Under medium emission scenarios the projected warming is 1.8 degrees with a range or 1.3 to 2.8 degrees.
    - The most likely future is a drier future, but there is considerable uncertainty between models and considerable debate within the scientific community on the appropriate level of confidence to place on projected drying compared to the projected warming.

2. Outcomes of Stakeholder Engagement:
    - There is widespread awareness about the general concept of climate change, which is understood as a phenomenon that will drive warmer temperatures and lower rainfall across the SA MDB.
    - There is recognition that extreme weather events are the most difficult to plan for and therefore provide the most difficult and most costly management challenges. This will be a key consideration of planning for climate change.
    - There is a consistent view that irrigation and dryland farming will be the industries impacted the most by warmer and drier conditions under future climate change. This will have flow on impacts to the community and Councils.
    - There is a widespread need for communities and industries to engage in planning and implementing an integrated approach to climate change across the whole region.
    - Adaptation can best be achieved by a leadership model with capacity to foster connections between all levels of Government and the ability to evaluate a wide range of existing and alternative industries.
    - Leadership elements will include a long term commitment and presence in the region, development of credible information resources and support to enable industries and communities to make decisions with confidence.

3. Opportunities Discussion Paper:
    - There is evidence that adaptation to climate change is already happening in South Australian Murray-Darling Basin. Selecting new crop varieties and changes to road maintenance are two examples.
    - One avenue for adaptation is to move toward a low carbon economy. There are some issues to consider with respect to low carbon economies such as: (1) Carbon pollution is increasingly taxed or traded across the world, (2) Fossil resources for agriculture and energy production, which are primary sources of carbon pollution, are becoming more scarce (3) Peak production of phosphorus is projected for 2040-2050, peak oil for between now and 2015, peak coal for between now and 2048, and peak natural gas for 2030, (4) beyond peak production, competition will drive resource prices higher until alternatives become feasible.
    - In developing strategy and actions for adapting to the effects of climate change, local government can consider vulnerability and risk management frameworks, community perspectives and existing climate change adaptation initiatives including the Local Government Association Mutual Liability Scheme (LGAMLS).

## KEY FINDINGS

The study region like the rest of Southern Australia is expected to be warmer (high confidence) and drier (lower confidence). When the output of the global climate models are ranked from coolest to warmest projections for the SA MDB NRM region for 2030 show a warming of between 0.5 to 1.3 degrees C with the mid range model showing 0.8 degrees. At 2030 the range is due to different models and is not very sensitive to the emission scenarios.

By 2070 there is a greater influence of emission scenarios (whether greenhouse gases are greatly increased or stabilised). Under medium emission scenarios the projected warming is 1.8 degrees with a range or 1.3 to 2.8 degrees. Under high emission scenarios the warming is projected to be 2.3 degrees with a range of 1.8 to 3.5 degrees C. The most likely future is a drier future, but there is considerable uncertainty between models and considerable debate within the scientific community on the appropriate level of confidence to place on projected drying compared to the projected warming.

In the coming decades the main source of uncertainty is the extent of temperature and rainfall changes in different global climate models. After 2050 there is significant uncertainty due to different emission scenarios. In this report we point the end-user to climate change projections that have three characteristics:

- Authoritative – in Australia this generally means CSIRO and the Bureau of Meteorology;
- Acknowledge the uncertainty – different projections at various spatial scales have different levels of uncertainty;
- Action orientated – the purpose of using projections of future climates is to act now at appropriate levels.

In addition to summarising the results for the region as a whole we examined climate change projections for temperature, rainfall and evaporation for 17 towns in the region. Two global climate models were used Miroc-H which is a model that shows moderate warming and drying for the region and CSIRO Mk3.5 which shows a greater degree of warming and drying. Both models were used under the SRES (special report for emission scenarios) of A1F1 and a setting of moderate global warming. This analysis showed although there is a difference between locations (greater warming inland than on the coast) that the difference between these two models is much greater than the adjustments for locations.

Not only is the region projected to be warmer and drier, it is also projected to have less runoff. As a general guide, the decline in runoff is about 2 to 3 times that of rainfall, hence a decline in rainfall of 10% leads to a decline in runoff of 20% or 30%.

# 1 INTRODUCTION

## 1.1 BACKGROUND ON CLIMATE CHANGE SCIENCE BEHIND PROJECTIONS

Global warming is usually used to describe the gradual increase in global average surface temperature as one of the consequences of increased greenhouse gases. The term climate change is more commonly used than global warming because of the many changes to other climatic parameters such as rainfall, wind and evaporation.

A climate change projection is the response of the climate system to levels of greenhouse gases. A climate change projection should have a date (e.g. 2030 or 2070) and an emission scenario (low, medium or high). The emission scenario can be a level of carbon dioxide in the atmosphere (e.g. 550 ppm) or from the special report on emissions scenarios (SRES)[1]. The term scenario in this context refers to “a coherent, internally consistent and plausible description of possible future states of the world” (IPCC, 2007).

Climate change is a much discussed and often contentious topic. It is not the purpose of this short scoping paper, or the project, to engage in a debate on climate science. The prospectus assumed an acceptance of the basic science of human induced climate change. Nevertheless, it is naïve to ignore the fact that incorporating climate change into planning for local councils will involve a diversity of views and some challenges to the basic climate science.

There are numerous books and pamphlets designed to explain the basics of climate science. The Commonwealth Department of Climate Change has a section of frequently asked questions on a website[2] that deals with questions such as whether global warming has stopped, the emails stolen from the Climate Research Unit of the University of East Anglia, the Himalayan Glaciers and the reliability of climate models. The popular science magazine New Scientist website[3] addresses the 18 most common climate change questions. The IPCC summary for policy makers is an excellent summary of the basic science.

## 1.2 CLIMATE VARIABILITY AND CLIMATE CHANGE

For this project a key question is how the internal climate variability will interact with human induced change over a planning period. The relationship between climate variability and change is usefully explained in Figure 1.1 prepared by Roger Jones CSIRO. The contrast is between variability within a stationary climate and variability within a changing climate. For any system, such as a vineyard, dryland farm or council infrastructure there is a degree of variability that can be managed and this is labelled the coping range. Beyond that range the system is vulnerable. In a changing climate, the damage to a system is most likely to come from the extremes and runs of extreme events rather than the mean.

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[1] http://www.ipcc.ch/pdf/special-reports/spm/sres-en.pdf

[2] http://www.climatechange.gov.au/climate-change/science.aspx

[3] http://www.newscientist.com/article/dn9913-faq-climate-change.html

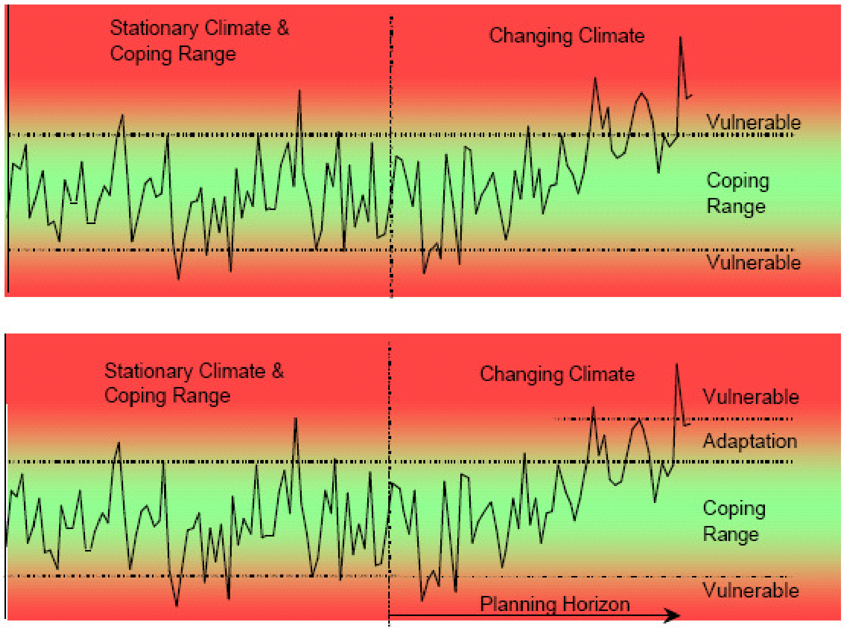

Figure 1.1 Conceptual diagram showing a variable climate that is stationary (left hand of diagram) and non-stationary (right hand of diagram). The coping range is also shown and the role of adaptation that increases the coping range (Roger Jones CSIRO).

This diagram also shows that the coping range can be widened with adaptation. For example more heat tolerant and water use efficient crops and cropping systems will have a wider coping rage. The diagram also shows how the planning horizon is relevant to any discussion of climate change. Climate change is going to feature less in a decision of planting an annual crop than a perennial crop like viticulture or decisions about whether children come back to the farm.

Nicholls (2006) reviewed the evidence for climate change in Australian records which is essentially trying to disentangle climate variability from climate change. He emphasised the importance of the two verbs – to *detect* a trend and to *attribute* the cause of the trend. Detection is finding a change and showing that it is something beyond what we might expect by random chance due to internal, natural climate variability. Attribution is the process of establishing the most likely causes for the detected change – for example human induced climate change. According to Nicholls' review, detection and attribution studies of Australian climate indicate that:

- The widespread warming is very likely to be due to increased greenhouse gas concentrations.
- The rainfall decrease in southwest Western Australia is likely due to a combination of increased greenhouse gas concentrations, natural climate variability, and land use change.
- The increased summer rainfall in northwest Australia may be due to increased aerosols resulting from human activity, especially in Asia.
- The apparent decline in pan evaporation is mainly due to changes in instrumental exposure.
- No study has attributed a cause to the rainfall decrease along the east coast.

In the period since Nicholls’ (2006) review there has been a substantial scientific study on the causes of the current drought in southern Australia (Nicholls 2009, Timball 2009, Verdon-Kidd and Kiem 2009, Ummenhofer et al. 2009). Although there is increased evidence of some degree of human induced change on rainfall, it is much harder to detect changes in rainfall due to the high degree of annual and decadal variability and even harder to attribute these changes to climate change. In July 2010 a report[4] from the Bureau of Meteorology drew attention to the increasing evidence for a greenhouse impact on some of the drying in the Murray Darling Basin.

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[4] Timbal B, Arblaster J*, et al.* (2010) 'Understanding the anthropgenic nature of the observed rainfall decline across south-eastern Australia. CAWCR Technical Report No 026, July 2010.' (Centre for Australian Weather and Climate Research: Melbourne).

# 2 A GUIDE TO THE CONFIDENCE AND UNCERTAINTY THAT COMES WITH PROJECTING FUTURE STATES OF CLIMATE

## 2.1 THE NEED FOR AUTHORITATIVE CONSISTENT CLIMATE CHANGE PROJECTIONS

Planning for climate change can be made unnecessarily complex by many sources offering guidance on what the future climate might be. The Intergovernmental Panel on Climate Change (IPCC) was established in 1988 by the World Meteorological Society and the United National Environment Programme to provide authoritative advice on climate change. It has produced four major assessment reports 1990, 1995, 2001, 2007. A fifth assessment will be released in 2011.

South Australia has two complementary sources of climate change projections, Suppiah et al 2006 CSIRO report Climate Change Under Enhanced Greenhouse Conditions in South Australia and the CSIRO BoM Climate Change in Australia technical report 2007. Both of these reports are based on global climate models prepared for the 4th Assessment Round of IPCC (2007) and are readily available on the internet.[5] In November 2009 there was a science update for the climate change in Australia report. The emphasis of the update was that emissions were tracking at the higher level of the envelope of projections and the scientific community in Australia and internationally continue to document changes in the climate system such as ocean warming, sea-level rise, continental-average temperatures, temperature extremes and wind patterns. Discussion with Dr Penny Whetton Climate Impacts and Risk Research Leader, CSIRO earlier this year has confirmed that future climate modelling will be done for the 5th Assessment Report of IPCC, but that this will not be available for another 1 to 2 years. She confirmed that the models chosen for the Suppiah *et al*. (2006) report should still be considered valid.

SARDI climate applications and the climate policy section of DENR have worked with the DPC and PIRSA to summarise the climate change projections for the eight NRM regions for these reports. These are available at http://www.environment.sa.gov.au/deh/nrm/nrm.html

This is not to dismiss new science or downscaling analysis that may become available for the region. Rather it is to use the existing projections as a foundation for decision makers. If for example a new study found that the likely rainfall reduction was 20% by say 2030 it is worth knowing that this is much more severe than the most likely projections for 2030.

In addition to rainfall, temperature, radiation, humidity and wind, the key issues for councils in the region are flow in the River Murray and sea level rise. The authoritative source of

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[5] http://www.climatechange.sa.gov.au/index, http://www.climatechangeinaustralia.gov.au/resources.php

information on flows in the Murray Darling Basin is The Murray Darling Basin Sustainable Yields Project[6] was released in July 2008.

The authoritative source for sea level rise is the Coastal Protection Board within the South Australian Department of Environment and Heritage.

## 2.2 THE NEED FOR CLIMATE CHANGE PROJECTIONS TO ACKNOWLEDGE THE UNCERTAINTY

It is important that users of climate change information acknowledge that there is uncertainty in the projections. Simply put, no one can supply a single map of what the climate will look like in SA MDB in 2030. Ideally as shown in Figure 2.1 there should be 9 maps that represent the two sources of uncertainty (emissions as columns and different models as rows). The percentiles are found by ranking the models from the warmest to the coolest or driest to the wettest. The 10th percentile is the one in 10 coolest and the 90th percentile is the one in 10 warmest. The 50th percentile is the median or mid ranked model. Although this mid ranked model is sometimes referred to as the best estimate, the best practice for risk management is to consider a range of outcomes.

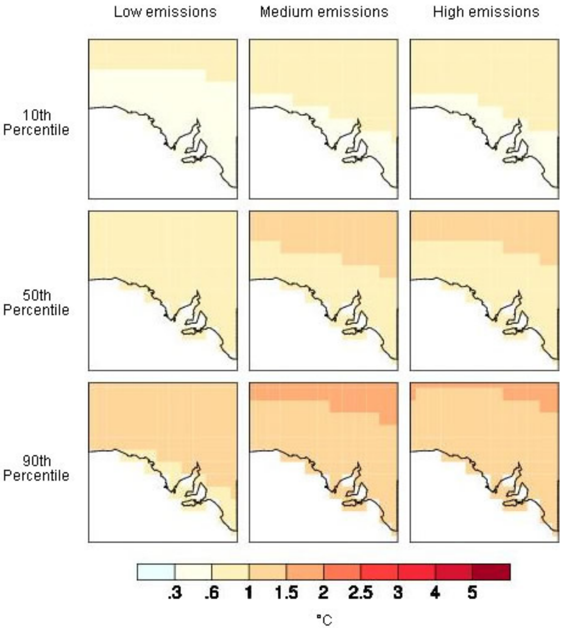

Figure 2.1 Temperature projections for South Australia for 2030 from CSIRO and BoM 2007.

