# TECHNICAL REPORT

## POTENTIAL IMPACT ON WATER RESOURCE AVAILABILITY IN THE MOUNT LOFTY RANGES DUE TO CLIMATE CHANGE

## 2010/03

Government of South Australia
Department for Water

# POTENTIAL IMPACT ON WATER RESOURCE AVAILABILITY IN THE MOUNT LOFTY RANGES DUE TO CLIMATE CHANGE

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October 2010

Technical Report DFW 2010/03

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ISBN 978-1-921528-98-9

**Preferred way to cite this publication**

Heneker TM and Cresswell D, 2010, *Potential Impact on Water Resource Availability in the Mount Lofty Ranges due to Climate Change*, DFW Technical Report 2010/03, Government of South Australia, through Department for Water, Adelaide

# PREFACE

On July 1st 2010, the Department for Water replaced the former Department of Water, Land and Biodiversity Conservation. The Department of Water, Land and Biodiversity Conservation and the abbreviation 'DWLBC' are referred to in several instances in this report. The reader is advised that these terms are retained in certain contexts within this document in order to provide a correct historical account of the investigation and the production of the technical report document.

# FOREWORD

South Australia's Department for Water leads the management of our most valuable resource—water.

Water is fundamental to our health, our way of life and our environment. It underpins growth in population and our economy—and these are critical to South Australia's future prosperity.

High quality science and monitoring of our State's natural water resources is central to the work that we do. This will ensure we have a better understanding of our surface and groundwater resources so that there is sustainable allocation of water between communities, industry and the environment.

Department for Water scientific and technical staff continue to expand their knowledge of our water resources through undertaking investigations, technical reviews and resource modelling.

**Scott Ashby**
**CHIEF EXECUTIVE**
**DEPARTMENT FOR WATER**

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# EXECUTIVE SUMMARY

In recent years, water resource availability across much of south-central and south-eastern Australia has been significantly lower than long-term averages. This has presented numerous challenges in providing sufficient water for a wide range of competing needs. It is not yet clear whether this recent climate is simply part of long-term natural variability or an indicator of a changing climate. Irrespective of the final determination, extended periods of reduced water availability has been highlighted as a critical aspect that needs to be brought to the forefront of water resource planning.

Historically, the extremes of natural climate variability, and in particular extended dry sequences, have often not been well considered. As they generally only occur every 30 to 40 years, the impacts are soon forgotten once conditions improve. It has been postulated that such sequences will become more frequent under what is commonly referred to as 'climate change'. This is possible and if occurs, the environmental, social and economic consequences may not be as quickly forgotten.

Climate change 'science', as undertaken and published by the Intergovernmental Panel on Climate Change (IPCC), does not suggest a single forecast of what the future climate will look like. Instead, a series of emissions scenarios that define rates of change in greenhouse gas and aerosol concentrations have been presented, together with corresponding changes in climate variables such as rainfall and temperature. These changes are based extensively on modelled simulations of the assumed future atmospheric conditions using *general circulation models* (GCMs) and their links with climate variables. As such, the distinction must be made between climate change *predictions* and *projections*. As with all climate change modelling, the results presented are *projections*, that is, scenarios of a possible future. They are not *predictions*.

In consideration of the above, an assessment of the potential impact of climate change scenarios on water resource availability in the Western Mount Lofty Ranges (WMLR) has been undertaken to determine likely changes to inflows to the water storage reservoirs for Adelaide. This technical report contains the methodology and results of this hydrological assessment and also provides an evaluation of the potential changes in the generation of urban stormwater.

Attempts have previously been made to assess the impact of climate change scenarios on rainfall and hence water resources. However, such investigations have generally only involved the scaling of historical rainfall records to match the projected percentage annual changes in rainfall as provided by GCMs at coarse grid scales (often in the order of 250 $km^2$). This coarse spatial scale and a difficulty in representing the distribution of daily events reduces the ability of the GCMs to provide the understanding necessary for detailed resource assessment. This assessment has utilised a statistical downscaling approach developed by the CSIRO in conjunction with hydrological models that were developed for the Mount Lofty Ranges (MLR) water allocation planning process by the former Department for Water, Land and Biodiversity Conservation (DWLBC).

The results presented have been obtained using data from only one GCM and only one simulation for each of two emissions scenarios (A2 and B2 rate of change of greenhouse gas and aerosol concentrations as determined by the IPCC). They should not be viewed as encompassing the full range of regional rainfall change due to anthropogenic climate change that could be generated by the large number of GCMs currently available and being developed. However, it is recommended that the results be viewed as an appropriate assessment of the impacts of likely future scenarios based on the best available information on climate change presently available, which clearly identifies the risks that Adelaide faces with declining availability of water supplies from its existing catchments. Results reflect the period 2035 to 2065 and as such, average results can be considered as representative of 2050.

# EXECUTIVE SUMMARY

The primary results of the investigation that have been detailed in this report are as follows:

1. Climate change represents a significant risk to Adelaide's water supply with increasing drier climate patterns and decreasing wetter patterns during winter likely under the scenarios considered.
2. The changing weather patterns translate to a potential reduction in annual rainfall of 13%, which leads to a potential reduction in annual runoff from the major MLR water supply catchments of over 30%.
3. The greatest impact on monthly rainfall totals that is likely to be translated to runoff generation appears to be during the autumn and early winter period from April to June. Rainfall was reduced by as much as 25% over this period.
4. Changes in evaporation rates were not modelled as part of the downscaling process. However, it is generally accepted that there will be an increase in evaporation based on temperature increases forecast by the GCMs. The application of a 5% increase in evaporation produced a reduction in the total resource produced within each catchment of approximately 3 to 4%, most likely due to low evaporation rates during winter. If future weather patterns lead to significant winter temperature increases, the impact of evaporation on water resource availability may increase significantly.
5. Some existing reservoir capacities are already significantly greater than the current levels of annual runoff from upstream catchments and if rainfall reduces, the recurrence of reservoir spills is likely to decrease significantly, even for those reservoirs that currently frequently spill. Environmental Water Provisions (EWP) should therefore be continually reviewed and incorporated into the ongoing planning of Adelaide's water supply systems to ensure the desired ecological objectives for downstream aquatic ecosystems can be met.

This report and associated modelling was completed in July 2008. It was co-funded by DWLBC and SA Water, for use in long-term planning of water resource management. It has previously been referenced as DWLBC Report 2008/25. In June 2009 the South Australian Government released *Water for Good*, the State's plan to secure water supplies for the future. *Water for Good* details policies and actions to secure sustainable water supplies for South Australia to 2050, taking into consideration population growth and the impacts of climate variation and change, such as those discussed in this report.

# 1. INTRODUCTION

## 1.1. PURPOSE

An assessment of the potential impact of climate change on water resource availability in the Western MLR has been undertaken to determine likely changes in inflows to the water storage reservoirs for Adelaide. This technical report contains the methodology and results of this hydrological assessment including an evaluation of the potential changes in the generation of urban stormwater.

## 1.2. BACKGROUND

The Western Mount Lofty Ranges (WMLR) region is located to the east of the city of Adelaide, extending from the Barossa Valley in the north to the Fleurieu Peninsula in the south. The region contains five major water supply catchments, which supply approximately 60% of Adelaide's current water needs. Rainfall within these catchments is already highly variable but observed decreases in rainfall totals over the last 20 to 30 years, coupled with the recent prescription of the entire region, has resulted in the quantification of future sustainable resource balances between supply and demand becoming a vitally important planning requirement.

In recent years, climate change has become a major component in future water resource planning across Australia. The Fourth Assessment Report of the IPCC indicated that over the next 30 years reducing rainfall and increasing evaporation in southern and eastern Australia, together with more frequent droughts, is likely to cause water security problems without adaptation measures (Hennessy et al. 2007). Given that South Australia is the driest state with some of the lowest rainfall areas across Australia, an understanding of the potential impact of climate change on water resource availability is paramount.

The impact of climate change is assessed using a set of carbon and greenhouse gas emissions scenarios developed by the IPCC. These scenarios are neither predictions nor forecasts but are alternative images of how the future might unfold (Nakicenovic et al. 2000). They represent a wide range of the main driving forces of future emissions, from demographic to technological and economic development, and encompass different future developments that might influence greenhouse gas sources and sinks, such as alternative structures of energy systems and land-use changes. The scenarios ensure a consistent basis for the assessment of potential climate change impacts, adaptation strategies and policies.