There is very little difference between high and low emissions in 2030. The diagram below shows the different sources of uncertainty for mean global warming. In a broad sense, South Australian future changes to temperature are similar to global changes with coastal regions a bit cooler and inland a bit warmer (see Figure 2.2, Suppiah et al 2006)

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[6] http://www.csiro.au/partnerships/MDBSY.html

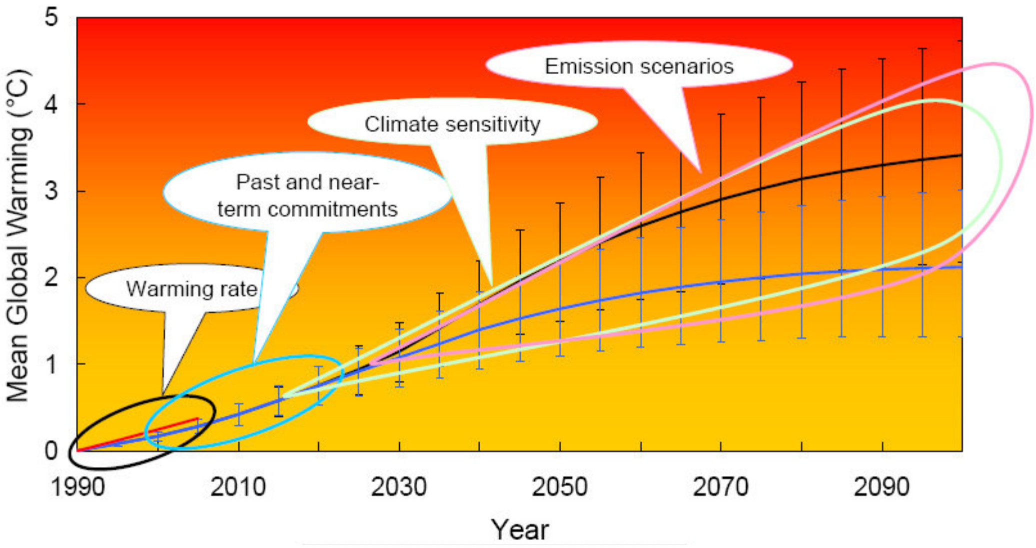

Figure 2.2. Different sources of uncertainty for mean global warming in coming decades (IPCC).

The range of expected warming in the coming 10 to 15 years is relatively small and can be estimated from recent trends in temperature and past and current emissions. The recent trends in temperature indicate that there will be year to year variability, but each decade is warmer than the previous decade. The range of global temperatures in 2030 or 2040 is larger but the main source of uncertainty is the question of how sensitive the climate is to greenhouse gases (not whether we are on a medium, high or very high emission pathway). At 2070 the range is much larger and this is because of the combined uncertainty of different emission pathways and the climate sensitivity. The fact that emissions are tracking higher than what was thought likely by IPCC is worrying, however the *main* impact of these higher emission scenarios will be expected in the later part of the century.

The level of confidence in warmer temperatures and increased heatwaves is much higher than the confidence about rainfall. Although there is a general consistency between models on drying in winter and spring in southern Australia, there is a wide range in the extent of the drying. The IPCC 4th Assessment Round summary for policy makers states “On scales smaller than 50 years, natural climate variability is relatively larger than human influences, making it harder to distinguish changes expected due to external e.g. man-made forcings.” (IPCC 2007). This is especially true of parameters such as rainfall. A number of extreme events associated with storm events are localised and can occur in short time periods. These events that are much smaller than the grid scale of the models are difficult to assess in climate change projections. Effective ways of modelling changes in extreme events is a focus of the Australian Climate Change program. SARDI climate applications is working on the climatology of heatwaves in the region (Grace et al 2009) and involved with a Managing Climate Variability Program project led by CSIRO sustainable ecosystems on changes in meteorological processes that lead to frost events.

## 2.3 THE NEED FOR CLIMATE CHANGE PROJECTIONS THAT ARE ACTION ORIENTATED

The uncertainty in climate change predictions should not be a reason to delay planning for a warmer and water constrained future with rising sea levels. In recent times adapting to climate change has become less reliant on climate change projections. That is not to say that it is unimportant to get the latest projections, but a focus on “bottom up” vulnerability rather than “top down” impact studies equips end users to make more sense of what a 10% decline in rainfall means for their system.

The approach taken in the Lower Murray Landscape Futures project was to use a set of scenarios of mild, moderate and severe warming with associated drying and a mild warming with a small increase in rainfall. These future scenarios are designed to stretch the thinking and assumptions of planners. A major advantage of these scenarios is that they provide a range of possible futures that can be considered rather than focussing on a single future that is the average of many models or being confronted with a bewildering range of models.

The challenge of planning with uncertainty is addressed in the issues paper on planning for adaptation produced by the Australian Government[7]

> *“Uncertainty is a reason for flexibility and creativity, not for delay. Some things about Australia’s future climate are fairly certain: it will be hotter, sea levels will rise, extremes such as heatwaves, droughts and storm surge will become more frequent and intense. Other things are less certain: the rate and magnitude of change depends on how sensitive the climate system is to greenhouse gases. Beyond mid-century it also depends on future emissions, making it sensitive to our success in reducing greenhouse gas emissions now and into the future. Rainfall projections are less certain. While it seems likely that the southern part of Australia will become drier there is less confidence about northern Australia and parts of the eastern seaboard. We have limited information about how climate change will affect some extreme events such as cyclones and hail storms.*
>
> *While some of this uncertainty can be reduced by better science, some residual uncertainty will always remain. Uncertainty about the future is not a reason to delay developing strategies for adapting to the impacts of climate change. Australians have considerable experience and success in dealing with other risks where there is uncertainty about what may happen in the future. Examples include commodity prices, currency exchange rates, and natural climate variability manifested in droughts and floods. The same flexible and creative approach is required to build resilience to climate change impacts.*
>
> *It will not be efficient or cost effective for adaptation responses to seek to prevent all adverse impacts of current and future climate change. Adaptation actions will need*

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[7] Australian-Government (2010) 'Adapting to Climate Change in Australia – A Position Paper.' (Department of Climate Change: Canberra).

> *to achieve a suitable balance between the risks of acting too early or too late, and balance the potential benefits of actions with the likely magnitude of impacts."*

Uncertainty in climate change projections is a well recognised problem, the previous director of the Bureau of Meteorology, Dr John Zillman[8] made the following points

- governments tend to look to the scientific community for clear and simple answers and become frustrated with equivocation and the fact that, as fast as scientific research resolves key uncertainties, new uncertainties are identified;

- those in the key stakeholder communities (especially the fossil fuel industry and the environmental movement at the extremes) tend to overstate either the uncertainties or the certainties to try to get government and community acceptance of the message that they want the science to deliver; and

- the community at large, who have learnt that science can predict the exact time of eclipses centuries ahead and technology can land a man on the moon, do not understand what is preventing the scientific community from doing just as well with climate change.

The Allen report on Climate Change and Vulnerability[9] commissioned by the Australian Government, acknowledged that uncertainty was a key obstacle to planning for climate change. However, they argue that "An adaptation strategy, to be effective must result in climate risk being considered as a normal part of decision-making, allowing governments, businesses and individuals to reflect their risk preferences just as they would for other risk assessments".

Including risk of any sort in planning is difficult. Professor Mark Burgman, director of the Australian Centre for Excellence for Risk Analysis at the University of Melbourne makes the point in his text book [10] that most scientific training leaves us with an unreasonable preoccupation with the best estimates of variables. We focus on means and central tendencies and rarely talk about the tails or extremes of a distribution.

Although not easy, risk information is used by decision makers. One of the outcomes of the recent drought that has affected water allocations has been the presentation of future water supply for irrigation as a risk assessment. The Sustainable Yields Project that examined water availability refers to considering the IF and the THEN of future streamflow. This is not

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[8] Zillman JW (2005) 'Uncertainty in the science of climate change. Occasional Paper 2/2005. Policy Paper # 3.' (Academy of the Social Sciences in Australia: Canberra).

[9] Allen Consulting Group (2005) 'Climate Change: Risk and Vulnerability
Promoting an Efficient Adaptation Response in Australia - Final Report, March 2005.' (Report to the Australian Greenhouse Office, Department of the Environment and Heritage).

[10] Burgman M (2005) 'Risks and Decisions for Conservation and Environmental Management. .' (Cambridge University Press: Cambridge.).

a question of IF climate change is real, but rather IF climate change is manifest in a certain amount of drying and warming THEN the hydrological implications are described. Importantly, there is uncertainty in both the IF and the THEN. Engineers have long been aware of planning with uncertainty. A good example that is discussed later in this report uses a probabilistic approach to the intensity, frequency and duration (IFD) of extreme rainfall events.

Where people are explicitly using climate risk information for planning under the current climate, it is easier to incorporate future climate change projections. It is much more difficult to incorporate climate change projections where the climate assumptions for current planning are implicit, ignored or seen as obvious but not stated.

An interesting example emerged in discussion with dryland farmers. Initial discussion focussed on a need for precise projections but an understanding of how farmers currently assess risk in deciles of rainfall led to much better learning by farmers, consultants and researches (Hayman and Alexander 2010)[11]. This was also shown in a project with low rainfall farmers on Eyre Peninsula (Doudle et al 2009)[12]. When a farmer says that a certain year was a decile 3 year, they are making a statement about uncertainty and risk that three years out of 10 are as dry or drier and 7 years out of 10 are wetter. Expressing climate change as a shift in the chance of getting different deciles rather than a percent change in rainfall led to interesting discussion on appropriate adaptation. An example used in a recent workshop with farmers in the region at Murray Bridge is given in Appendix 1.

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[11] Hayman PT, Alexander BM (2010) Wheat, wine and pie charts: advantages and limits to using current variability to think about future change in South Australia's climate. In 'Managing Climate Change. Papers from the GREENHOUSE 2009 Conference'. (Eds I Jubb, P Holper, W Cai) pp. 113-122. (CSIRO: Melbourne ).

[12] Doudle S, Hayman PT, Wilhelm N, Alexander BM (2009) Farmer's capacity to adapt to climate change- SA case studies. Agricultural Science 21, 13-19.

## 3 CLIMATE CHANGE PROJECTIONS FOR SA MDB REGION AS A WHOLE

The following two tables summarise the climate change projections for the SA MDB region for 2030 and 2070.

| **Variable** | **Season** | **Low emissions** | | | **Medium emissions** | | | **High emissions** | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | **10p** | **50p** | **90p** | **10p** | **50p** | **90p** | **10p** | **50p** | **90p** |
| Temperature Degrees C | Annual | 0.5 | **0.8** | 0.8 | 0.5 | **0.8** | 1.3 | 0.5 | **0.8** | 1.3 |
| | Summer | 0.5 | **0.8** | 0.8 | 0.5 | **0.8** | 1.3 | 0.5 | **0.8** | 1.3 |
| | Autumn | 0.8 | **0.8** | 0.8 | 0.8 | **0.8** | 1.3 | 0.8 | **0.8** | 1.3 |
| | Winter | 0.5 | **0.5** | 0.8 | 0.5 | **0.8** | 1.3 | 0.5 | **0.8** | 1.3 |
| | Spring | 0.5 | **0.8** | 1.3 | 0.5 | **0.8** | 1.3 | 0.5 | **0.8** | 1.3 |
| Rainfall % | Annual | -7.5 | **-3.5** | 0.0 | -15 | **-3.5** | 3.5 | -15 | **-3.5** | 3.5 |
| | Summer | -15. | **0.0** | 7.5 | -15 | **-2.0** | 10.0 | -15 | **-2.0** | 10.0 |
| | Autumn | -7.5 | **0.0** | 7.5 | -10 | **0.0** | 7.5 | -10. | **0.0** | 7.5 |
| | Winter | -15 | **-3.5** | 0.0 | -15 | **-7.5** | 0.0 | - 15 | **-7.5** | 0.0 |
| | Spring | -15 | **-7.5** | 2.0 | -15 | **-7.5** | 2.0 | -15 | **-7.5** | 2.0 |
| Potential Evapo-Transpiration % | Annual | 0.0 | **0.0** | 3.0 | 0.0 | **3.0** | 6.0 | 0.0 | **3.0** | 6.0 |
| | Summer | 0.0 | **0.0** | 3.0 | 0.0 | **0.0** | 6.0 | 0.0 | **0.0** | 6.0 |
| | Autumn | 0.0 | **3.0** | 6.0 | 0.0 | **3.0** | 6.0 | 0.0 | **3.0** | 6.0 |
| | Winter | 0.0 | **6.0** | 10.0 | 0.0 | **6.0** | 10.0 | 0.0 | **6.0** | 10.0 |
| | Spring | 0.0 | **0.0** | 3.0 | 0.0 | **0.0** | 3.0 | 0.0 | **0.0** | 3.0 |
| Relative Humidity % | Annual | -1.5 | **-0.8** | 0.0 | -1.5 | **-0.8** | 0.0 | -1.5 | **-0.8** | 0.0 |
| | Summer | -1.5 | **0.0** | 0.0 | -1.5 | **-0.8** | 0.0 | -1.5 | **0.0** | 0.0 |
| | Autumn | -1.5 | **0.0** | 0.0 | -1.5 | **0.0** | 0.5 | -1.5 | **0.0** | 0.5 |
| | Winter | -2.0 | **-0.5** | 0.0 | -2.5 | **-0.8** | 0.0 | -2.5 | **-0.8** | 0.0 |
| | Spring | -1.5 | **-0.8** | 0.0 | -2.5 | **-1.5** | 0.0 | -1.5 | **-1.0** | 0.0 |
| Downward Solar Radiation % | Annual | 0.0 | **0.0** | 1.5 | 0.0 | **0.0** | 1.5 | 0.0 | **0.0** | 1.5 |
| | Summer | 0.0 | **0.0** | 0.0 | 0.0 | **0.0** | 0.0 | 0.0 | **0.0** | 0.0 |
| | Autumn | 0.0 | **0.0** | 0.0 | 0.0 | **0.0** | 1.5 | 0.0 | **0.0** | 1.5 |
| | Winter | 0.0 | **1.5** | 3.5 | 0.0 | **1.5** | 3.5 | 0.0 | **1.5** | 3.5 |
| | Spring | 0.0 | **0.0** | 1.5 | 0.0 | **0.0** | 1.5 | 0.0 | **0.0** | 1.5 |
| Wind Speed % | Annual | -3.5 | **0.0** | 3.5 | -3.5 | **0.0** | 3.5 | -3.5 | **0.0** | 3.5 |
| | Summer | 0.0 | **0.0** | 7.5 | 0.0 | **3.5** | 7.5 | 0.0 | **3.5** | 7.5 |
| | Autumn | -5.0 | **0.0** | 3.5 | -7.5 | **0.0** | 3.5 | -7.5 | **0.0** | 3.5 |
| | Winter | -12 | **0.0** | 3.5 | -12 | **0.0** | 3.5 | -12 | **0.0** | 3.5 |
| | Spring | -5.0 | **0.0** | 3.5 | -7.5 | **0.0** | 3.5 | -7.5 | **0.0** | 3.5 |

Table 3.1. Climate projections for the SA Murray Darling Basin region. Projections for 2030 are given relative to the period 1980-1999. Individual years will show variation from this average. The 50th percentile (50p; the mid-point of the spread of model results) provides a best estimate result. The 10th and 90th percentiles (10p and 90p; lowest 10% and highest 10% of the spread of model results) provide a range of uncertainty. Emissions scenarios are from the IPCC Special Report on Emission Scenarios where Low emissions is the B1 scenario, Medium is A1B and high is A1FI. Projections from CSIRO and BoM 2007.

| **Variable** | **Season** | **Low** | | | **Medium** | | | **High** | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | **10p** | **50p** | **90p** | **10p** | **50p** | **90p** | **10p** | **50p** | **90p** |
| Temperature Degrees C | Annual | 0.8 | **1.3** | 1.8 | 1.3 | **1.8** | 2.8 | 1.8 | **2.3** | 3.5 |
| | Summer | 0.8 | **1.3** | 1.8 | 1.3 | **1.8** | 2.8 | 1.3 | **2.3** | 3.5 |
| | Autumn | 0.8 | **1.3** | 1.8 | 1.3 | **1.8** | 2.8 | 1.3 | **2.3** | 3.5 |
| | Winter | 0.8 | **1.3** | 1.8 | 1.3 | **1.8** | 2.8 | 1.3 | **2.3** | 3.5 |
| | Spring | 0.8 | **1.3** | 2.3 | 1.3 | **1.8** | 2.8 | 1.8 | **2.8** | 3.5 |
| Rainfall % | Annual | -15 | **-7.5** | 3.5 | -30 | **-10** | 5.0 | -30 | **-15** | 7.5 |
| | Summer | -30 | **-3.5** | 15 | -30 | **-3.5** | 30 | -30 | **-7.5** | 30 |
| | Autumn | -15 | **-3.5** | 15 | -30 | **-3.5** | 20 | -30 | **-3.5** | 25 |
| | Winter | -30 | **-7.5** | 3.5 | -30 | **-15** | 3.5 | -30 | **-15** | 5 |
| | Spring | -30 | **-15** | 3.5 | -30 | **-15** | 3.5 | -60 | **-30** | 5 |
| Potential Evapo-Transpiration % | Annual | 0.0 | **3.0** | 6.0 | 0.0 | **6.0** | 10.0 | 0.0 | **6.0** | 14.0 |
| | Summer | 0.0 | **3.0** | 6.0 | 0.0 | **6.0** | 10.0 | 0.0 | **6.0** | 14.0 |
| | Autumn | 2.0 | **6.0** | 10.0 | 3.0 | **6.0** | 14.0 | 4.0 | **10.0** | 18.0 |
| | Winter | 2.0 | **10.0** | 18.0 | 3.0 | **12.0** | 18.0 | 4.0 | **16.0** | 18.0 |
| | Spring | -2.0 | **2.0** | 6.0 | -2.0 | **3.0** | 10.0 | -3.0 | **4.0** | 10.0 |
| Relative Humidity % | Annual | -2.5 | **-1.5** | 0.0 | -3.5 | **-1.5** | 0.0 | -4.5 | **-2.5** | 0.0 |
| | Summer | -2.5 | **-0.8** | 0.0 | -2.5 | **-1.5** | 0.8 | -4.5 | **-1.5** | 0.8 |
| | Autumn | -2.5 | **-0.8** | 0.8 | -3.5 | **-1.5** | 1.5 | -4.5 | **-1.5** | 1.5 |
| | Winter | -4.0 | **-1.0** | 0.8 | -4.5 | **-1.5** | 1.5 | -4.5 | **-1.5** | 1.5 |
| | Spring | -3.5 | **-1.5** | 0.0 | -4.5 | **-2.5** | -0.5 | -4.5 | **-3.5** | -0.8 |
| Downward Solar Radiation % | Annual | 0.0 | **0.0** | 2.5 | 0.0 | **1.0** | 2.5 | 0.0 | **1.5** | 2.5 |
| | Summer | 0.0 | **0.0** | 1.5 | -1.0 | **0.0** | 2.5 | -1.5 | **0.0** | 3.5 |
| | Autumn | -1.5 | **0.0** | 1.5 | -2.0 | **0.0** | 3.5 | -3.5 | **0.0** | 3.5 |
| | Winter | -1.0 | **3.5** | 7.5 | -1.5 | **3.5** | 10.0 | -2.0 | **3.5** | 15.0 |
| | Spring | 0.0 | **1.0** | 3.5 | 0.0 | **1.5** | 3.5 | 0.0 | **2.0** | 5.0 |
| Wind Speed % | Annual | -7.5 | **0.0** | 7.5 | -7.5 | **0.0** | 7.5 | - 12 | **0.0** | 12.5 |
| | Summer | -3.5 | **3.5** | 10.0 | -3.5 | **7.5** | 12.5 | -5.0 | **7.5** | 17.5 |
| | Autumn | -10 | **0.0** | 7.5 | -12 | **-2.0** | 10 | -17 | **-2.0** | 12.5 |
| | Winter | -12 | **-2.0** | 7.5 | -17 | **-3.5** | 7.5 | -17 | **-5.0** | 12.5 |
| | Spring | -10 | **0.0** | 7.5 | -15 | **0.0** | 12.5 | -17 | **0.0** | 17.5 |

Table 3.2. Climate projections for the SA Murray Darling Basin region. Projections for 2070 are given relative to the period 1980-1999. Individual years will show variation from this average. The 50th percentile (50p; the mid-point of the spread of model results) provides a best estimate result. The 10th and 90th percentiles (10p and 90p; lowest 10% and highest 10% of the spread of model results) provide a range of uncertainty. Emissions scenarios are from the IPCC Special Report on Emission Scenarios where Low emissions is the B1 scenario, Medium is A1B and high is A1FI. Projections from CSIRO and BoM 2007.As for Table 1 but time period of 2070. Note that by 2070 there is a wider range in all parameters at any emission level and there is a significant difference between emissions.

The figures below are a graphical representation of Tables 3.1 and 3.2. In each case the grey bar represents the range of the 10th and 90th percentile and the black line the median or mid-point of the models.

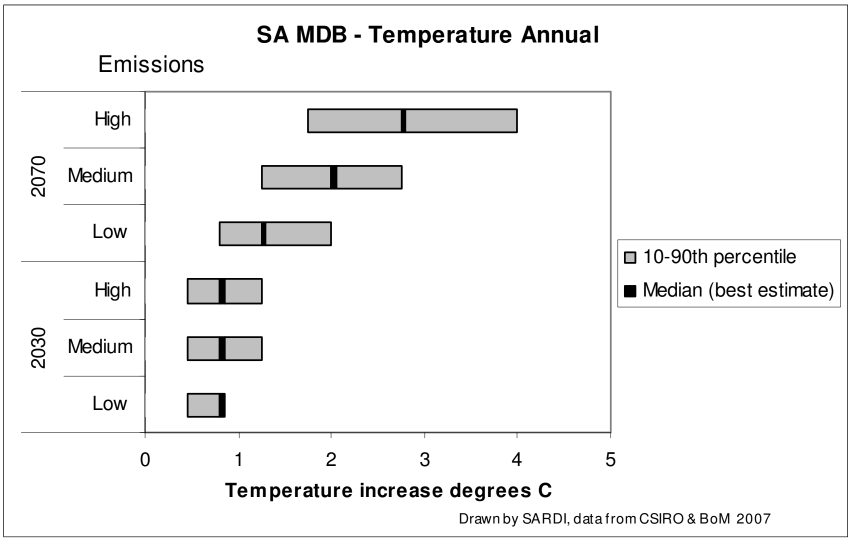

Figure 3.1. 2030 and 2070 annual temperature change for SA MDB.

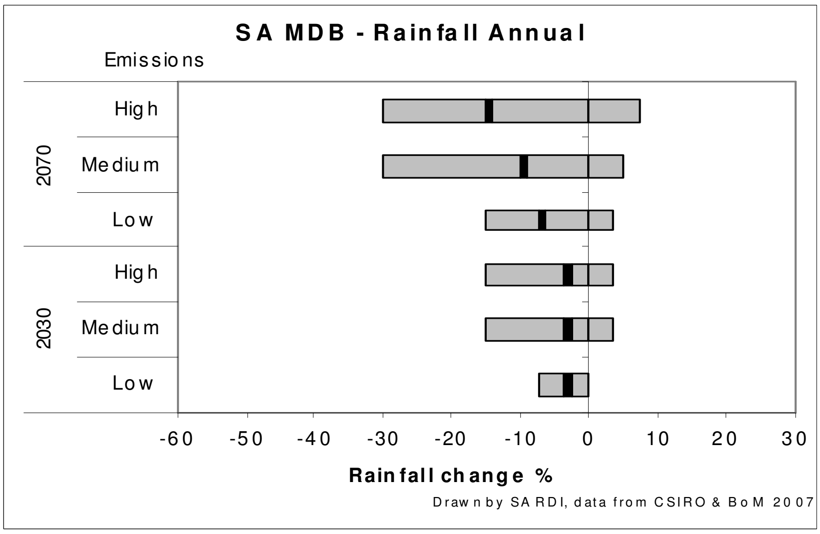

Figure 3.2. 2030 and 2070 annual rainfall changes for SA MDB.

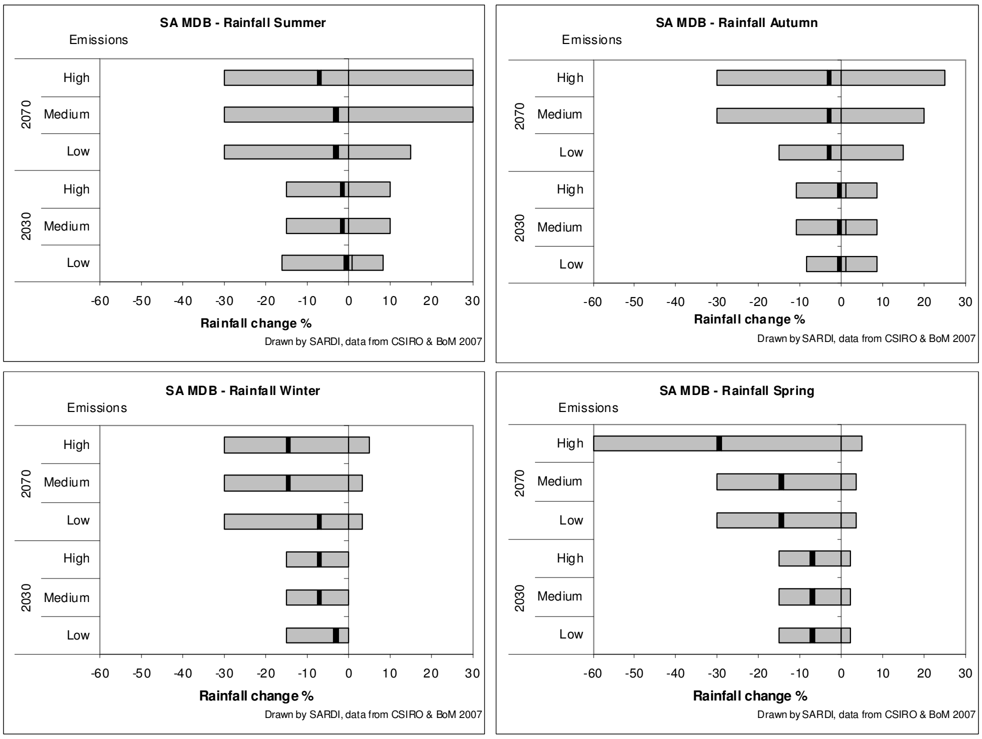

Figure 3.3. Seasonal rainfall changes showing the greater rainfall change in winter and spring compared to summer and autumn. Care should be taken in interpreting the increase in summer rainfall as the base amount of summer rainfall is very low.

In the case of constructing a scenario of a future climate, it is problematic to combine the 1 in 10 warmest outcome and the 1 in 10 driest outcome as they are unlikely to be the same model. An alternative approach is to take the 13 GCMs that were identified by Suppiah (2006) as performing the best in predicting the 1960 to 1990 rainfall, temperature and mean sea level pressure for South Australia. These are listed in Table 3.3 and the results for rainfall and temperature shown for different seasons and future time periods in Figures 3.4 to 3.7.

| Legend | Abbreviation | Climate Modelling Group | Country |
|---|---|---|---|
| Dark Green | BCCR | Bjerknes Centre Climate Research | Norway |
| Red | GFDL | Geophysics Fluid Dynamics | USA |
| Purple | IAP | Institute of Atmospheric Physics | China |
| Pink | Miroc | Centre for Climate Research | Japan |
| Black | MIUB | Met Inst of University of Bonn | Germany |
| Grey | MK3 | CSIRO | Aust |
| Dark Blue | MPI-ECAHM5 | Max Plank Institute | Germany |
| Light Green | MRI | Meteorological Research Institute | Japan |
| Orange | CC50 | CSIRO | Aust |
| Yellow | UK met office | Hadley Centre | UK |
| Light Blue | NCAR | National Centre for Atmospheric Res | USA |

Table 3.3. Global climate models from Suppiah et al (2006). The colour scheme is used in the following figures.

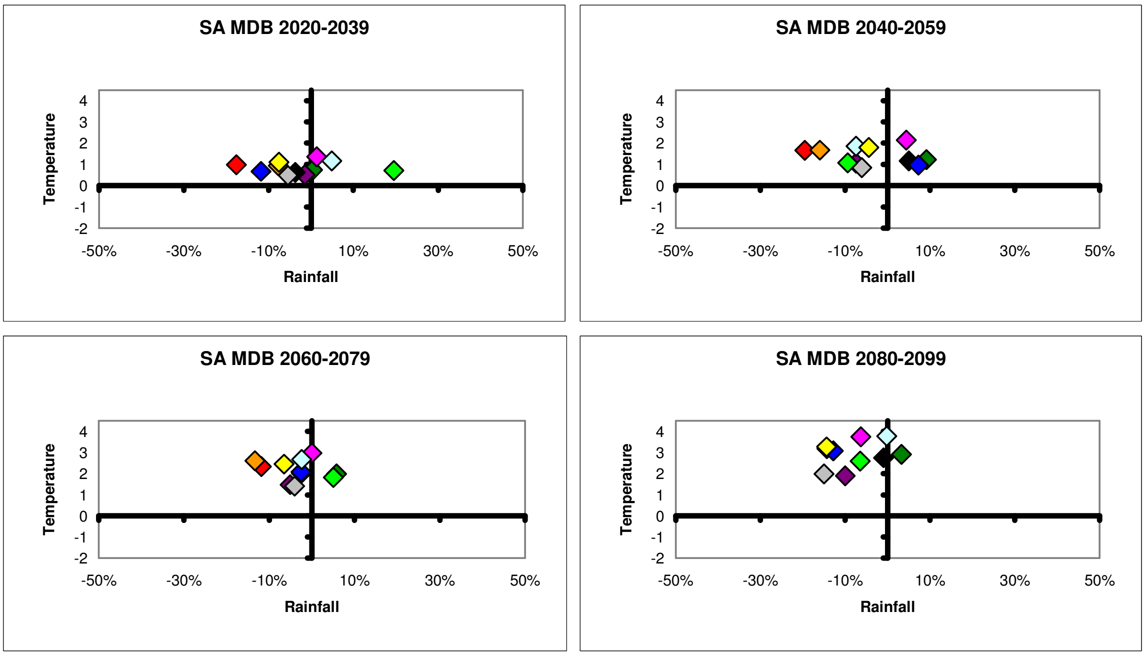

Figure 3.4. The 13 global climate change models from Suppiah et al. (2006) for the SA MDB. Colour scheme as per Table 3.3. In later decades there is a strong confidence in warming and a general trend towards drying, i.e. a move towards the top left hand quadrant. The scenarios used in the Lower Murray Landscapes Future projection of mild warming/drying (1oC warming and 5% drying); moderate warming/drying (2oC warming and 15% drying); severe warming/drying (4oC warming and 25% drying), and mild warming/wetting (1oC warming and 5% wetting) are plausible and capture the spread of the points.

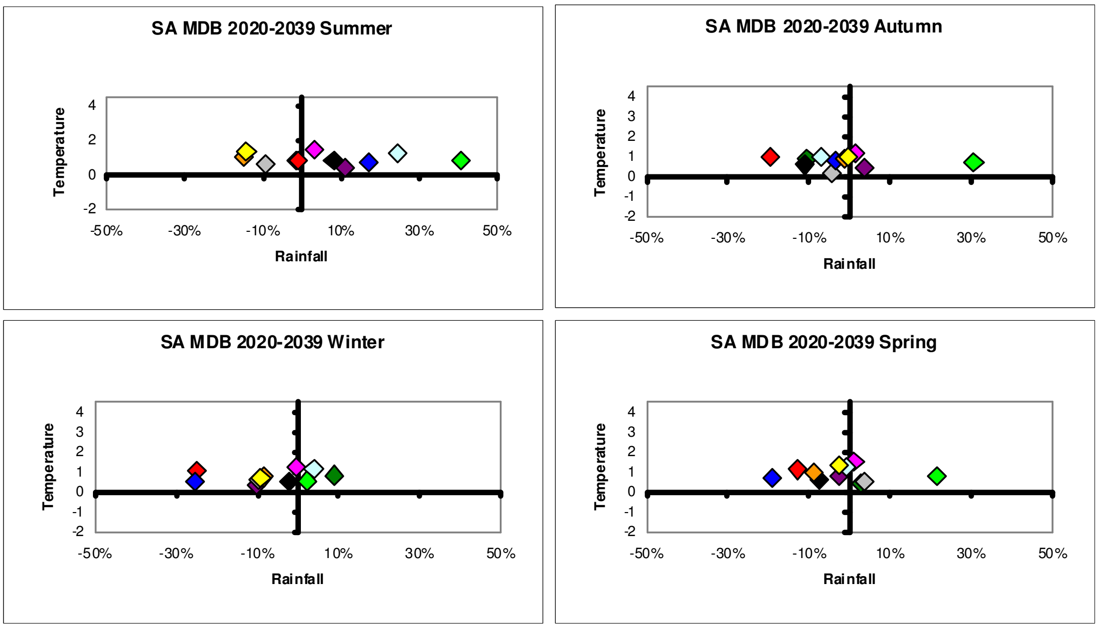

Figure 3.5 Rainfall and temperature changes in the two decades centred on 2030 from the 13 GCMs from Suppiah et al. (2006). Colour scheme as per Table 3.3.