While attempts have previously been made to assess the impact of climate change on rainfall and hence water resources, such investigations have generally only involved the scaling of historical rainfall records to match the projected percentage annual changes in rainfall as provided by GCMs at coarse grid scales (often in the order of 250 by 250 km) for individual emissions scenarios. Changes in the distribution of daily events that are expected under climate change scenarios are not accounted for, and although GCMs provide a method for investigating the complex interactions and feedbacks of the oceans, land and atmosphere, they only operate on a coarse spatial scale and therefore cannot provide the understanding necessary for detailed resource assessment.

CSIRO have developed a statistical downscaling approach to provide a means of overcoming the scaling limitations by simulating regional- or point-scale weather as a function of large-scale atmospheric fields and reproducing observed daily, multi-site precipitation statistics (Charles et al. 2004). This work has provided a more robust foundation for assessing potential changes to rainfall due to climate change.

Over the last five to seven years, hydrological computer models have been developed by DWLBC using the WaterCress platform (Cresswell 2000) for each of the five water supply catchments and the major urban catchments in the WMLR. These models have been constructed with an aim of assessing risks to water resources from pressures such as farm dam development and climate change, thereby allowing a more informed approach to ecologically sustainable development.

The availability of the above downscaling methods for rainfall projection and hydrological catchment models now allows a more realistic assessment of the water resources available for supply to Adelaide, both under current rainfall conditions and with potential future changes to those conditions due to climate change.

## *1.3. OBJECTIVES AND METHODOLOGY*

The overall objective of this study is to provide an assessment of the potential impact of climate change on water resource availability in the MLR that can form a technical foundation for the consideration of future management options and policy decisions for the supply of water to Adelaide.

To achieve this objective, two distinct stages were required:

1. Generation of synthetic rainfall data that replicates current rainfall conditions and projected future rainfall conditions as a result of selected anthropogenic climate change scenarios.
2. Quantification of the resulting potential impact on water resource availability and hence potential changes in inflows into the water storage reservoirs for Adelaide from the selected climate change scenarios.

The first of these objectives has been completed by CSIRO in conjunction with DWLBC over the last five years (Charles, Heneker & Bates 2008; Charles & Bates 2006). Climate change projections were obtained from the CSIRO Mk3 GCM (Gorden et al. 2002) simulations that use projected future concentrations of greenhouse gases and aerosols. These projections were then used with the developed statistical downscaling techniques to generate potential future daily rainfall series at 20 locations within the MLR catchments. Daily rainfall series replicating current rainfall statistics were obtained from downscaling GCM current climate conditions.

As discussed above, the emissions scenarios set the rate of change of greenhouse gas and aerosol concentrations (as determined by the IPCC), representing possible future directions in world population, economic growth, technological development and energy usage (Nakicenovic et al. 2000). The distinction between projections and predictions is important. It is not possible to quantify the degree of certainty in future emissions scenarios and hence it is impossible to predict future climate. Two future emission scenarios, referred to by the IPCC as A2 and B2, were chosen for evaluation. The A2 scenario is at the higher end of emissions scenarios and assumes a continued high rate of greenhouse gas emissions. It is characterised by a regionally oriented, self-reliant, heterogeneous world with continuously increasing populations and a focus on regional economic development rather than technological change and global environmental concerns. In comparison, the B2 scenario has a slower emissions growth as governments and industry move towards environmental and social sustainability.

The second stage then incorporated the generated current and projected rainfall data into existing DWLBC hydrological models of the Western MLR catchments. These models cover the predominantly rural catchments that provide inflows into the water storage reservoirs for Adelaide in addition to some of the urban catchments of the Adelaide Plains. The urban catchment models are also able to provide assessments of future stormwater generation. The following was then undertaken to assess the potential impact of climate change on water supply for Adelaide:

1. The runoff from each reservoir and urban catchment was modelled under current conditions and each of the A2 and B2 climate change scenarios. This represents the total change in water resources generated in each catchment.

2. An initial assessment was undertaken of the ability of each reservoir system to capture and supply the water resources generated in each catchment under each of the A2 and B2 climate change scenarios, assuming each reservoir remains at its current capacity and demand for resources from those reservoir systems does not change. The latter assumes that increases in demand would be supplied from alternative sources such as desalination or from expansion of the existing infrastructure.
3. Changes in evaporation rates were not modelled as part of the downscaling process. It is generally accepted that there will be an increase in evaporation based on temperature increases forecast by the GCMs. However, variations in evaporation are likely to be extremely complex and depend on how the weather patterns passing across South Australia are altered under future climate scenarios. In addition, complexities have arisen in recent years due to recorded pan evaporation data across the State showing decreasing, rather than increasing, trends. This may be a result of a number of factors including recent increased levels of atmospheric dust but more study is needed as evaporation changes may also have a significant impact on water resource availability. An assessment of a 5% increase in evaporation was undertaken here.

The assessment undertaken in this report relates to climate change projections obtained from only one GCM, and only one simulation each for the A2 and B2 scenarios. Therefore, they should not be viewed as encompassing the full range of possible regional rainfall change due to anthropogenic climate change that could be generated by the large number of GCMs currently available and being developed. However, it is recommended that the results be viewed as an appropriate assessment of the impacts of likely future scenarios based on the best available information.

# 2. CATCHMENT DESCRIPTIONS

## 2.1. OVERVIEW

The Western MLR contains five major catchments, which together supply approximately 60% of Adelaide's current water needs. These catchments, namely the South Para, Torrens, Onkaparinga, Little Para and Myponga, supply eight major reservoirs with a total capacity of almost 200 GL. The location and size of these major reservoirs within the aforementioned catchments is presented in Table 1 and Figure 1.

**Table 1 Water Supply Catchments and Major Reservoirs in the Mount Lofty Ranges**

| Catchment | Reservoir | Storage Capacity (ML) |
|---|---|---|
| South Para | Warren | 5,100 |
| | South Para | 45,000 |
| Little Para | Little Para | 20,800 |
| Upper Torrens | Millbrook | 19,000 |
| | Kangaroo Creek | 16,000 |
| Onkaparinga | Mount Bold | 45,900 |
| Myponga | Myponga | 26,800 |

While Table 1 shows the major reservoirs that store water for supply to Adelaide, there are a number of off-stream reservoirs including the Barossa (4,500 ML), Hope Valley (2,800 ML) and Happy Valley (11,600 ML) and associated diversion channels that allow the transfer of water from the major reservoirs or the collection of a significant proportion of downstream runoff, particularly in the Upper Torrens and Onkaparinga Catchments.

Currently, the River Murray supplies the remaining 40% of Adelaide's water needs. This occurs primarily via two major pipelines, namely the Mannum to Adelaide and the Murray Bridge to Onkaparinga Pipelines. The Mannum to Adelaide Pipeline supplies the Upper Torrens catchment, discharging upstream of the Millbrook and Kangaroo Creek Reservoirs. It can also be used to fill the Little Para Reservoir if required. The Murray Bridge to Onkaparinga Pipeline discharges into the Onkaparinga River above the Mount Bold Reservoir. Transfers of River Murray water to the South Para Reservoir are also possible, although these volumes are low and infrequent in comparison. A third pipeline from the River Murray, the Swan Reach to Stockwell Pipeline, is also able to supply the South Para Reservoir.

The mean annual rainfall across the major water supply catchments is between 700 and 800 mm. The catchments are significantly cleared and although cleared catchments provide more runoff than naturally vegetated or forested catchments, proportions of this runoff are diverted to meet the water resource demands of local land owners. Recent increased demand for irrigation water, resulting from the expansion of irrigated agriculture, has caused an expansion in the number and size of farm dams and groundwater extractions (Heneker 2003). Inflow to the major reservoirs has reduced and environmental stresses within these catchments have increased. While prescription of the region should limit these effects to their current levels, future water allocation decisions will need to consider the sensitivity of future climate and development scenarios as well as environmental water provisions (EWPs).