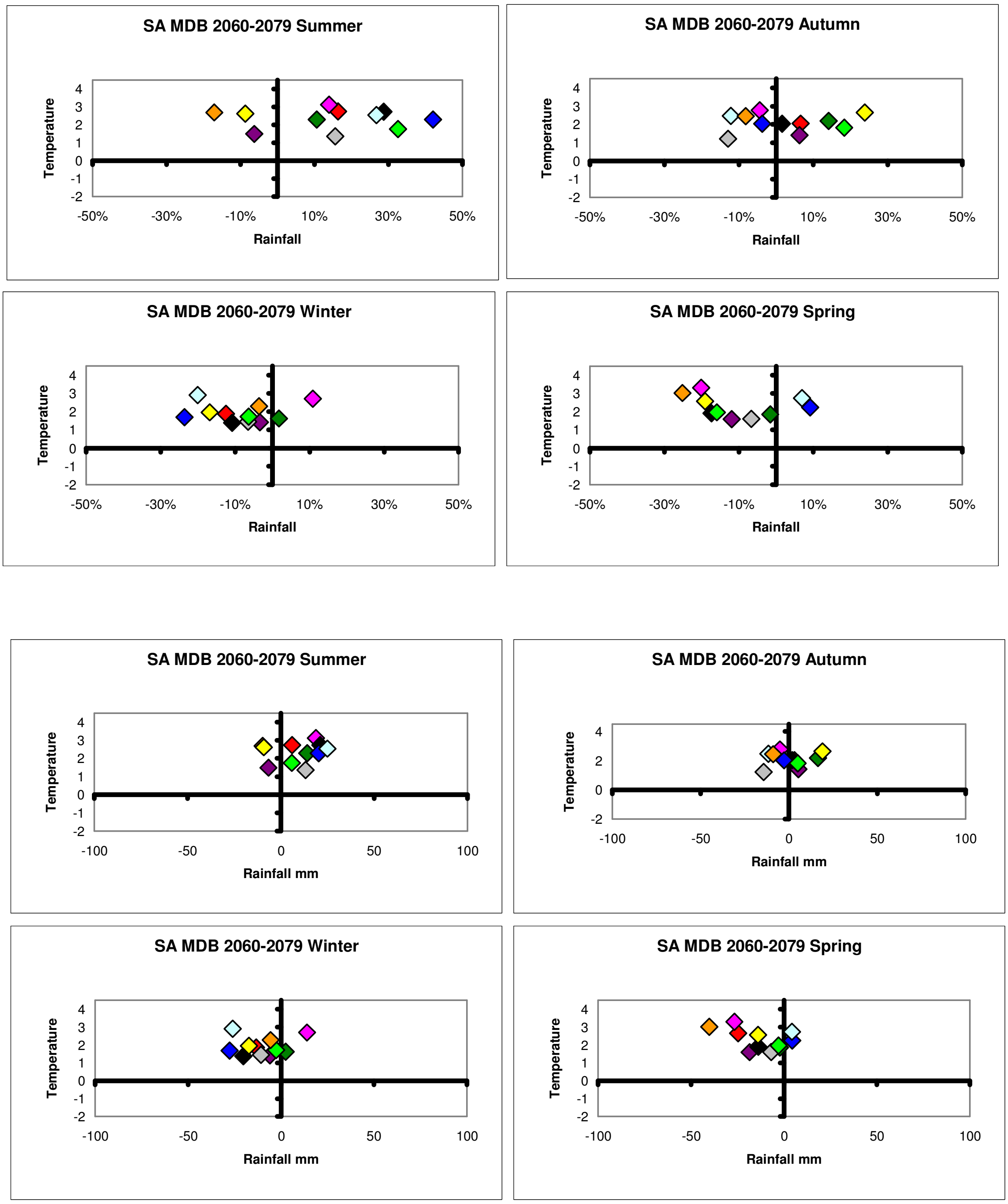

Figure 3.6 Rainfall and temperature changes in the two decades centred on 2070 from the 13 GCMs from Suppiah et al 2006 and A1 scenario. Colour scheme as per Table 3.3. The top panel shows the four seasons with the x axis as a percentage and the bottom axis shows the same data but as mm. This highlights the point that the increase in summer rain is high in percentage terms but low in mm of rainfall, especially considering the high potential evaporation rate (often over 10 mm per day) in summer.

The graphs in Figure 3.7 are drawn from the data in Table 3.1 and 3.2. The general trend towards increased evapotranspiration, decreased relative humidity and increased incoming solar radiation is consistent with warmer and drier conditions. However at 2030 these changes are relatively minor compared to the rainfall and temperature changes. There is no clear signal with wind.

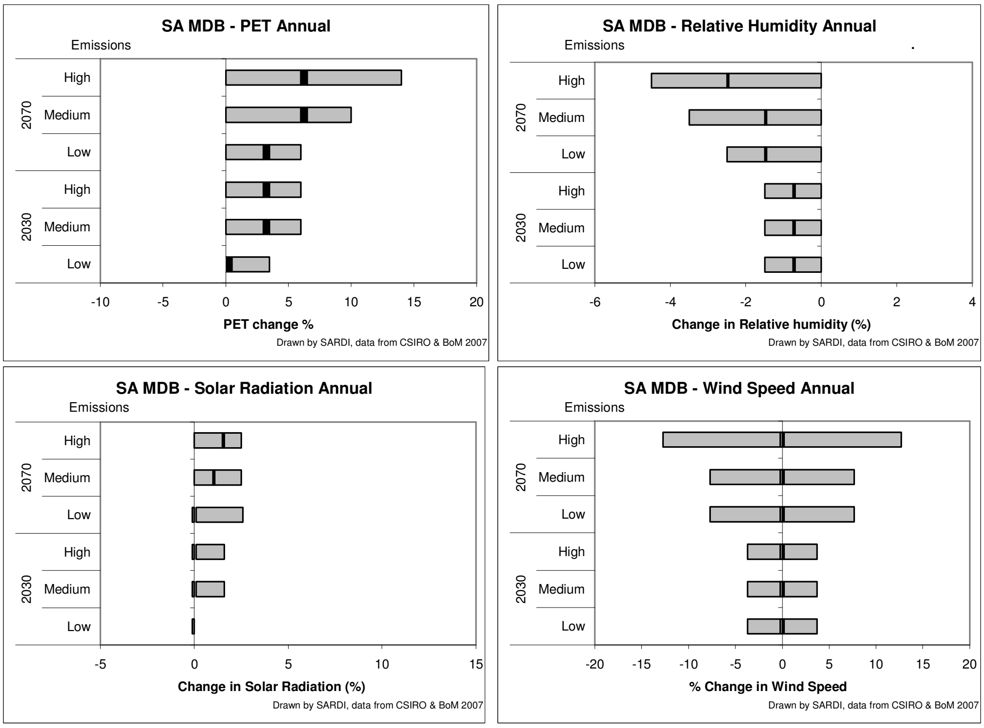

Figure 3.7. Changes in potential evapotranspiration, relative humidity, solar radiation and wind speed for 2030 and 2070 under low, medium and high emission scenarios. Note the change in scale.

# 4 CLIMATE CHANGE PROJECTIONS FOR INDIVIDUAL TOWNS IN SA MDB REGION

Discussion with the consultants responsible for the development of integrated water management plans (IWMPs) for the Strengthening Basin Communities project led to a request for changes in mean temperature (degrees C), rainfall (%) and evaporation (mm) for 2 models Miroc H (mild drying) and CSIRO Mk 3.5 (more severe drying) for a range of towns in the study region. These models were selected by Nidumolu et al (2010) in the CSIRO study of the dairy industry in the Murray region as they cover a range of outcomes and have evaporation data readily available along with rainfall and temperature. These models are only two possible climate futures and are selected to 'bookend' the range of possible outcomes. The advantage of using the output from models is that each future scenario is internally consistent in terms of rainfall, temperature and evaporation.

Table 4.1 indicates that warming at an inland site like Loxton (0.79 degrees for Miroc-H and 1.07 CSIRO Mk3.5) is greater than a coastal site like Goolwa (0.68 degrees for Miroc H and 0.81 for CSRIO Mk3.5). It is generally expected that inland regions will warm more than coastal regions and this is a consistent finding between the models. Table 4.1 also shows that the difference between models is greater than the difference between locations, this is especially the case for rainfall with the Miroc-H model showing much less drying than CSIRO Mk3.5. As outlined earlier, these are two possible future climates and the rainfall, temperature and evaporation from each model is internally consistent. However, care should be taken in overemphasising single model output.

The graphs on the following pages show the monthly changes in temperature, rainfall and evaporation for the two models.

Table 4.1 Projected changes from current conditions of Annual Temperature (degrees C), Annual Rainfall (%) and Annual Evaporation (mm) in 2030. Predictions derived from two Models: Miroc-H and CSIRO Mk3.5 under a SRES scenario of A1F1 and moderate warming.

| **Council** | **Town** | **Temperature (°C)** | | **Rainfall (% change)** | | **Evaporation (mm)** | |
|---|---|---|---|---|---|---|---|
| | | **Miroc-H** | **CSIRO MK3.5** | **Miroc-H** | **CSIRO MK3.5** | **Miroc-H** | **CSIRO MK3.5** |
| Berri Barmera Council | Berri | 0.80 | 1.09 | -1.1 | -12.5 | 22.0 | 38.3 |
| District Council of Loxton Waikerie | Loxton | 0.79 | 1.07 | -1.3 | -12.8 | 23.9 | 39.8 |
| District Council of Loxton Waikerie | Waikerie | 0.79 | 1.05 | -1.3 | -12.2 | 23.7 | 41.1 |
| Southern Mallee District Council | Pinnaroo | 0.76 | 1.03 | -1.9 | -12.6 | 27.7 | 45.7 |
| Southern Mallee District Council | Lameroo | 0.74 | 0.98 | -2.3 | -12.8 | 33.2 | 48.6 |
| Renmark Paringa Council | Renmark | 0.80 | 1.09 | -1.1 | -12.5 | 22.0 | 38.3 |
| Karoonda East Murray | Karoonda | 0.73 | 0.95 | -2.3 | -12.4 | 32.6 | 48.8 |
| Alexandrina Council | Goolwa | 0.68 | 0.81 | -2.8 | -11.5 | 42.8 | 55.0 |
| The Coorong District Council | Tailem Bend | 0.72 | 0.91 | -2.5 | -12.1 | 32.9 | 47.6 |
| The Coorong District Council | Meningie | 0.69 | 0.86 | -2.8 | -12.1 | 39.4 | 50.8 |
| Mid Murray Council | Blanchetown | 0.77 | 1.01 | -1.6 | -12.2 | 26.4 | 42.8 |
| Mid Murray Council | Morgan | 0.79 | 1.05 | -1.2 | -12.0 | 22.3 | 39.4 |
| Mid Murray Council | Swan reach | 0.75 | 0.99 | -1.9 | -12.2 | 28.9 | 45.3 |
| Mid Murray Council | Mannum | 0.72 | 0.92 | -2.3 | -11.9 | 33.0 | 47.7 |
| District Council of Mount Barker | Mount Barker | 0.72 | 0.90 | -2.4 | -11.7 | 36.2 | 49.9 |
| District Council of Mount Barker | Hahndorf | 0.72 | 0.90 | -2.4 | -11.7 | 36.2 | 49.9 |
| Rural City of Murray Bridge | Murray Bridge | 0.71 | 0.89 | -2.6 | -11.9 | 35.5 | 49.3 |
| Regional Council of Goyder | Burra | 0.78 | 1.01 | -1.5 | -11.8 | 26.3 | 44.0 |
| Regional Council of Goyder | Eudunda | 0.78 | 1.01 | -1.5 | -11.8 | 26.3 | 44.0 |

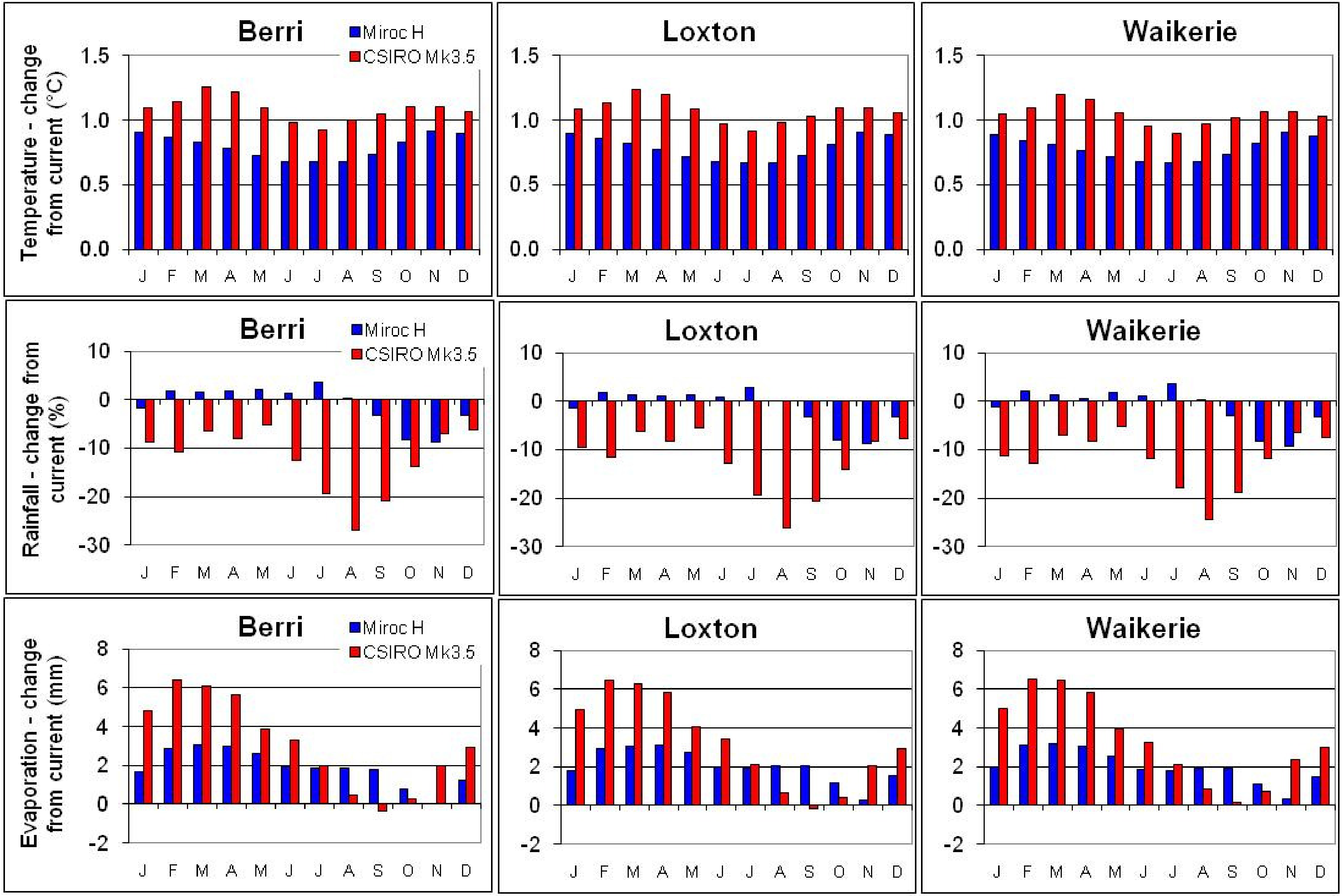

Figure 4.1 Monthly changes in temperature, rainfall and evaporation for two climate models Miroc-H and CSIRO MK 3.5. Data from Ozclim

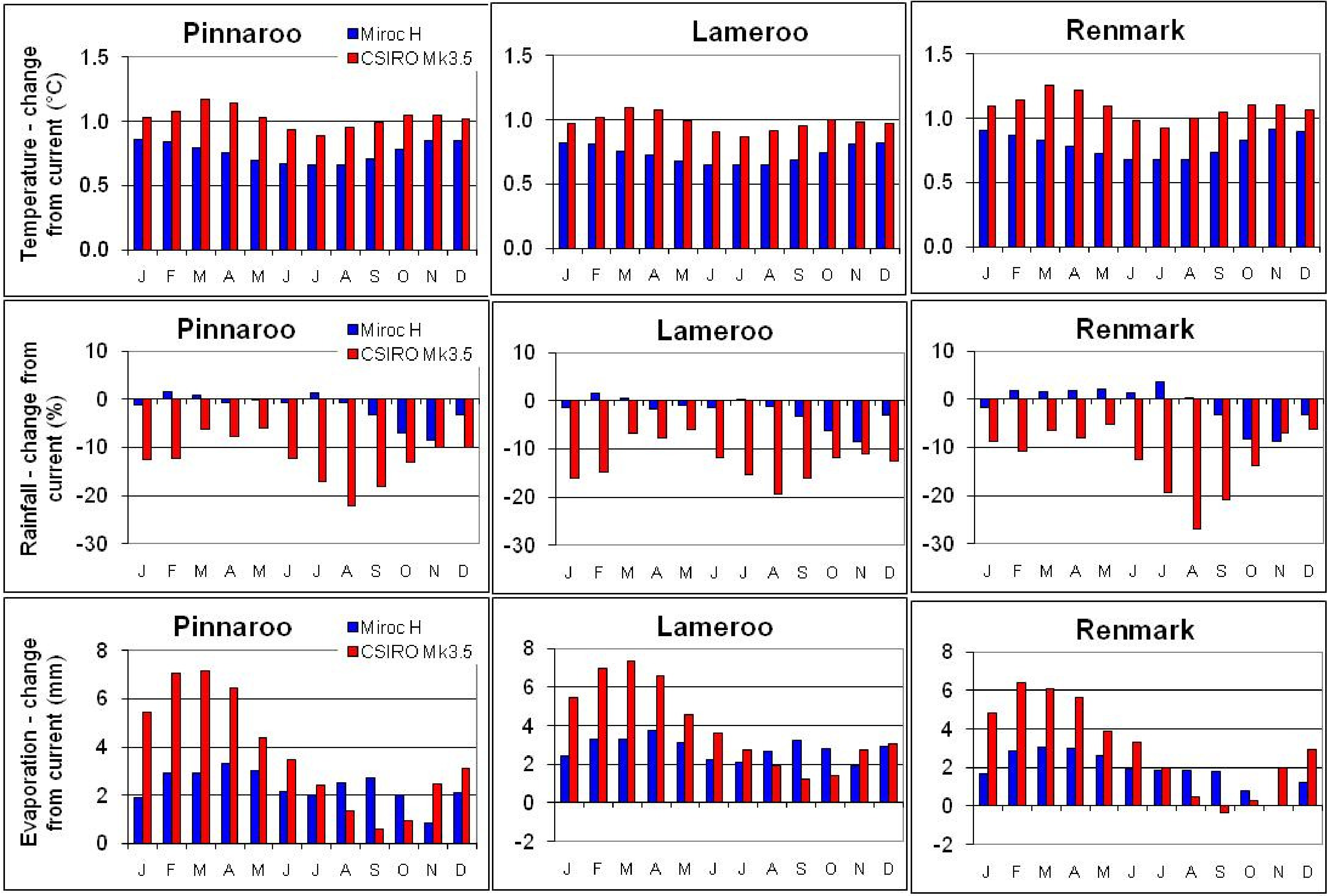

Figure 4.1 (continued) Monthly changes in temperature, rainfall and evaporation for two climate models Miroc-H and CSIRO MK 3.5. Data from Ozclim.

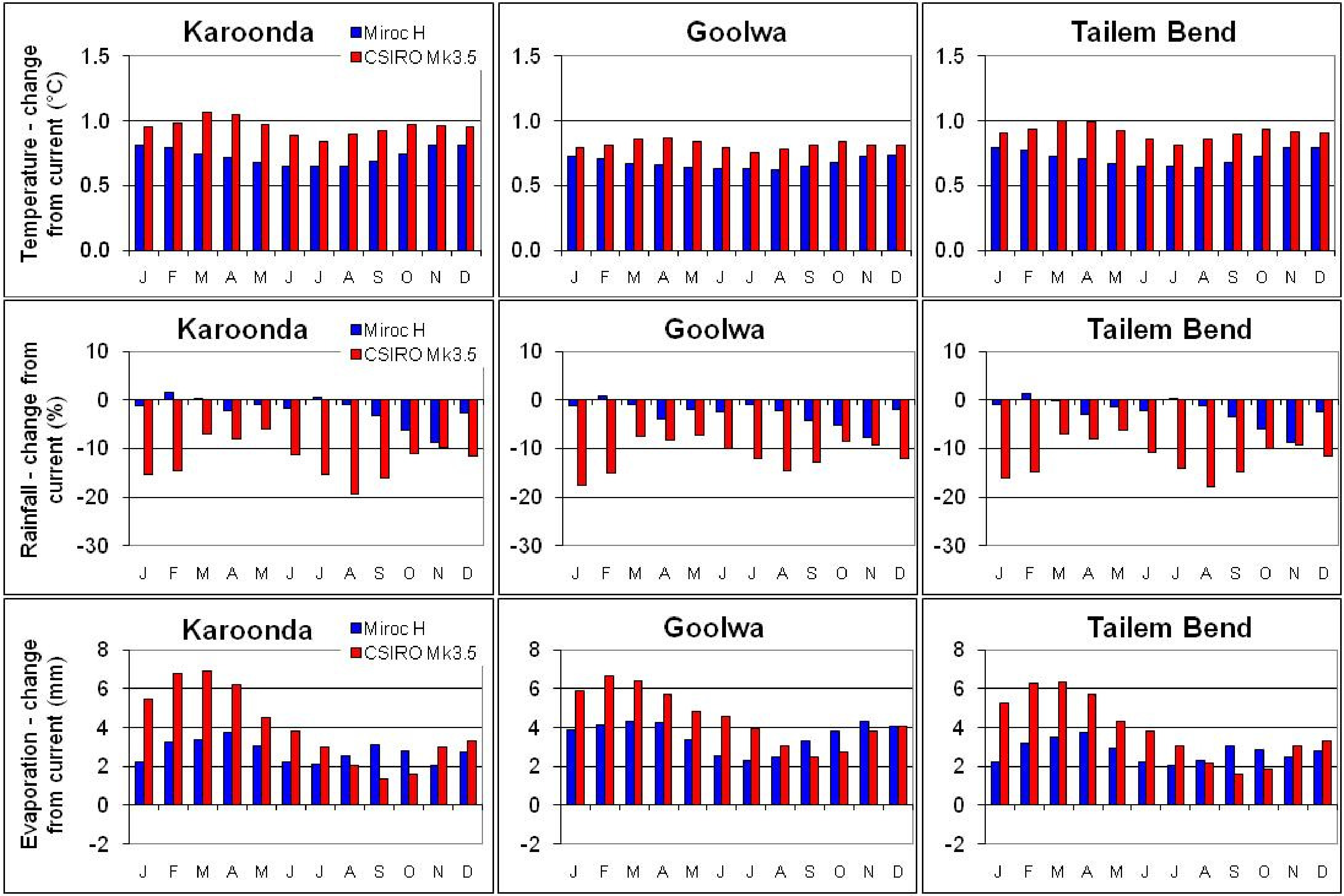

Figure 4.1 (continued) Monthly changes in temperature, rainfall and evaporation for two climate models Miroc-H and CSIRO MK 3.5. Data from Ozclim.

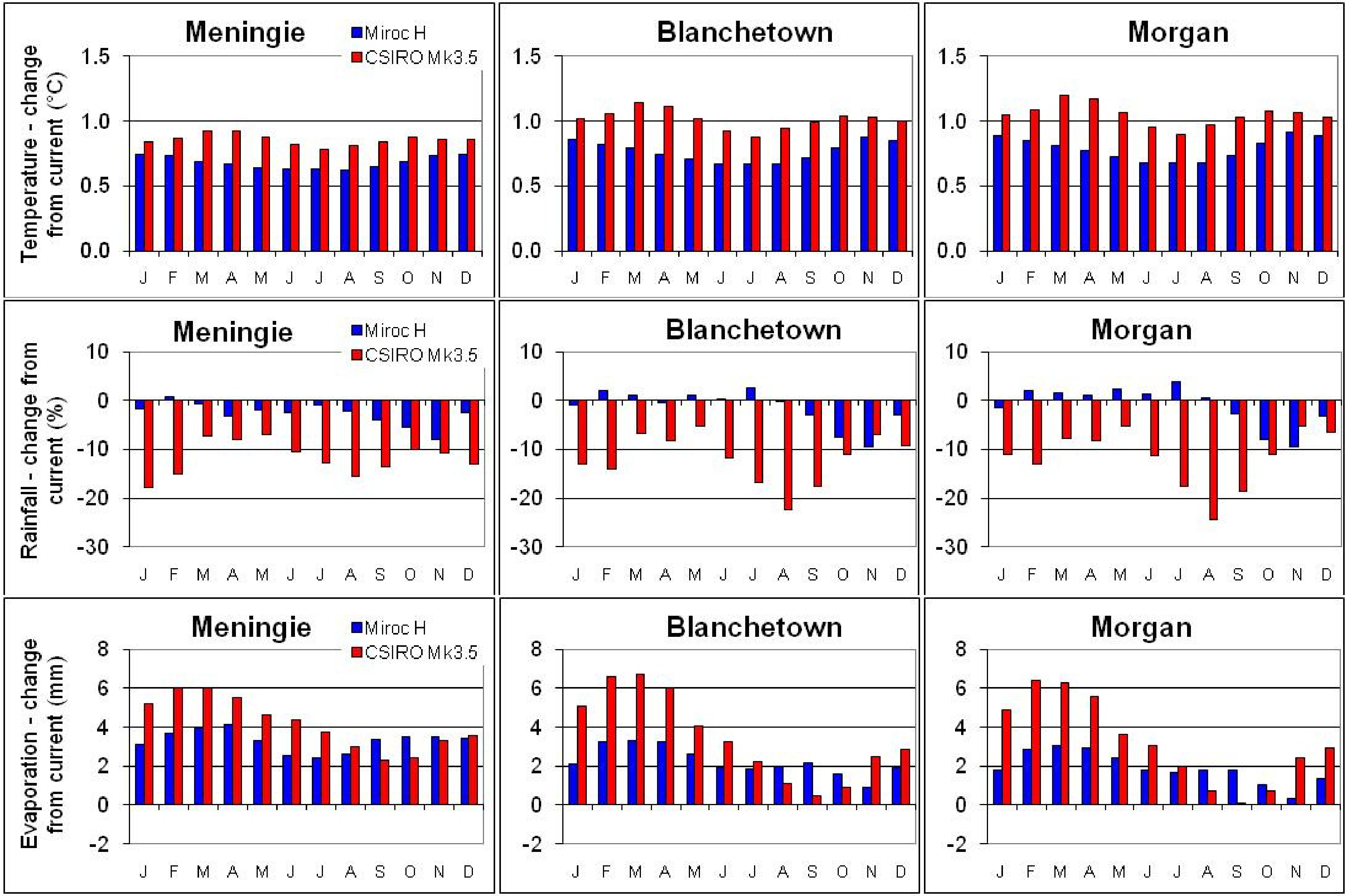

Figure 4.1 (continued) Monthly changes in temperature, rainfall and evaporation for two climate models Miroc-H and CSIRO MK 3.5. Data from Ozclim.

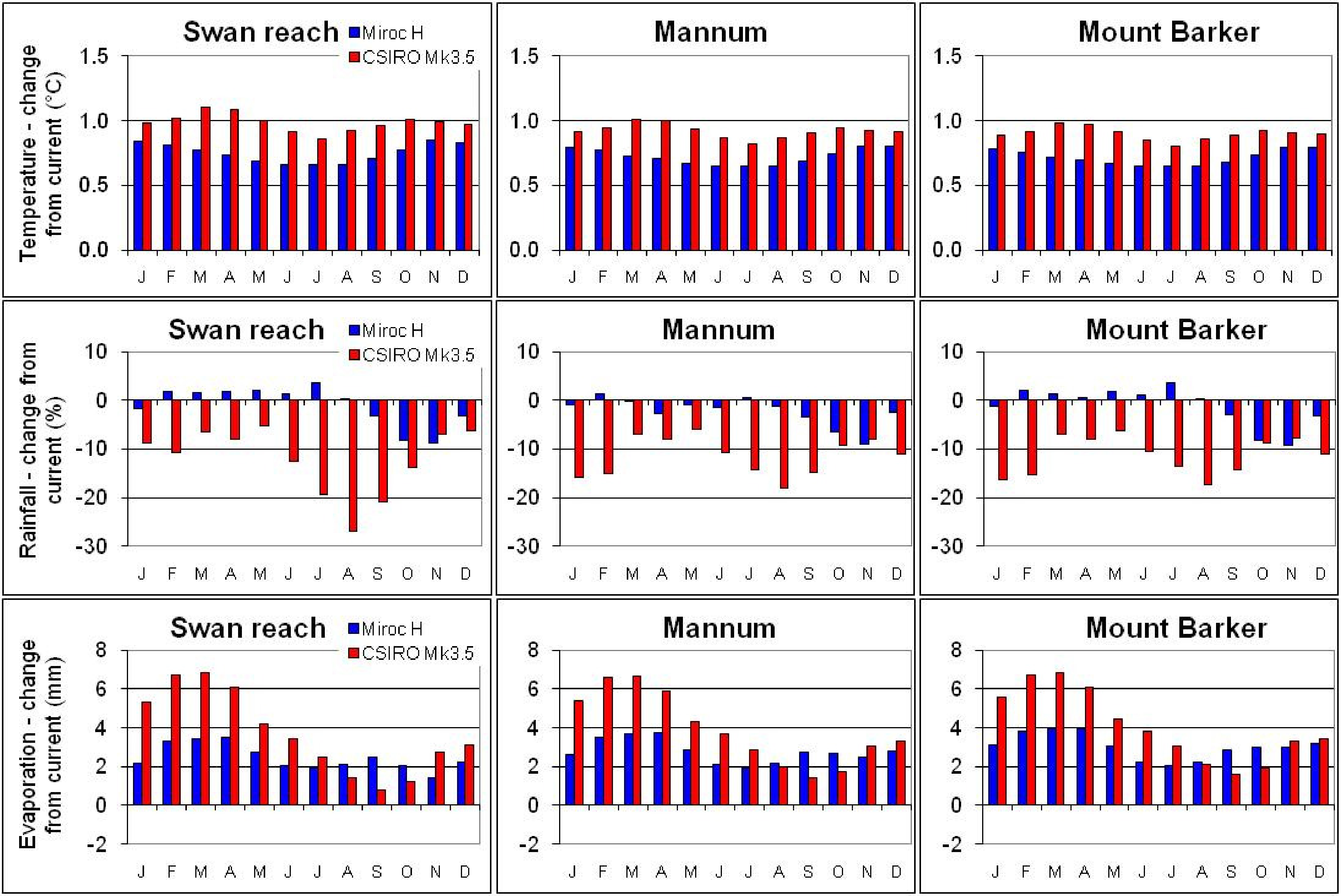

Figure 4.1 (continued) Monthly changes in temperature, rainfall and evaporation for two climate models Miroc-H and CSIRO MK 3.5. Data from Ozclim.