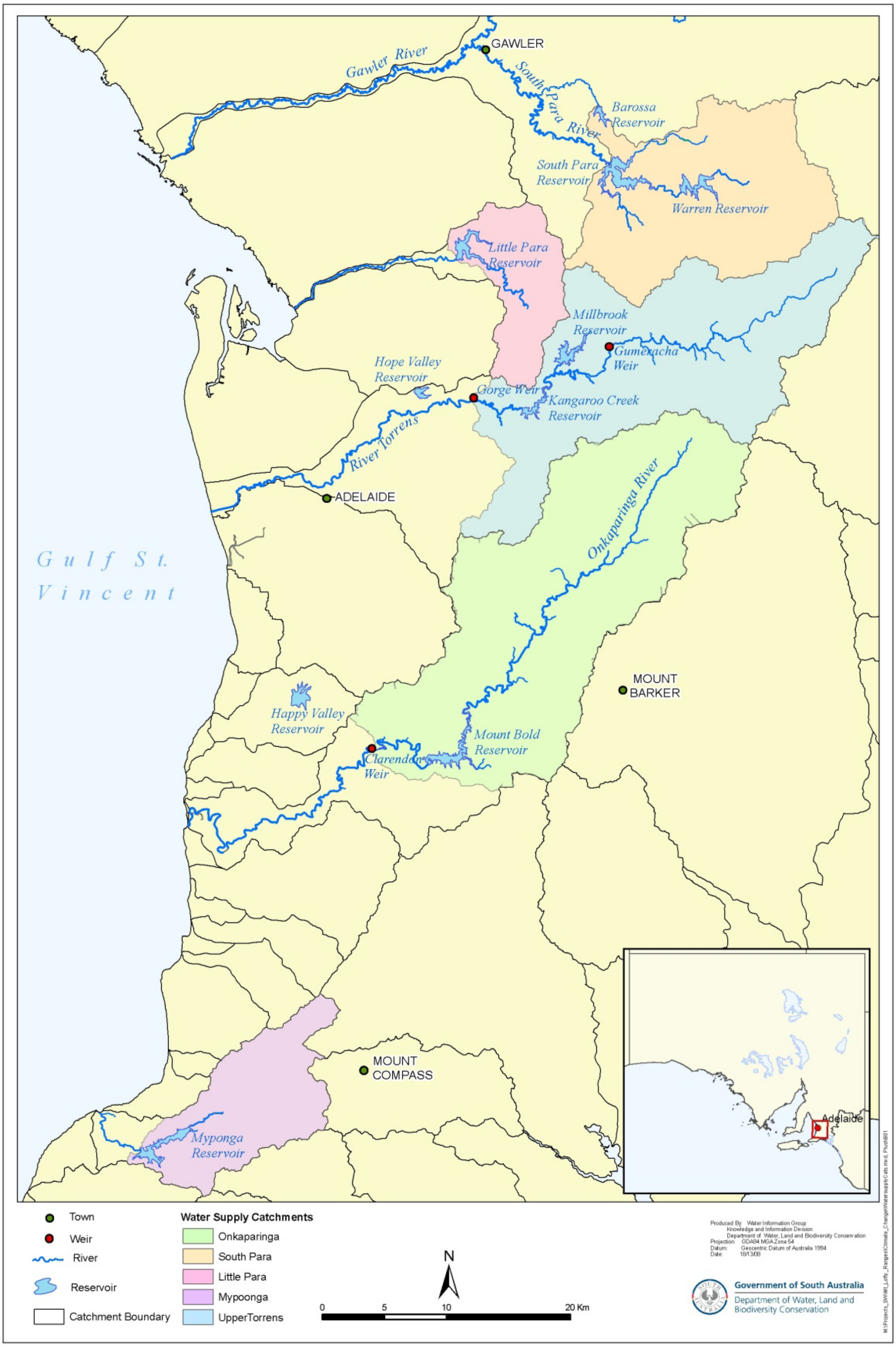

Figure 1 Location of Water Supply Catchments

The following contains descriptions of water supply operations and infrastructure within the five catchments, including assumptions used to model system inflows that provide an initial estimate of the interception capacity of each reservoir system, in particular:

- The majority of runoff from the rural catchments occurs during winter and spring. It was assumed that the reservoirs would contain 10% of the total available storage at commencement of winter in order to maximise the runoff captured, and hence the ability to capture and store runoff was calculated as 90% of the total reservoir volume.
- The average winter usage (June to October) from each reservoir was determined by distributing estimated total winter usage across the reservoir network.

It should be noted that this is an initial estimate of interception capacity only and that future modelling is proposed using the generated runoff estimates as input to the SA Water operated Headworks Optimisation Model - Adelaide (HOMA) model. This will ensure accurate representation of the reservoir system and operations including inter-annual variability in demand, dead storage, emergency supply, and water quality considerations and transfers.

Annual water use from farm dams was assumed to be 30% of the total storage volume (McMurray 2003) in each catchment.

## 2.2. SOUTH PARA CATCHMENT

The South Para Catchment is located about 60 km north-east of Adelaide. The mean annual rainfall across the entire South Para Catchment is approximately 700 mm, but varies with elevation from 800 mm in the higher reaches to 600 mm at the most downstream point of the reservoir system.

There are two major on-stream reservoirs, the Warren and the South Para, and a smaller off-stream reservoir, the Barossa, with a combined upstream catchment area of 234 km$^2$. The Barossa Reservoir has only a small contributing catchment and receives the majority of its water directly from the South Para Reservoir. These reservoirs have a combined storage of 54,600 ML and since 1968, spills from the reservoir system have only occurred on six occasions or approximately once every seven years.

Additional water can be transferred to these reservoirs from the River Murray via the Swan Reach to Stockwell and Mannum to Adelaide Pipelines. Recently, the River Murray inputs have been limited to flows through a small pipeline connection from the Mannum to Adelaide Pipeline. The Swan Reach to Stockwell Pipeline has not been used because it transfers filtered water. Past records show that on average, 21,000 ML annually has been diverted from storage to water supply, of which 16,800 ML originated from local catchment runoff and 4200 ML was supplied from the River Murray (Teoh 2006a). In December 2001, the Barossa Infrastructure Limited (BIL) scheme began, supplying water from the River Murray to the Barossa Valley via the Warren Reservoir. The scheme is currently approved to deliver up to 7000 ML per year.

The winter usage (June to October) from the reservoir was estimated at 5000 ML, resulting in an annual storage capacity of approximately 55,000 ML. The impact to the environment has therefore been assessed as the reduction in the frequency of occurrence of this runoff volume and the total volume of reservoir spill (total annual runoff in excess of 55,000 ML). In addition to the water supply reservoirs, there are estimated to be 980 farm dams located in the catchment (Teoh 2006a), with an aggregated storage volume of nearly 3000 ML or approximately 5% of the total reservoir storage. Annual usage from these storages was assumed to be approximately 1000 ML (30% of total storage volume).

## 2.3. LITTLE PARA CATCHMENT

The Little Para Catchment is located 20 km north-east of Adelaide and has a total catchment area of 85 km$^2$. The reservoir was constructed in 1978 with the dual purpose of water supply infrastructure for Adelaide and for flood protection of nearby suburbs. While its storage volume is 20,800 ML, its upstream catchment is small and the majority of the water stored and subsequently supplied is sourced from the River Murray via the Mannum to Adelaide Pipeline. Its small catchment has meant that the reservoir seldom reaches capacity and has historically only spilled twice.

The mean annual catchment inflow is around 7000 ML (Williams 2007) but a large proportion of this is required to be released as an environmental flow to compensate reduced recharge into aquifers of the Northern Adelaide Plains following the construction of the reservoir. The environmental rules require a release from the reservoir at a controlled rate totalling 3.2 GL/year. In recent years this release rate has not been met but future management of the system should expect that these volumes will be released.

The winter usage (June to October) from the reservoir was estimated at 5000 ML, resulting in an annual storage capacity of approximately 24,000 ML. In addition to the water supply reservoir there are estimated to be 430 farm dams located in the catchment (Williams 2007), with an aggregated storage volume of nearly 950 ML or approximately 5% of the total reservoir storage. Annual usage from these storages was assumed to be approximately 300 ML (30% of total storage volume).

## 2.4. UPPER TORRENS CATCHMENT

The Upper Torrens Catchment is located immediately east of Adelaide, with a total catchment area of 340 km$^2$ that contributes runoff to water supply. The mean annual rainfall of the catchment is around 760 mm, but varies from 650 mm in the upper reaches to around 1000 mm at Gorge Weir, the western-most point from where flows can be diverted for water supply.

The water supply operations that transfer water into, within and from the catchment make this an extremely complicated system. There are two major reservoirs, Millbrook and Kangaroo Creek, which have a total storage capacity of 35,000 ML and a total catchment area of 300 km$^2$.