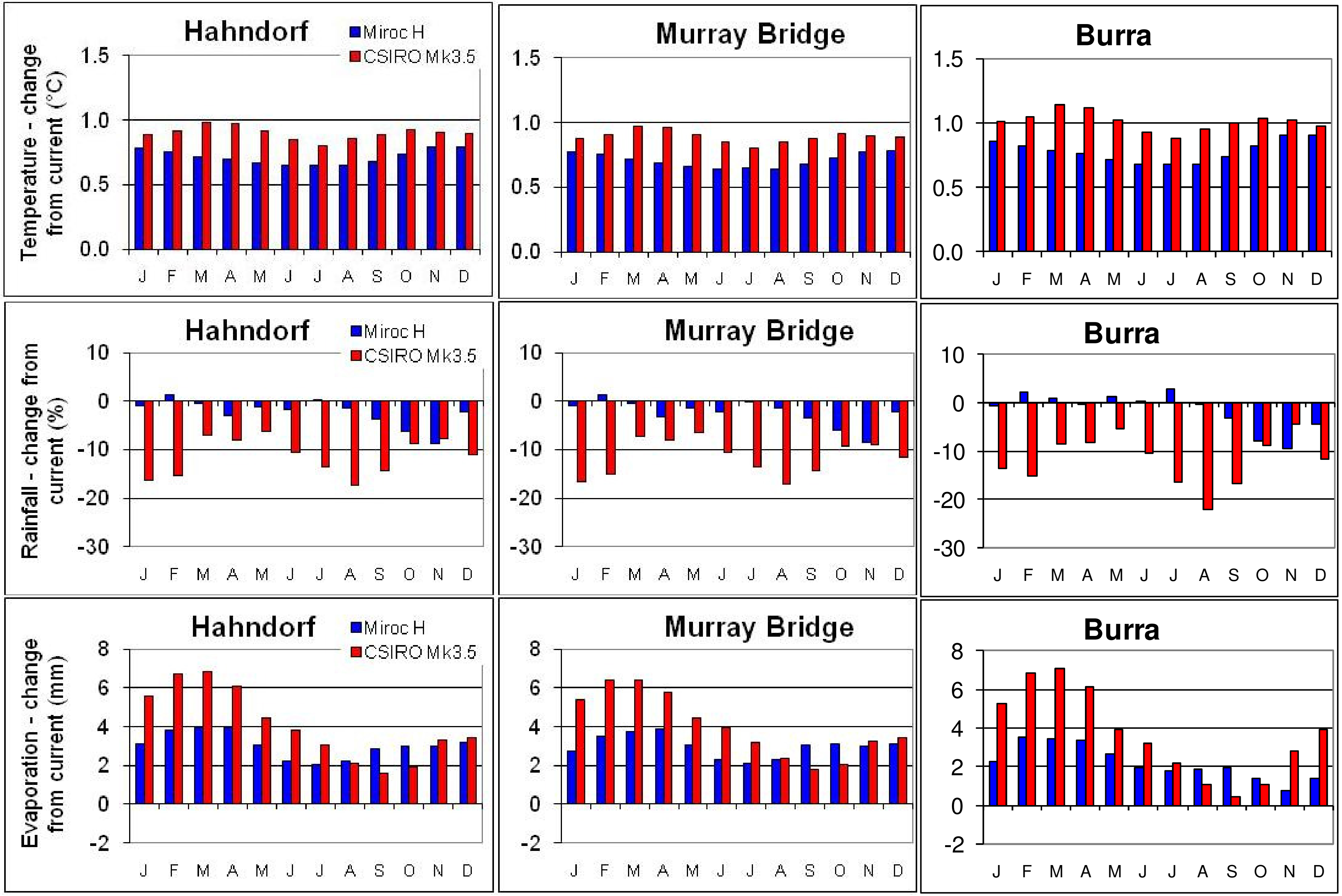

Figure 4.1 (continued) Monthly changes in temperature, rainfall and evaporation for two climate models Miroc-H and CSIRO MK 3.5. Data from Ozclim.

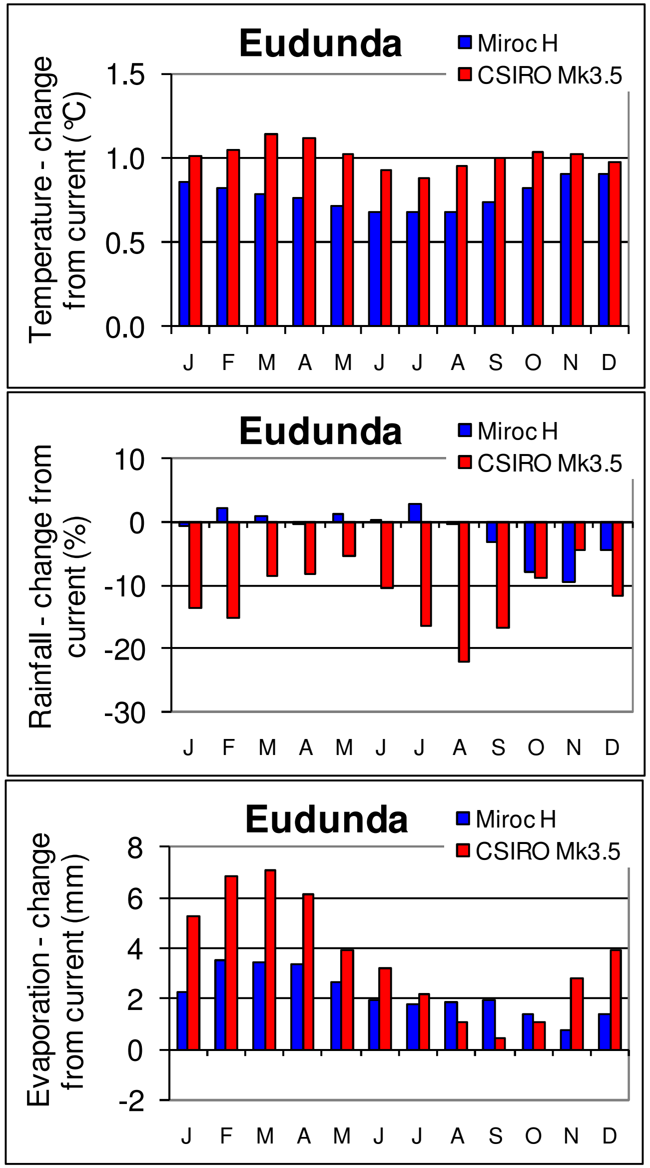

Figure 4.1 (continued) Monthly changes in temperature, rainfall and evaporation for two climate models Miroc-H and CSIRO MK 3.5. Data from Ozclim.

When the monthly adjustments are applied to Loxton climate records for the period 1980 to 99 it is apparent that the annual pattern of rainfall, temperature and evaporation is strong relative to the shifts.

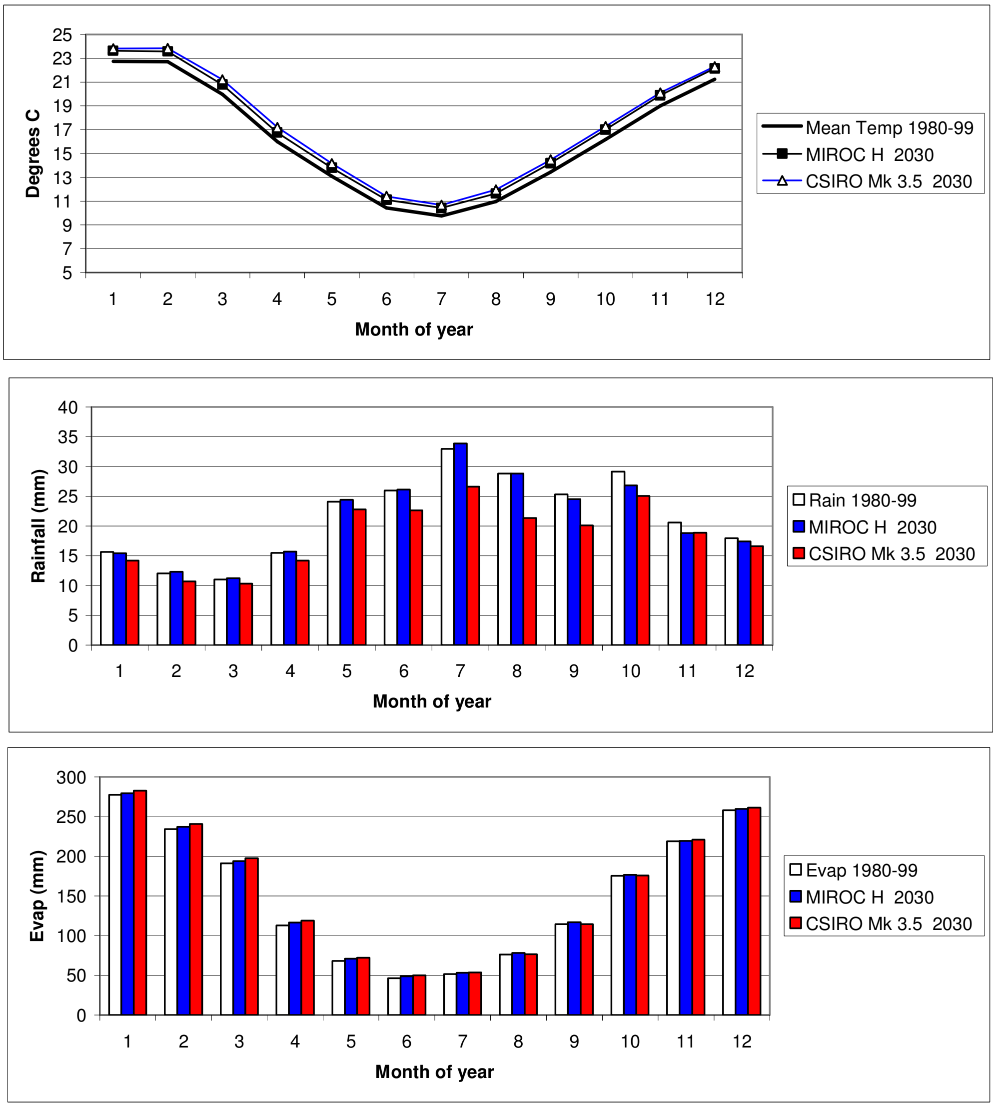

Figure 4.2 Monthly temperature, rainfall and evaporation for Loxton – drawn by applying the changes from Figure 4.1 to the 1980-99 climate data.

# 5 PROJECTIONS FOR FLOWS IN MURRAY RIVER AND STREAM FLOW IN EASTERN MT LOFTY RANGES

## 5.1 OVERVIEW

The Murray Darling Basin Sustainable Yields Project[13] was released in July 2008. It estimates the current and likely future (2030) water availability in each catchment and aquifer for the entire MDB, considering climate change and other risks, and surface-groundwater interactions. Three global warming scenarios were used, with 15 global climate models, and modelled future development including commercial forestry, farm dams and groundwater extractions. The global climate models were a sub- sample of the 24 models used for Tables 3.1 and 3.2, the 15 were selected as they had daily data available.

Figure 5.1 summarises some of the results – the mid-point of the estimates is that in 2030 water availability in the Murray will be 14% less than the 1895 to 2006 period (Black bar). The 10 years shown as the red bar (1997-2006) have seen a 30% decline. Under the driest modelled conditions (Brown bar) water availability would decline by 40% and under the wettest extreme it would increase by 7%. This is an active area of research and reports that include the ongoing drought of 2007 and 2008 are likely to show an even more worrying situation.

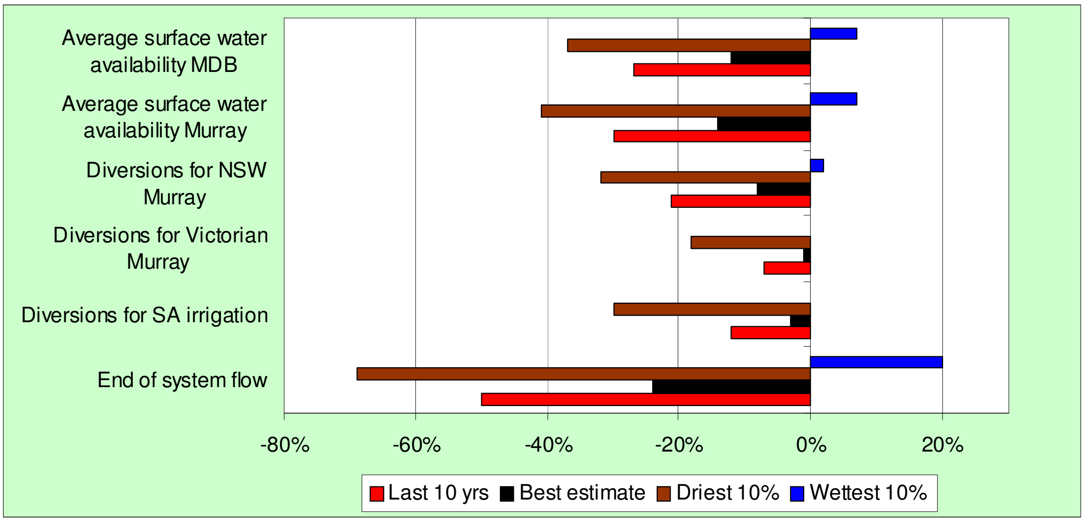

Figure 5.1 Changes in water availability. Figure drawn from data in CSIRO sustainable yields project (http://www.csiro.au/partnerships/MDBSY.html).

The modelling exercise also shows that under current policy the greatest impact of a changed climate will be at the end of system flow.

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[13] http://www.csiro.au/partnerships/MDBSY.html

## 5.2 WHAT ESTIMATES SHOULD BE USED FOR RIVER FLOW IN THE EASTERN MT LOFTY RANGES?

*The mid estimate from CSIRO for EMLR is an 18% reduction in runoff by 2030. The period from 1997 to 2006 has seen a reduction that is twice as bad as this (36%). As described in more detail in this section, rather than use the 18% reduction it seems more sensible to first consider the impacts and adaptation options of say a 5%, 10%, 20%, 30%, 40% and 50% reduction and then consider which of these are more or less likely.*

The following points are taken from the CSIRO Sustainable Yields report for the Eastern Mt Lofty Ranges (EMLR).[14]

- The EMLR covers 0.4% of the MDB and contributes about 0.5% of the total runoff.

- The streams of the EMLR gain water from catchment runoff in the hills and are highly seasonal with peak flows in winter and spring and hence will be very sensitive to the timing of changes in rainfall.

- The hydrology of the region is complex with streams contributing to groundwater once they reach the plain. There are approximately 8000 dams with an estimated storage capacity of 22 GL.

- It is not easy to find long term trends in rainfall or runoff. The period 1997 to 2006 was dry across the whole MDB. For EMLR the mean rainfall during this period was 7% below the long term average and the runoff was 36% below the long term average. The decrease in rainfall was not shown to be statistically significant, but the decrease in runoff was statistically significant at the 10% probability level (this means that there is a 90% chance that this difference is not just noise in the data). For most of the Murray Darling Basin the impact of a rainfall decline is doubled or tripled when expressed as stream flow.

- The CSIRO sustainable water yields project used 15 different global climate models. Nearly all the modelling results showed a decrease in runoff. When the models were ranked from the greatest decrease to the smallest decrease (or slight increase) the middle model gave a 15 % reduction in mean annual runoff by 2030 relative to 1990. The extreme estimates that came from a high global warming scenario ranged from 44% reduction in runoff to no change. A low global warming scenario ranged from a 15% reduction in runoff to no change.

- When projected increases in commercial forestry and farm dams were included the median or best estimate of the combined impact of climate change, forestry and farm dams was an 18% reduction in stream flow, with a range of a 3% to 46% reduction.

- Compared to some other catchments the CSIRO report indicated that because it is a smaller and reasonably well understood catchment, the runoff estimates were

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[14] CSIRO (2007) Water Availability in the Eastern Mount Lofty Ranges October 2007

relatively sound. This indicates that most of the uncertainty lies in the projections of future climate and to a much lesser extent on the effects of forestry and farm dams.

It would seem unwise to simply plan for 18% reduction from the 20 year period centred on 1990, especially as the period from 1997 to 2006 has been 36% below 1990 (exactly double). The question of how much this decline is due to decadal variability and how much is due to greenhouse gas forcing is the subject of considerable scientific research on detection and attribution.

Our recommendation is to take a scenario approach by considering the impacts and adaptation options associated with a range of runoff reduction (say 5%, 10%, 20%, 30%, 40% and 50% reduction) and then use the scenario that is locally considered to having the greatest likelihood of occurring. The advantage of this approach is that it forces a more active consideration of the likely impacts and gives a greater appreciation of the sensitivity of the impacts to larger runoff reductions.

# 6 DISCUSSION OF CURRENT AND PROJECTED RAINFALL AND RUNOFF

## 6.1 INTENSITY OF RAINFALL

A major resource for planning infrastructure such as roads, stormwater and sewer systems is the Australian Rainfall and Runoff guidelines. The National Committee of Water Engineers of Engineers Australia has received funding from the Australian Department of Climate Change to update the current edition of the Rainfall and Runoff guidelines produced in 1987. This will involve the incorporation of climate change. A recent report (February 2010) highlights some of the advances and challenges of including climate change in the hydrologic balance. They note *"there is no methodology available that is able to capture the full range of changes which are likely to occur as a result of anthropogenic climate change."* The revised rainfall and runoff guidelines will be the new authority and the comments here should be taken as intermediary.

Across the world a major concern with climate change is an increase in the intensity of rainfall. For example, the Fourth Assessment Round of the IPCC is the summary of projected changes indicated that more intense precipitation events were "very likely over many areas". This is because a warmer atmosphere will hold more water and a warmer atmosphere is generally a more active atmosphere. Where average annual rainfall increases it is likely that intensity will increase; even where there is a reduction in average annual rainfall it is possible to have an increase in the intensity. As discussed in more detail below, areas of southern Australia where there is a significant decrease in rainfall may be a partial exception to this rule.

***The projected changes to rainfall intensity are relatively modest for the SA MDB region compared to more northern parts of Australia for two reasons, first the expected percent change by 2050 is modest (2%) and second, the intensity is relatively low in the first place.***

In other words a 2% change in Loxton rainfall intensity is less than a 2% change in Cairns rainfall intensity and much less than a 6% change in Cairns rainfall intensity. Important exceptions are in the Mt Lofty ranges where there is a greater degree of uncertainty due to topography.

Rainfall intensity can refer to daily rainfall or for periods as short as 5 minutes. Daily rainfall intensity can be expressed as the 99th percentile (approximately the rainfall on the 4th wettest day of the year) a given amount (e.g. the chance of more than 25 mm falling in a day) or an event that occurs once every few years (e.g. a 1-in-20 year event). A one in 20 year event has a 5% chance of happening in any given year.

## 6.2 DETAILS ON THE RAINFALL INTENSITY UNDER THE CURRENT CLIMATE

Before considering changes to rainfall intensity under future climates it is useful to consider the characteristics of rainfall intensity under the current climate for locations in the study region. The Intensity, Frequency and Duration tool on the Bureau of Meteorology water website provides a 2.5 km resolution across Australia.

Figure 6.1 is the rainfall intensity chart for Murray Bridge. The x axis is duration ranging from 5 minutes to 3 days on a log scale. The y axis is the rainfall intensity expressed in mm/hour (also on a log scale).

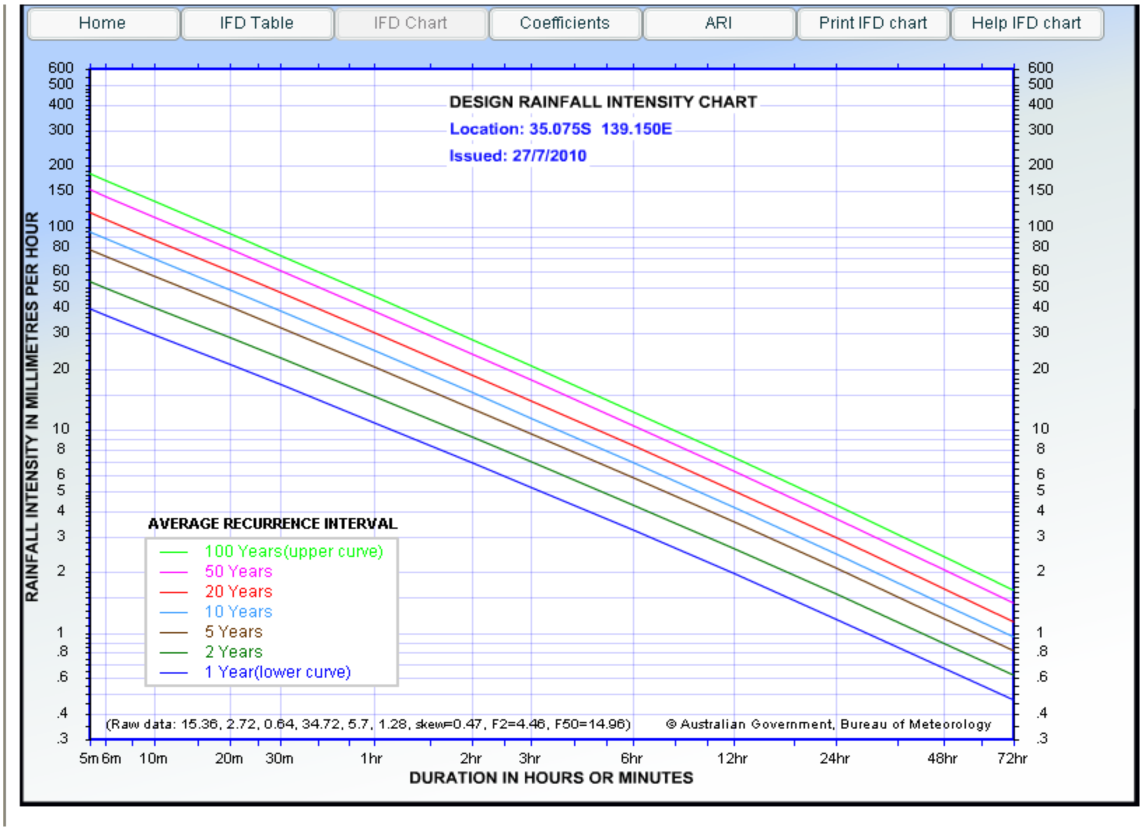

Figure 6.1 Rainfall intensity chart from IFD tool available at [www.bom.gov.au/hydro](http://www.bom.gov.au/hydro)

Using the 5 Year return period (brown line), at Murray Bridge a street gutter should be able to cope with a rainfall intensity of about 60 mm/hour for a 10 minute period and 80 mm per hour for 5 minutes. Note the Y axis is the rate not the amount. The amount is simply the rate multiplied by the duration so a 10 minute downpour at 30 mm per hour would read 5 mm in a rain gauge. Figure 6.1 can be used to check the chance of getting 30 mm over an hour (i.e. an average intensity of 30mm per hour for a duration of 1 hour = 1 in 20 years). Figure 6.1 shows that the 1 in 100 year 5 minute intensity is 183 mm/hour which is just over 15 mm of rain falling in 5 minutes.

Table 6.1 shows the 1 in 100 year event and 1 in 5 year event for rainfall in an hour for a range of towns in the region. The 1 in 100 year frequency for Murray Bridge is 45 mm per hour and once in five year chance of 20 mm per hour. This is slightly higher than the average of the towns listed for a 1 in 100 year event and marginally lower than the towns listed for a 1 in 5 year event.. Table 6.1 also lists the events for Melbourne, Sydney and Townsville. As expected Townsville has a much higher intensity of rainfall. An engineer in a Sydney council is dealing with 42 mm/hour as a 1 in 5 event. Although not shown in the table, the yearly expectation for Townsville for hourly rainfall of 44 mm/hour is equivalent to what most of the towns in SA MDB have as their 1 in 100 year rate. Even under the most extreme projections for coming decades, the changes for towns in the local council regions is likely to be less than what is experienced on NSW and Queensland coastal regions under the current climate.

| | 1 in 100 yr event | | 1 in 5 yr event | |
|---|---|---|---|---|
| | mm/hr | Deviation from averge of listed SA towns (44mm/hr) | mm/hr | Deviation from averge of listed SA towns (21mm/hr) |
| Mt Barker | 46 | 5% | 22 | 3% |
| M'Bridge | 45 | 3% | 20 | -4% |
| Karoonda | 40 | -8% | 21 | -2% |
| Keith | 45 | 3% | 21 | -2% |
| Renmark | 46 | 5% | 23 | 9% |
| Waikerie | 45 | 3% | 22 | 5% |
| Blanchetow | 44 | 1% | 21 | 1% |
| Nuriootpa | 40 | -9% | 20 | -5% |
| Gawler | 43 | -2% | 20 | -5% |
| Average | 44 | | 21 | |
| Melb | 50 | 13% | 26 | 22% |
| Sydney | 70 | 60% | 42 | 95% |
| Townsville | 117 | 167% | 71 | 232% |

Table 6.1 Result of Intensity Frequency Duration (IFD) analysis for a range of locations. The rainfall intensity in mm/hr for a duration of an hour and frequency of 1 in 100 and 1 in 5 yr events. The averages are for the 9 listed towns.

To summarise, there are valuable resources such as the rainfall intensity graphs that can be used to better understand rainfall for current planning, these show that although there are extreme events in the region that will stress systems, that these are much lower than other parts of Australia.

### Future projections

The Climate Change in Australia report (CSIRO and BoM 2007 p 73) addresses the issue of intensity of rainfall. *"An increase in daily precipitation intensity (rain per rain-day) and the number of dry days is likely. Extreme daily precipitation (highest 1%) tends to increase in the north and decrease in the south with widespread increases in summer and autumn, but not in the south in winter and spring when there is a strong decrease in mean precipitation".* Figure 6.2 shows annual and seasonal change in mean rainfall (left column) and changes in 1 in 100 year daily rainfall intensity (right column). The annual and summer change is in the neutral range between -1 and +1%, autumn 1 to 2% and winter and spring a reduction.

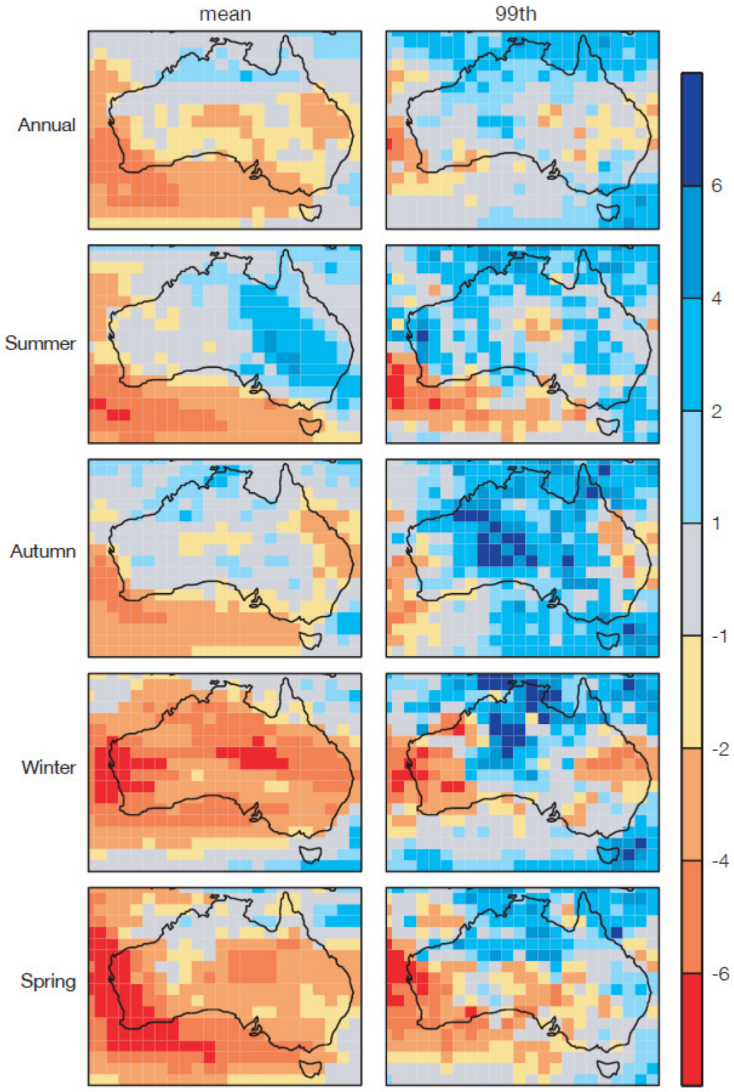

Figure 6.2 from CSIRO and BoM 2007 percentage changes in annual average and seasonal average mean rainfall (left column) and 99th percentile daily precipitation intensity (right column) in 2050 under the A1B emission scenario for the median of 15 models. The 99th percentile is about the 4th heaviest event in a year.

Rafter and Abbs (2009)[15] used the 20 year return period of daily rainfall as a measure of intensity. Figure 6.3 shows the result from the CSIRO Mk 3.5 model for 2055 and 2090 which shows considerable variation across Australia and an increased intensity in 2090. However, the SA Murray Darling Basin NRM region shows a decrease in the 1 in 20 year intensity. As discussed by Rafter and Abbs (2009) there are considerable differences between global climate models in the direction (increase or decrease), the degree of change and the spatial patterns across Australia.

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[15] Rafter T, Abbs D (2009) An analysis of future changes in extreme rainfall over Australian regions based on GCM simulations and Extreme Value Analysis. CAWCR Research Letters URL:http://www.cawcr.gov.au/publications/researchletters.php 3, 44-49.

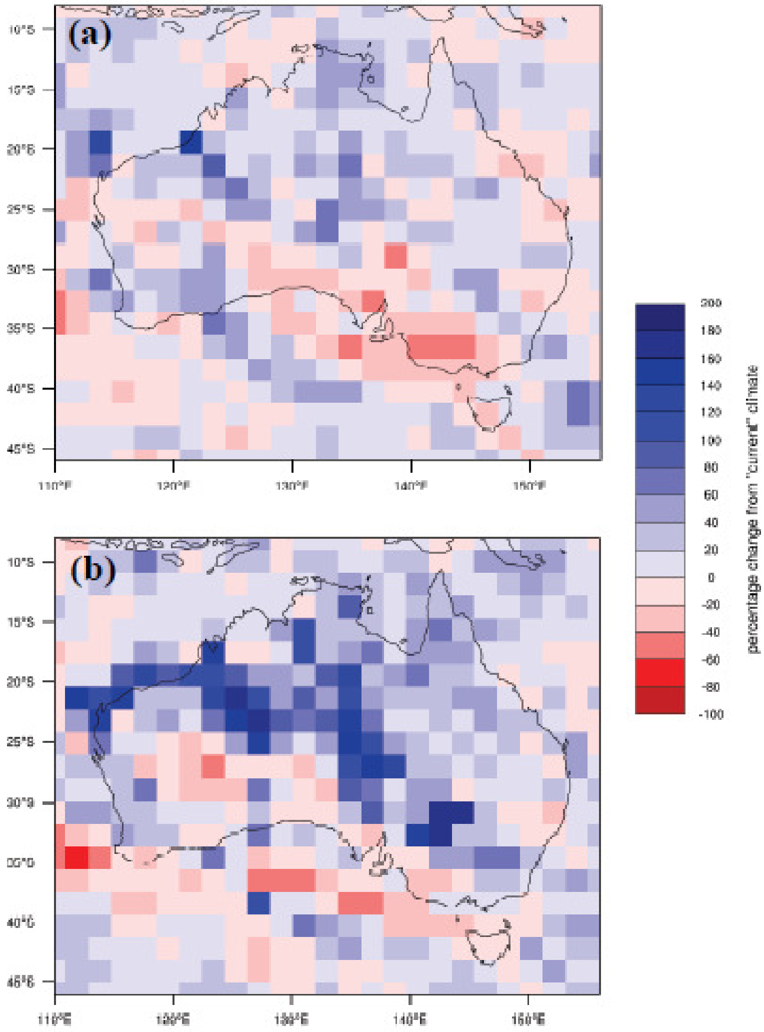

Figure 6.3 from Rafter and Abbs (2009) the percent change from 1980 climate in 1 in 20 year extreme rainfall for a) 2055 and b) 2090 using CSIRO Mk 3.5 model. Note that this is one model, as pointed out by authors, other global climate models lead to different conclusions.