Millbrook Reservoir (16,000 ML) is essentially an off-stream storage as it derives very little of its water supply from its local catchment area. The majority of inflows are diverted from Gumeracha Weir, which controls approximately half of the total catchment area, and consist of both local catchment runoff and transfers from the River Murray via the Mannum to Adelaide Pipeline. From here, water may be pumped for treatment, released into the Kangaroo Creek Reservoir or diverted to the Little Para Reservoir. Despite being an on-stream storage, Kangaroo Creek Reservoir (19,000 ML) has very little catchment area, instead relying heavily on releases and spill from Millbrook Reservoir and spill over Gumeracha Weir.

The mean annual catchment inflow to the reservoir system has been calculated at 37,000 ML (Heneker 2003). In addition, the Mannum to Adelaide Pipeline delivers approximately 19,000 ML/year from the River Murray, of which around a quarter is discharged directly into Millbrook Reservoir or to the Anstey Hill Treatment Plant. The remainder is released through scours at Mount Pleasant and Angas Creek, and the main channel of the River Torrens is then used as a transfer aqueduct to Gumeracha Weir and subsequently Millbrook Reservoir.

The two reservoirs are conjunctively managed to maximise the storage of local catchment inflows and River Murray transfers while maintaining flood protection for the eastern suburbs of Adelaide. Millbrook Reservoir generally spills only after intense local catchment rainfall when the reservoir has already been filled to capacity. Since 1971, spill from Kangaroo Creek Reservoir, and hence the system itself, has occurred on 14 occasions or approximately four in every ten years.

Spill from Kangaroo Creek Reservoir and local catchment runoff generated between the reservoir and Gorge Weir is able to be diverted to Hope Valley Reservoir or directly for treatment. Mean annual local catchment runoff intercepted at this point, primarily from the high rainfall Sixth Creek Catchment, is approximately 9000 ML.

The winter usage (June to October) from the reservoir was estimated at 12,000 ML, resulting in an annual storage capacity of approximately 44,000 ML. The impact to the environment has therefore been assessed as the reduction in the frequency of occurrence of this runoff volume and the total volume of reservoir spill (total annual runoff in excess of 44,000 ML).

Calculation of the interception capacity of the reservoir system has assumed that no local catchment runoff is diverted to Little Para Reservoir, although this often occurs during wetter years. The outcomes from this study will be predominantly influenced by water resource availability during drier years, and as such this assumption is not considered to alter the results.

In addition to the water supply reservoirs, there are estimated to be 1350 farm dams located in the catchment, with an aggregated storage volume of nearly 5750 ML or approximately 14% of the total reservoir storage. Annual usage from these storages was assumed to be approximately 1700 ML (30% of total storage volume). Previous modelling (Heneker 2003) showed that around 3000 ML of runoff is intercepted and retained each year from these dams.

## *2.5. ONKAPARINGA CATCHMENT*

The Onkaparinga Catchment is located about 25 km south-east of Adelaide, with a total catchment area of 560 km$^2$ that contributes runoff to water supply. The mean annual rainfall of the catchment is around 770 mm, but varies from 1080 mm in the upper reaches to around 800 mm at Clarendon Weir, the western most point from where flows can be diverted for water supply.

The Mount Bold Reservoir is the primary catchment storage, with a total capacity of 47,300 ML and a catchment area of 385 km$^2$. Spill from Mount Bold Reservoir and local catchment runoff generated between the reservoir and Clarendon Weir may be diverted to the Happy Valley Reservoir, a small off-stream, balancing storage. The total area that can potentially contribute to water supply is 442 km$^2$.

The mean annual runoff from the local catchment has been calculated at 47,500 ML (Teoh 2003). In addition, the Murray Bridge to Onkaparinga Pipeline delivers approximately 27,500 ML/year from the River Murray, which is discharged through scours near Hahndorf. The main channel of the Onkaparinga River is then used as a transfer aqueduct to Mount Bold Reservoir.

Since 1971, spills from the reservoir system have occurred on 21 occasions or around once every two years. The mean annual spill from Mount Bold Reservoir is 14,200 ML, while the mean annual spill passing Clarendon Weir is 15,100 ML. Water passing Clarendon Weir is lost from the water supply system.

The winter usage (June to October) from the reservoir was estimated at 28,000 ML, resulting in an annual storage capacity of approximately 69,300 ML. The impact to the environment has therefore been assessed as the reduction in the frequency of occurrence of this runoff volume and the total volume of reservoir spill (total annual runoff in excess of 69,300 ML).

In addition to the water supply reservoirs there are estimated to be 2700 farm dams located in the catchment, with an aggregated storage volume of nearly 8500 ML or approximately 15% of the total reservoir storage (Teoh 2003). Annual usage from these storages was assumed to be approximately 2500 ML (30% of total storage volume). Previous modelling (Teoh 2003) showed that around 4400 ML of runoff is intercepted and retained each year from these dams.

## 2.6. MYPONGA CATCHMENT

The Myponga Catchment is located 40 km south of Adelaide, with a total catchment area of approximately 120 km$^2$ supplying the Myponga Reservoir, which has a storage capacity of 20,000 ML. The mean annual rainfall of the catchment is approximately 830 mm.

The Myponga Reservoir primarily supplies towns in its immediate vicinity, as well as being the main source of water for the Southern Coast Water Supply Scheme. This scheme supplies water to the southern coast towns of the Fleurieu Peninsula, including Victor Harbor, Goolwa and Normanville. As such, it has not been included here as a source to meet Metropolitan Adelaide water supply demands.

The interception capacity of the reservoir system, and hence its ability to store runoff, was assumed to be equal to the size of the reservoir, that is, 26,800 ML. Extraction and hence use of water stored in the reservoir is currently limited by the 50 ML/day capacity of the treatment plant. Therefore, the interception capacity defined considers the maximum resource availability of the system and the impact to the environment, particularly the spill frequency and subsequent changes in environmental flows, relates to this maximum value.

## 2.7. URBAN CATCHMENTS

Current pressures on established conventional water sources for supply to Adelaide have led to a renewed push to consider alternatives such as the capture and use of stormwater runoff generated across urban areas. Since urban areas are also subject to the potential impact of climate change, the current and future water resource availability across urban Adelaide has also been calculated.

Modelling of urban areas has historically been carried out primarily for flood investigation as opposed to water resource assessments and as a result, limited models exist for these catchments within the Adelaide area. While DWLBC has yet to develop a regional model for the Adelaide Plains Catchments, models have been established for the Patawalonga (Teoh 2006b) and Lower Torrens (Teoh & Kotz 2007) catchments. At the time of model development, the impervious catchment areas used were 56 and 48 km$^2$ respectively and the modelling results showed an estimated annual runoff total from the combined catchments of 46,200 ML. Increasing development over time will increase these areas and the subsequent runoff produced.

Clark (2007) used similar modelling techniques to DWLBC to estimate a mean annual runoff from the urban Adelaide catchments of 113,300 ML, comprising 32,000 ML from the hills face catchments, 37,900 ML of roof runoff and 43,400 ML from paved surfaces. For the Patawalonga and Lower Torrens Catchments, the estimated annual runoff was 55,100 ML. In order to estimate total urban runoff from the Adelaide Plains Catchments, the runoff estimate from Clark (2007) was scaled by the ratio of runoff from the DWLBC Patawalonga and Lower Torrens Catchment models, producing a mean annual runoff total from urban areas of 95,000 ML.

In addition to the runoff generated within the urban catchments themselves, reservoir spills of 21,000 ML/year are estimated to flow through urban areas from the five upstream catchments. This spill currently aids in the maintenance of environments downstream of the reservoirs and will be considered separately in the urban stormwater balance.

# 3. RAINFALL PROJECTIONS UNDER CLIMATE CHANGE SCENARIOS

## *3.1. OVERVIEW OF METHODOLOGY*

The availability of water resources for communities and ecosystems relies heavily on processes such as runoff generation and groundwater recharge that are susceptible to changes in rainfall and evaporation. As a result, realistic projections of changes to rainfall at both regional and localised scales due to anthropogenic climate change has become an increasingly important component to the long-term management of water resources.

### 3.1.1. GENERAL CIRCULATION MODELS

Coupled GCMs are sophisticated computer programs that simulate the physical processes of the atmosphere and oceans. Equations for conservation of mass, momentum and energy for a large number of points are solved on a three-dimensional grid that covers the globe.