Abbs (2008)[16] noted that for heavy rain to occur the following ingredients were required

- A synoptic pattern that brings moisture laden air to the region
- A lifting mechanism causes moist air to rise and cool, thus leading to the condensation of water vapour into clouds. Lift can be achieved by meteorological features such as fronts and convection or through topographic features such as orography and land-sea contrasts.
- A buoyant atmosphere so that once lift is triggered the air will continue to rise to produce deep, moist convective clouds.

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[16] Abbs D, Rafter T (2008) 'The Effect of Climate Change on Extreme Rainfall Events in the Western Port Region. Impacts of Climate Change on Human Settlements in the Western Port Region: An Integrated Assessment.' (CSIRO Marine and Atmospheric Research: Melbourne).

Some of these features are captured in the coarse resolution Global Climate Model simulations as shown in Figures 6.2 and 6.3, but the averaging will mean that the effect will be less pronounced than occurs in reality. In more sophisticated downscaling work at a much higher resolution Abbs (2008) has shown that local regions, especially complex topography near the coast can lead to greater changes to localised rainfall intensities.  This highlights the need for caution in generalised interpretations for the Mt Lofty Ranges. Although it is very difficult to project future rainfall at a sub-daily scale, systems are very sensitive to small changes in rainfall intensity.  One of the challenges of climate change is that it will be increasingly challenging to have simple lookup tables for design specifications.

It is prudent for planners to consider the possibility that even if total rainfall decreases, the intensity of rainfall may increase. However there is less confidence that rainfall intensity will increase in southern Australia compared to northern Australia.  It is important to recognise that the current intensity of rain fall is relatively low. This has two implications; first a percentage increase in rainfall intensity will not be as great compared to regions where the current rainfall intensity was high and second that although the projected increase is coming from a low base, it could cause damage as infrastructure and planning has occurred with low intensity.

## 6.3 RAINFALL AND RUNOFF

The relationship between rainfall and the amount of runoff is not a simple linear one. Factors from both the characteristics of rainfall and the soil on which it is falling will influence how much of the rain goes into the soil (infiltration) and how much runs off.  The relationship is variable and depends on pre-rain soil wetness, slope of the ground surface, roughness of the ground surface, rainfall intensity and soil texture.  Let’s consider each of these factors.

- Pre-rain soil wetness.  This is often called “antecedent soil water content” and refers to the fact that a dry soil will allow more rain to infiltrate and therefore less to run off.  If soils are already wet from previous rainfall or irrigation, little additional water can move into the soil (the soil pores are already full of water) and hence water from rain will pond on the surface and potentially runoff.
- Slope of the ground surface.  The amount of runoff will be directly related to the slope of the land.  If we consider two patches of soil that are of similar wetness but one is on a steep slope and another on the flat, a similar rainfall event will cause more water to run off the sloping patch as any free water on the ground surface will move downhill and have less time to infiltrate into the soil.
- Roughness of the ground surface.  A patch of soil that has a smooth surface will have more runoff than a patch that has been cultivated or has vegetation on it that acts to hold rain water in micro storages on the surface. The rougher the ground surface, the less runoff.
- Rainfall intensity.  If a large volume of water rapidly comes onto the soil surface there is little time for the water to infiltrate and more of it will run off.  In contrast, the same volume of water coming onto the surface over an extended time i.e. at a

low rate or intensity is likely to result in little runoff if the soil was fairly dry (antecedent water content being low).

- Soil texture. Coarse textured soils like sands have higher infiltration rates that fine textured clay soils. For similar rainfall events, clay soils will have greater run off than sandy soils.

With all of these factors influencing the infiltration runoff relationship it is not surprising that there is a lot of interaction between them. For example, a high intensity rainfall storm can result in a lot of runoff even if the soil was in a reasonably dry condition. As another example, a sloping catchment with lots of surface roughness, vegetation litter and vegetation cover can store large volumes of water that trickles out as runoff over a long period of time.

The relationship between rainfall and runoff can be characterised for a particular catchment using measurements of rainfall and stream flow from the catchment. With a series of rainfall and stream flow events over time it is possible to build up a generalised relationship that is reasonably characteristic for the particular catchment. From this characterisation it is then possible to indicate a general relationship between annual rainfall and runoff. In catchments of the eastern Mt Lofty Ranges in South Australia that are generally dry rather than wet, a 10% decrease in annual rainfall will likely result in a 30% decrease in runoff and hence quite reduced stream flow. This generalised response for measured catchments around Australia is illustrated in the figure below.

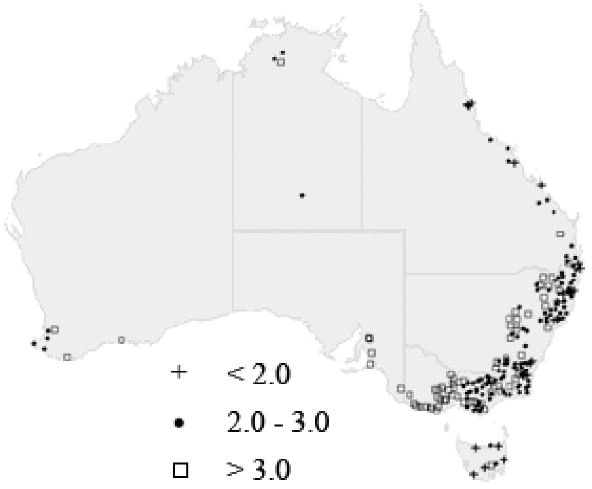

Figure 6.4. Rainfall elasticity of runoff. If value is 3, then a 10% decline in rainfall = 30% in runoff and 30% decline in rainfall = 90% decline in runoff. [17]

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[17] Chiew, F.H.S., 2006, An overview of methods for estimating climate change impact on runoff, 30th Hydrology and Water Resources Symposium, 4-7 December 2006, Launceston, Tasmania.

# 7 BRIEF DISCUSSION OF KEY DRIVERS FOR EVAPORATION

*The projections shown in Tables 3.1 and 3.2 indicate an increase of annual potential evapotranspiration of 0 to 6% for 2030 and 0 to 14% for 2070. Understanding the driving variables of potential evapotranspiration indicates that temperature is only one factor and not the most important factor. The change in potential evapotranspiration is relatively small compared to the changes in rainfall and the reduced water use that improved irrigation efficiency could bring about.*

Incoming solar radiation has the largest effect on potential evapotranspiration. If future atmospheric conditions generate more cloudiness then the amount of energy from incoming solar radiation will be less. The changes in the incoming solar radiation are closely related to the projected changes in rainfall, hence it would be expected that winter and spring drying (with accompanying less cloudiness) will lead to increased potential evapotranspiration.

The second most influential effect on rates of evaporation is wind. Generally the windier it is the greater will be the evaporation rate. A comprehensive study of standard weather stations around Australia has shown that while temperatures have gone up, in line with the global trends, the rates of measured evaporation have either stayed the same or gone down. Associated data suggests that wind runs have decreased slightly, i.e. it is getting slightly calmer and so evaporation rates are not increasing (Roderick et al. 2007; McVicar et al. 2008).

Finally, evaporation is influenced by the dryness of the air and this in turn is directly related to temperature. Warmer air has a greater capacity to hold water vapour. The increase in potential evapotranspiration is about 2 to 3 % per degree of warming (Lockwood 1999).

Evapotranspiration can be increased by advection when drier, hotter air is transported into the crop by wind, and this can be an important factor in the water balance of irrigated crops in a semiarid climate[18].

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[18] Tolk et al (2006) Agronomy Journal 98, 1646–1654.

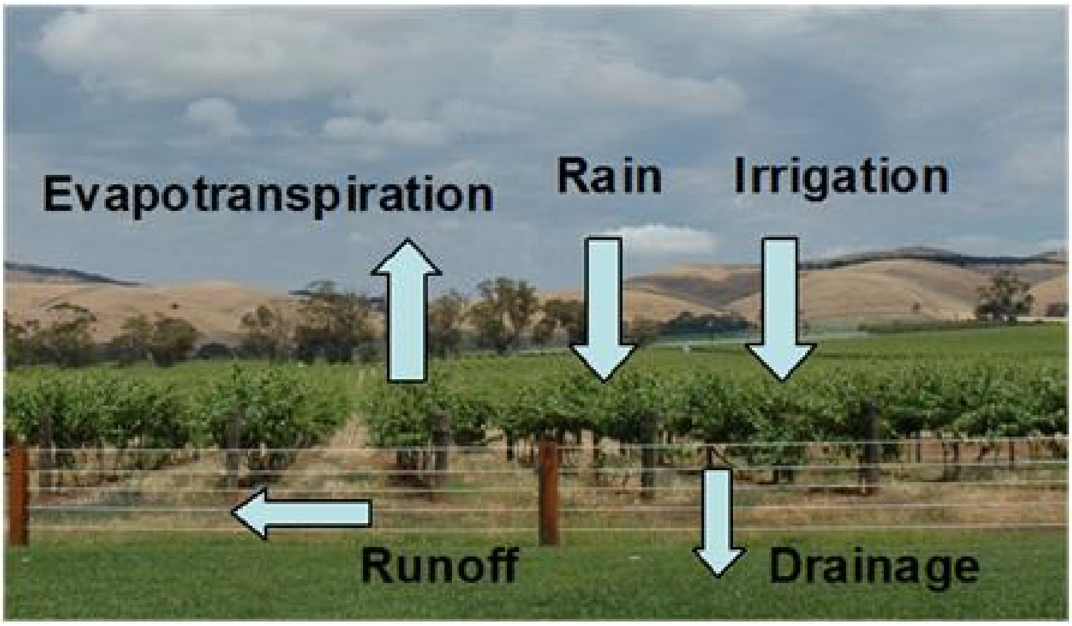

Figure 7.1. A simple representation of the water balance in a vineyard

The figure above is a simple representation of the water balance.[19] Water use by an irrigated crop can be determined by the atmosphere and the Crop coefficient.
The Crop coefficient (Kc) is affected by the type and stage of the crop; principally the leaf area.

For wine grapes the crop coefficients during the growing season increase in spring (Figure 7.2). It is not easy to say how the crop coefficient will change with climate change. A higher concentration of carbon dioxide is likely to increase the plant vigour and hence increase the rate of growth, but at the same time the efficiency of transpiration is also likely to change - and so the overall effect may be for the crop coefficient to be little changed.

Warmer temperatures also cause crop development to be faster and hence the duration of a crop say from sowing or bud burst to harvest is shorter. More rapid crop development will change the shape of the crop coefficient curve possibly bringing forward canopy development and hence higher early season water use.

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[19] Hayman PT, Leske P, Nidumolu UB (2009) 'Climate change and viticulture. Informing the decision making at a regional level. South Australian Wine Industry Association and South Australian Research and Development Institution.' (GWRDC Project SAW 06/01: Adelaide, Australia).

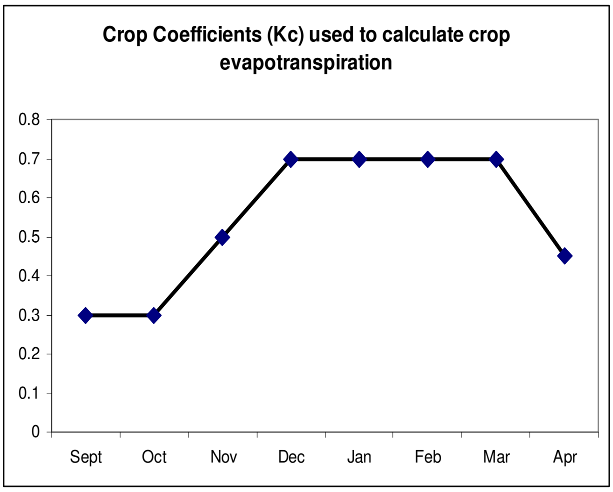


Figure 7.2. Crop coefficients used by SA Rural Solutions for planning vineyard irrigation.

Across the study region evapotranspiration is already very high in summer. With warming, this is likely to increase, however an understanding of the driving variables of evapotranspiration indicates that the extent of the increase depends on cloud cover and wind as well as temperature. The recommendation is to use the 0 to 6% increase in potential evapotranspiration.

# 8 OVERVIEW OF PROJECTED SEA LEVEL RISE

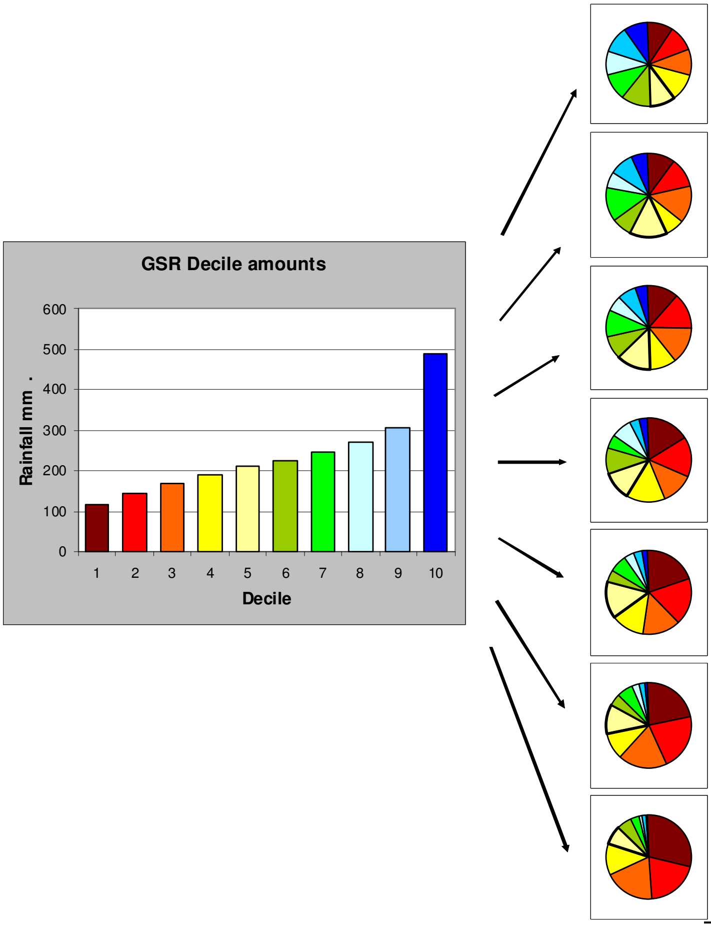
The authoritative source for sea level rise is the Coastal Protection Board within the Department of Environment and Natural Resources (DENR). Conversations with Dr Murray Townsend on 29th of April 2010 identified the current sea level rise policy of site levels to allow for 0.3 m rise to 2050 and a further 0.7 m in the following 50 years. These numbers should take into account local land subsidence. There are a number of key uncertainties about sea level rise, but the uncertainty is all one sided; that is the contribution of catastrophic effects such as ice caps melting will add to the more modest rises predicted by the models. There are no expected processes that will lead to a reduction in sea level rise.

## APPENDIX 1

The chance of different growing season rainfall (April to October) deciles for Sedan in the Murray Mallee under different climate change projections of declines in average rainfall.

Under no change in rainfall the chance of being in the driest 3 deciles and wettest 3 deciles is the same. At 10% drying the chance of being in the driest 3 deciles is 40% which is twice the chance of being in the wettest 3 deciles.

This approach can also be used to examine the chance of 2 poor seasons in a row.



| Rainfall Decline | D1-D3 | D8-D10 | Ratio of poor to good |
|---|---|---|---|
| 0% | 30% | 30% | 1 :1 |
| 5% | 36% | 23% | 1.6 :1 |
| 10% | 40% | 19% | 2.1 :1 |
| 15% | 44% | 15% | 2.8 :1 |
| 20% | 52% | 10% | 5.3 :1 |
| 25% | 61% | 6% | 9.4 :1 |
| 30% | 68% | 3.7% | 18.3 :1 |