Assessments of the potential impact of climate change on rainfall have generally only involved the scaling of historical rainfall records to match the projected percentage annual changes in rainfall as provided by GCMs at coarse grid scales (often in the order of 250 $km^2$). Perkins et al. (2007) indicated that while physically based climate models such as GCMs perform reasonably well in simulating current synoptic-scale atmospheric fields, they tend to overestimate the frequency and underestimate the intensity of daily rainfall. Therefore, the models tend not to reproduce the statistics of historical records at the spatial scales required for detailed resource assessments within climate-dependent systems (Charles, Heneker & Bates 2008).

### 3.1.2. STATISTICAL DOWNSCALING

CSIRO have developed a statistical downscaling approach using a non-homogeneous hidden Markov model (NHMM) to provide a means of overcoming the aforementioned scaling limitations. This approach simulates regional- or point-scale weather as a function of large-scale atmospheric fields to reproduce observed daily, multi-site rainfall statistics (Charles et al. 2004).

The NHMM relates multi-site, daily rainfall occurrence patterns to atmospheric variables or 'predictors' modelled within the GCMs (e.g. mean sea level pressure) through a finite number of unobserved or 'hidden' weather states. With reference to the MLR, these weather states may include wet or dry conditions across the region, or concurrent wet conditions in the north and dry conditions in the south.

A first-order Markov process then defines the daily transitions from one weather state to another, with its transition probabilities conditional on the set of selected atmospheric predictors. Characteristics of these weather states are examined by constructing composite plots of their precipitation occurrence patterns and associated atmospheric predictor fields, thereby allowing the investigation of the relationships between the synoptic patterns and spatial rainfall patterns over time.

Model selection is an intensive process involving the sequential fitting of NHMMs with an increasing number of weather states and predictors to a network of rainfall stations. The calibrated NHMMs are evaluated in terms of the physical realism and distinctness of the weather states as well as statistical testing to select a parsimonious model that fits the data well (Hughes, Guttorp & Charles 1999).

After the calibration of the NHMMs for multi-site, daily rainfall occurrence patterns, models of the joint distribution of daily rainfall amounts are calibrated through the specification of conditional distributions (on a weather state basis). This approach captures the mean, variability and inter-site correlations of daily precipitation amounts (Charles, Bates & Hughes 1999).

### 3.1.3. STATISTICALLY DOWNSCALED CLIMATE CHANGE PROJECTIONS

The potential impact of climate change on future rainfall conditions is evaluated using emission scenarios. These scenarios are defined in terms of the rate of change of greenhouse gas and aerosol concentrations as determined by the IPCC. Rainfall projections under two emission scenarios, A2 and B2, were completed by CSIRO in conjunction with DWLBC. The A2 scenario is the higher end of the emissions scenarios and assumes a continued high rate of greenhouse gas emissions. The B2 scenario has a slower emissions growth as governments and industry move towards environmental and social sustainability.

NHMMs were fitted to a network of 20 rainfall stations (described below) with long-term records within the MLR catchments. Analysis was undertaken on a seasonal basis with the rainfall data divided into two, six month seasons defined as winter (May to October) and summer (November to April). The NHMM fitted to each season used six weather states and three atmospheric predictors. Atmospheric ‘reanalysis’ data is available from 1958 and hence 25 years of data were used for fitting the NHMM (1978 to 2002), and the 20 preceding years (1958 to 1977) were used for validation.

The statistical downscaling undertaken used the period 1975 to 2004 to evaluate current conditions, and 2035 to 2064 for future projections. The NHMMs were then driven using the selected atmospheric predictors extracted from the CSIRO Mk3 GCM (Gorden et al. 2002) A2 and B2 simulation runs. Multiple realisations of daily rainfall were generated, conditional on the individual GCM-derived predictor series. This produced 100 sets of 30 years of generated daily data for each scenario under both current and future conditions. When changes to rainfall under future conditions is examined, comparisons need to be made using the current conditions rainfall data generated for the given scenario as opposed to actual recorded data. It is then expected that model errors will generally cancel each other out and provide a good estimate of differences in rainfall totals and patterns due to climate change.

Downscaled simulations replicated observed inter-annual rainfall occurrence and volume variability, including the earlier validation period which experienced different rainfall statistics to the fitting period. Spell lengths, distribution of rainfall totals and inter-site correlations were also well reproduced for the validation period. Thus the selected models were considered valid for the full range of natural climate variability experienced during the 1958 to 2002 period (Charles, Bates & Fleming 2005).

The methodology; calibration of the NHMM including descriptions of the selected weather states; atmospheric predictors and associated synoptic patterns; validation of the model; and subsequent climate change projections are documented extensively in Charles, Bates and Fleming (2005) and Charles and Bates (2006).

## *3.2. SIMULATED CURRENT AND FUTURE RAINFALL DATA*

### 3.2.1. INPUT DATA

A network of 20 rainfall stations within the MLR catchments was selected based on data quality and suitability for hydrological modelling. The location of these stations is shown in Figure 2. Daily rainfall data for these stations were extracted from the Patched Point Dataset (PPD) (Jeffrey et al. 2001) for the period 1958 to 2002. The stations and the mean annual rainfall recorded over the specified period are presented in Table 2. The PPD combines observed Bureau of Meteorology (BOM) daily rainfall records with infilled and de-accumulated missing or accumulated rainfall. However, recent research has discovered that some recorded rainfall data is actually an accumulation of several days’ rainfall but is not 'tagged' as such in the BOM records (Viney & Bates 2004). Station selection also took this into account, rejecting stations with such 'untagged accumulations'.

**Table 2 Rainfall Station Network**

| Station Name | BoM Station Number | Mean Annual Rainfall (mm)[1] | % Winter Rainfall[2] |
|---|---|---|---|
| Greenock | 023305 | 530 | 69 |
| Nuriootpa | 023312 | 490 | 69 |
| Tanunda | 023318 | 520 | 70 |
| Birdwood | 023705 | 710 | 74 |
| Bridgewater | 023707 | 960 | 74 |
| Cherry Gardens | 023709 | 900 | 72 |
| Clarendon | 023710 | 790 | 72 |
| Echunga | 023713 | 760 | 72 |
| Gumeracha | 023719 | 740 | 74 |
| Hahndorf | 023720 | 820 | 73 |
| Keyneton | 023725 | 520 | 72 |
| Lobethal | 023726 | 880 | 75 |
| Meadows | 023730 | 830 | 72 |
| Cudlee Creek | 023731 | 850 | 74 |
| Morphett Vale | 023732 | 560 | 72 |
| Mount Pleasant | 023737 | 640 | 72 |
| Old Noarlunga | 023740 | 520 | 71 |
| Uraidla | 023750 | 1050 | 73 |
| Williamstown | 023752 | 670 | 73 |
| Woodside | 023829 | 760 | 74 |

[1] Calculated over period from 1958 to 2002

[2] Winter is defined here as May to October

**Figure 2 Rainfall Station Network**

### 3.2.2. EVALUATION OF FITTING AND DOWNSCALING CURRENT CONDITIONS

The statistical downscaling of current conditions was undertaken for the period from 1975 to 2004. As discussed in Section 3.1.3, when changes to runoff and hence water availability under potential future conditions is examined, comparisons will be made using the current conditions rainfall data generated for the given scenario (A2 or B2) as opposed to actual recorded data. However, a good replication of observed data is also required. Table 3 shows the mean annual rainfall from the observed PPD data used to fit the NHMM, the downscaled reanalysis data and the downscaled current conditions (A2 and B2 simulation runs).

**Table 3 Observed and Downscaled Rainfall under Current Conditions**

| Station Name | BoM Station Number | Mean Annual Rainfall (mm) (% Difference with [1]Observed, [2]Reanalysis) | | | |
|---|---|---|---|---|---|
| | | Observed | Reanalysis[1] | Current Conditions A2[2] | Current Conditions B2[2] |
| Greenock | 023305 | 516 | 521 (1) | 548 (6) | 554 (7) |
| Nuriootpa | 023312 | 492 | 498 (1) | 525 (6) | 529 (8) |
| Tanunda | 023318 | 527 | 529 (0) | 557 (5) | 564 (7) |
| Birdwood | 023705 | 686 | 694 (1) | 725 (5) | 732 (7) |
| Bridgewater | 023707 | 1012 | 1032 (2) | 1074 (6) | 1080 (7) |
| Cherry Gardens | 023709 | 900 | 917 (2) | 956 (6) | 959 (7) |
| Clarendon | 023710 | 791 | 783 (1) | 818 (3) | 822 (4) |
| Echunga | 023713 | 774 | 773 (0) | 800 (3) | 808 (4) |
| Gumeracha | 023719 | 766 | 750 (2) | 783 (2) | 792 (3) |
| Hahndorf | 023720 | 765 | 793 (4) | 826 (7) | 833 (9) |
| Keyneton | 023725 | 509 | 513 (1) | 537 (5) | 543 (7) |
| Lobethal | 023726 | 842 | 863 (2) | 897 (6) | 905 (7) |
| Meadows | 023730 | 830 | 837 (1) | 868 (4) | 876 (6) |
| Cudlee Creek | 023731 | 841 | 841 (0) | 881 (5) | 887 (5) |
| Morphett Vale | 023732 | 552 | 551 (0) | 576 (4) | 580 (5) |
| Mount Pleasant | 023737 | 621 | 614 (1) | 638 (3) | 651 (5) |
| Old Noarlunga | 023740 | 519 | 506 (3) | 529 (2) | 533 (3) |
| Uraidla | 023750 | 1048 | 1072 (2) | 1113 (6) | 1120 (7) |
| Williamstown | 023752 | 649 | 685 (2) | 716 (9) | 723 (11) |
| Woodside | 023829 | 707 | 713 (1) | 745 (5) | 750 (6) |

Note: A mean annual rainfall difference of 0% between the observed PPD data and the downscaled data does not necessarily imply that the values are equal but that the difference is less than 0.5% and hence negligible

Differences between the mean annual rainfall from the observed and reanalysis data generally result from errors in the downscaling model. Although there is a higher proportion of observed data that is over-estimated in the reanalysis data, the results show that the downscaling model produces a good replication at each station. Differences between the results from the reanalysis and the downscaled A2 and B2 simulation data results from bias added by an inability by the GCM to correctly reproduce atmospheric predictors used in the downscaling. The results presented are considered reasonable but are tested further in Section 4.2 in terms of runoff generation.

### 3.2.3. RAINFALL STATION SUBSTITUTIONS FOR HYDROLOGICAL MODELLING

Selection of the NHMM rainfall station network was based on both quality and hydrological catchment modelling suitability criteria. As a result, not all rainfall stations that had been used to calibrate available DWLBC hydrological models form part of the NHMM network. To quantify the potential changes to rainfall at a catchment scale and then assess the impact on inflows into the reservoir systems, some substitution of the closest network station to those used in the hydrological models was required. Where necessary, an adjustment factor was applied to the rainfall data to ensure that the spatially averaged rainfall totals derived from isohyets were consistent with the station average.

The rainfall station substitutions are discussed below. The ability of the substituted rainfall data to reproduce reasonable results was tested by generating runoff using observed data and the current conditions downscaled data. The results are shown in Section 4.2 and overall the substitution was found to be acceptable.

#### 3.2.3.1. South Para Catchment

The South Para Catchment model used six rainfall stations as shown in Table 4. However, only one of these stations was selected in the NHMM network, which was used as a substitute for five of the model stations. The sixth station, used for a small area of the upper catchment, was substituted for a network station located in the Upper Torrens Catchment.

**Table 4 Rainfall Stations in the South Para Catchment**

| Catchment Model Station | BoM Station Number | Substituted NNHM Network Station | Adjustment Factor |
|---|---|---|---|
| Williamstown (Mount Crawford Forest) | 023763 | Williamstown PO | 1.109 |
| Glen Gillian | 023756 | Williamstown PO | 1.035 |
| Kersbrook | 023758 | Gumeracha | 0.980 |
| South Para Reservoir | 023820 | Williamstown PO | 0.990 |
| Para Wirra | 023836 | Williamstown PO | 0.970 |
| Williamstown PO | 023752 | – | – |

#### 3.2.3.2. Little Para Catchment

There are no long-term rainfall stations located in the Little Para Catchment, and during the development of the catchment model the best option was to combine data from three sequential station records at Golden Grove (Williams 2007). The rainfall station at Golden Grove, near the Little Para Reservoir, has been relocated twice but each time has remained close to its original location. Hence the final Golden Grove rainfall record used consists of data from the three stations shown in Table 5 and provides a period of record from 1906 to present.

**Table 5 Rainfall Stations in the Little Para Catchment**

| Catchment Model Station | BoM Station Number | Substituted NNHM Network Station | Adjustment Factor |
|---|---|---|---|
| Golden Grove | 023091<br>023717<br>023802 | Cudlee Creek | 1.0 |

No stations in the NHMM network are located within the Little Para Catchment, with the closest station being at Cudlee Creek in the Upper River Torrens Catchment. While this station is some distance from Golden Grove, it is in close proximity to the upper reaches of the Little Para Catchment and therefore suitable for substitution. Rainfall in the upper reaches is significantly higher than near the Little Para Reservoir and when the catchment model was developed, rainfall factors were used to increase the rainfall input from the lower to the upper reaches. A large adjustment factor was therefore applied to rainfall factors within the model before these factors were applied to the substituted data. This essentially scaled the higher rainfall data from the upper to the lower reaches of the catchment.

#### 3.2.3.3. Upper Torrens Catchment

The Upper Torrens Catchment model used six rainfall stations as shown in Table 6, five of which were selected in the NHMM network. As such, only one station substitution was required.

**Table 6 Rainfall Stations in the Upper Torrens Catchment**

| Catchment Model Station | BoM Station Number | Substituted NNHM Network Station | Adjustment Factor |
|---|---|---|---|
| Birdwood | 023705 | - | - |
| Gumeracha | 023719 | - | - |
| Cudlee Creek | 023731 | - | - |
| Mount Pleasant | 023737 | - | - |
| Uraidla | 023750 | - | - |
| Ashton Co-op | 023803 | Uraidla | 1.04 |

#### 3.2.3.4. Onkaparinga Catchment

All rainfall stations used in the Onkaparinga Catchment model were within the selected NHMM network. A summary of the stations used in the model is presented in Table 7.

**Table 7 Rainfall Stations in the Onkaparinga Catchment**

| Catchment Model Station | BoM Station Number |
|---|---|
| Uraidla | 023750 |
| Morphett Vale | 023732 |
| Clarendon | 023710 |
| Echunga | 023713 |
| Lobethal | 023726 |
| Woodside | 023829 |
| Hahndorf | 023720 |
| Bridgewater | 023707 |
| Cherry Gardens | 023709 |

#### 3.2.3.5. Myponga Catchment

The Myponga Catchment model used one rainfall station as shown in Table 8, which was not part of the selected NHMM network. The closest station available for substitution was Clarendon and while this is some distance away, mean annual rainfalls were similar.

Unlike the models for the catchments above, the Myponga Catchment model was under development. A preliminary calibration was therefore required for this investigation. Data from the PPD were used and the calibration process identified significant problems with this data. The calibration period from 1974 to 2005 contained six years where data were missing from the BOM data sets and had been infilled in the PPD. The infilled rainfall did not appear to be reasonable, which led to significant difficulties obtaining an accurate calibration. An assessment of the PPD is required in this area.

**Table 8 Rainfall Stations in the Myponga Catchment**

| Catchment Model Station | BoM Station Number | Substituted NNHM Network Station | Adjustment Factor |
|---|---|---|---|
| Myponga | 023738 | Clarendon | 1.04 |

Data missing from the Myponga record was then infilled separately using short-term nearby stations. The calibration then produced more suitable results, although it is recognised that this model needs further work.

### 3.2.3.6. Urban catchments

The NHMM network contained no stations located on the Adelaide Plains. While the closest stations to the Patawalonga and Lower Torrens Catchments are located in the Adelaide Hills, these were not considered because it was recognised that rainfall at higher elevations would not be representative of the rainfall at the lower elevations on the Adelaide Plains. Of the rainfall stations in the NHMM network, four (Nuriootpa, Tanunda, Morphett Vale and Old Noarlunga) are located at lower elevations or on the plains. However, all stations are a significant distance from the catchments to be modelled.

Comparison of two of these stations, Morphett Vale to the south and Tanunda to the north, indicated that the statistics of the generated data were similar. As such, the rainfall recorded at the Morphett Vale station was selected to be representative of the Adelaide Plains. The annual rainfall at Morphett Vale (560 mm) was then used to adjust the rainfall multiplying factors within the Patawalonga and Lower Torrens Catchment models, ensuring that local rainfall totals were accurate.

Rainfall stations in the NHMM network were available at higher elevations within these catchments. The Cherry Gardens station was used for Patawalonga Catchment and the Uraidla station for Lower Torrens Catchment.

## 3.2.4. RESULTS FOR SCENARIO A2

The A2 emissions scenario assumes a continued high rate of greenhouse gas emissions, resulting from focuses on regional economic development rather than technological change and global environmental concerns. The results of downscaling from the CSIRO Mk3 GCM A2 simulation run for the period 2035 to 2064 (Charles & Bates 2006) showed that:

- the projected winter weather state mean trends indicate an increase in the drier patterns and a decrease in the wetter patterns.
- there are only slight changes in the station daily rainfall distributions between the current and projected future downscaled simulations.
- projected monthly totals are consistently reduced.

In comparison to the B2 scenario, there were also indications that the A2 scenario produces a greater reduction in very wet winters.

The increasing drier climate patterns and decreasing wetter patterns during winter are shown by the reductions in the mean and median annual rainfall for each catchment presented in Tables 9 and 10 respectively. Overall, a 13% reduction in rainfall totals within the water supply catchments was identified, with similar reductions seen in the hills and plains catchments. The distribution of the variation of monthly rainfall for each catchment is shown in Figures 3 to 7 and the changes in monthly rainfall totals in Figures 8 to 12.

**Table 9 Reductions in Mean Annual Catchment Rainfall Under Scenario A2**

| Catchment | Mean Annual Rainfall (mm) | | % Reduction in Rainfall |
|---|---|---|---|
| | Current Climate Conditions | A2 Climate Change Conditions | |
| South Para | 771 | 669 | 13.2 |
| Little Para | 670 | 581 | 13.3 |
| Upper Torrens | 760 | 659 | 13.3 |
| Onkaparinga | 892 | 774 | 13.3 |
| Myponga | 831 | 719 | 13.5 |
| Patawalonga | 715 | 621 | 13.2 |
| Lower Torrens | 522 | 455 | 12.9 |

**Table 10 Reductions in Median Annual Catchment Rainfall Under Scenario A2**

| Catchment | Median Annual Rainfall (mm) | | % Reduction in Rainfall |
|---|---|---|---|
| | Current Climate Conditions | A2 Climate Change Conditions | |
| South Para | 766 | 667 | 12.8 |
| Little Para | 662 | 577 | 12.8 |
| Upper Torrens | 755 | 659 | 12.7 |
| Onkaparinga | 886 | 773 | 12.7 |
| Myponga | 827 | 716 | 13.4 |
| Patawalonga | 711 | 621 | 12.7 |
| Lower Torrens | 517 | 454 | 12.3 |

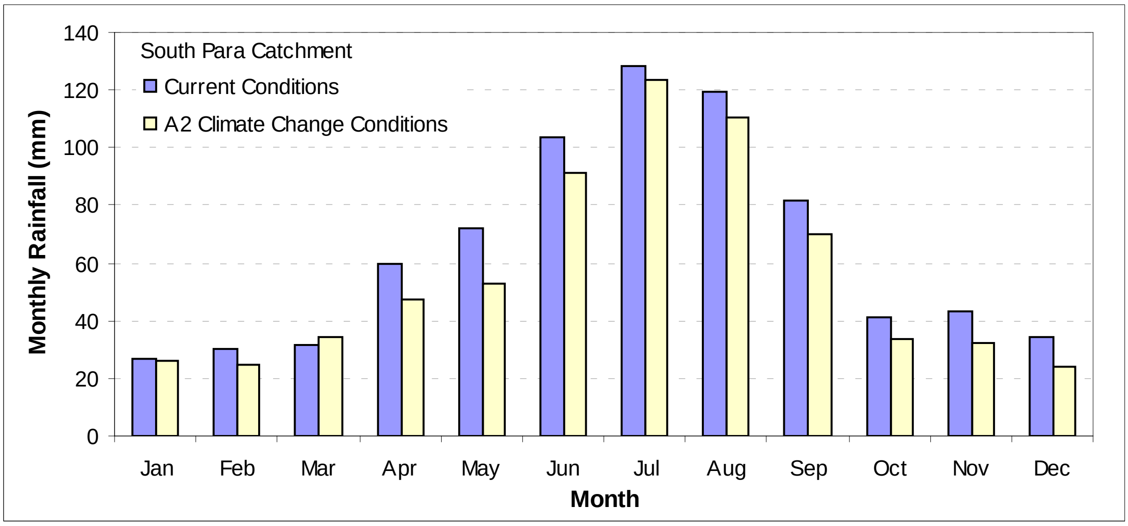

Figure 3 South Para Catchment: Mean Monthly Rainfall (Current Conditions and Scenario A2)

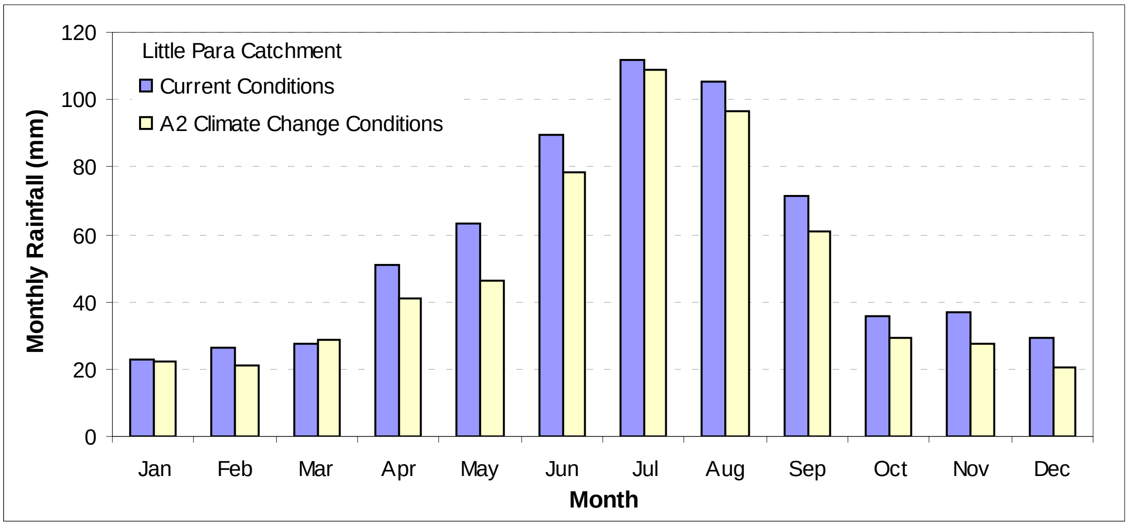

Figure 4 Little Para Catchment: Mean Monthly Rainfall (Current Conditions and Scenario A2)

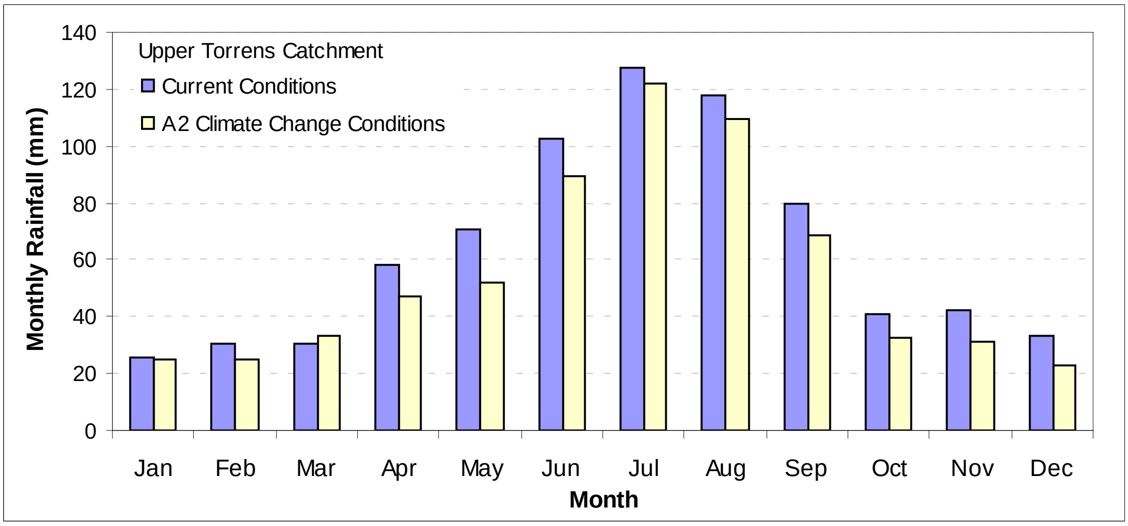

Figure 5 Upper Torrens Catchment: Mean Monthly Rainfall (Current Conditions and Scenario A2)

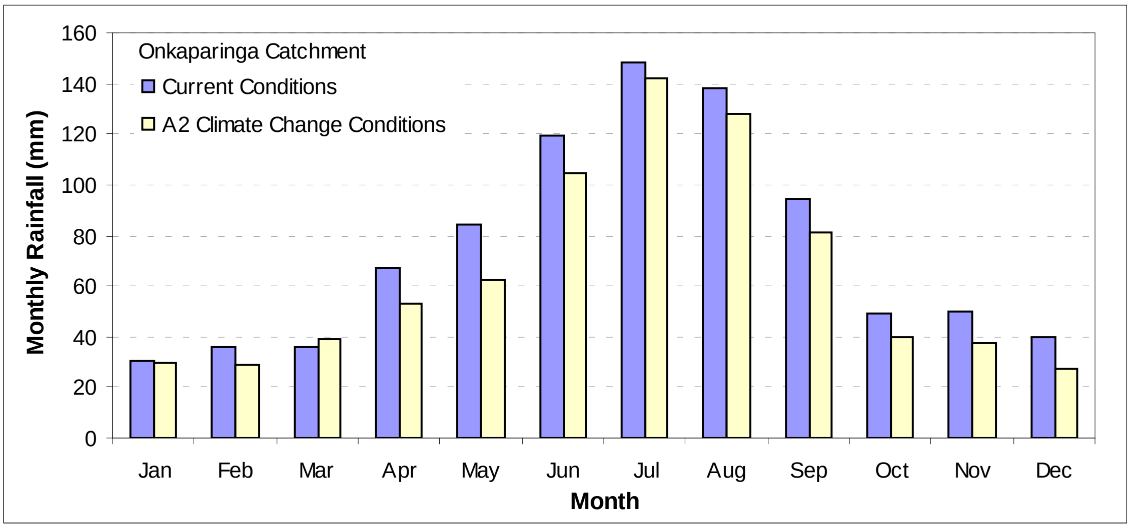

Figure 6 Onkaparinga Catchment: Mean Monthly Rainfall (Current Conditions and Scenario A2)

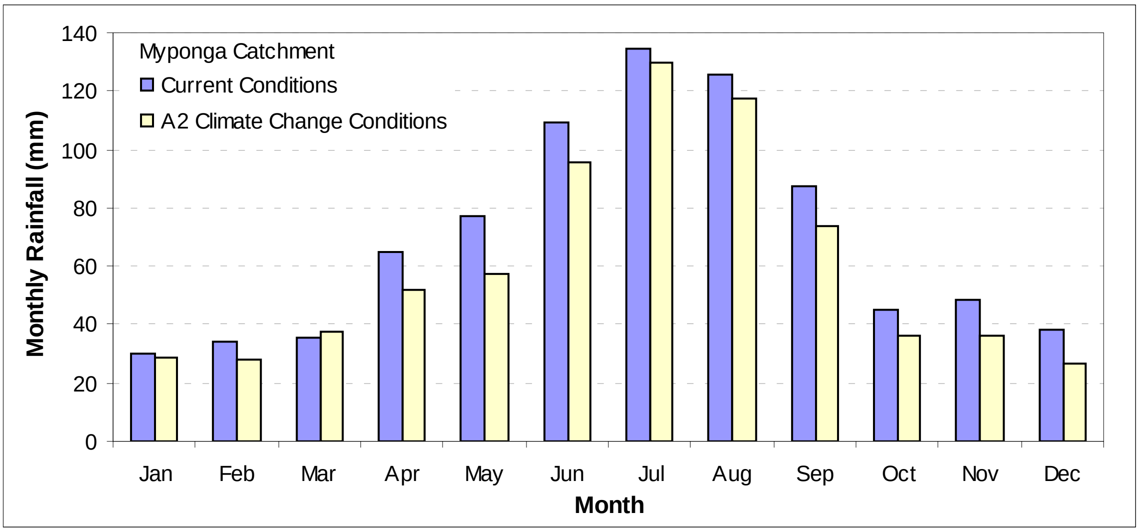

Figure 7 Myponga Catchment: Mean Monthly Rainfall (Current Conditions and Scenario A2)

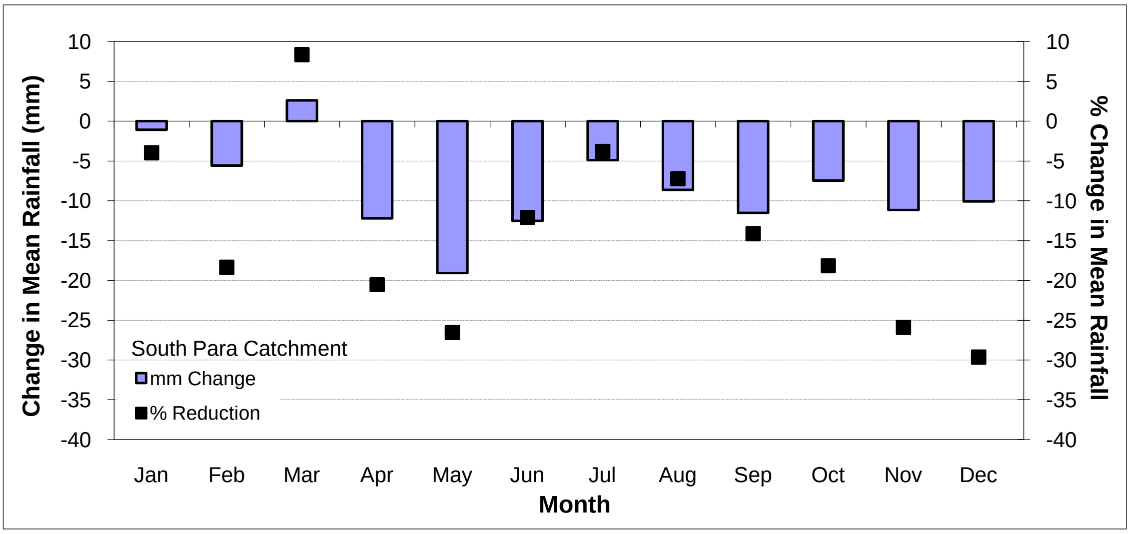

Figure 8 South Para Catchment: Mean Monthly Rainfall Changes Under Scenario A2

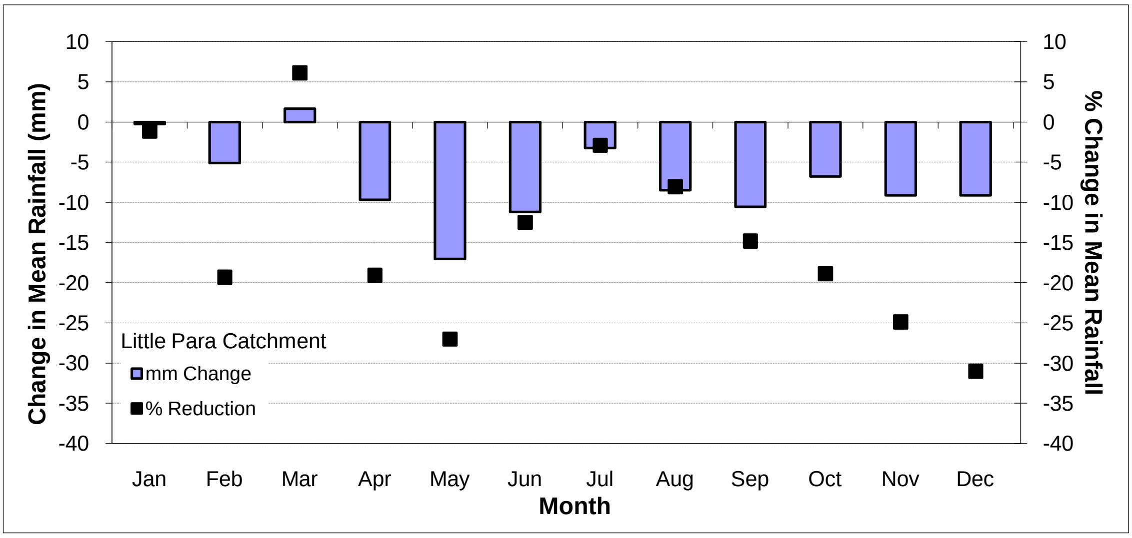

Figure 9 Little Para Catchment: Mean Monthly Rainfall Changes Under Scenario A2

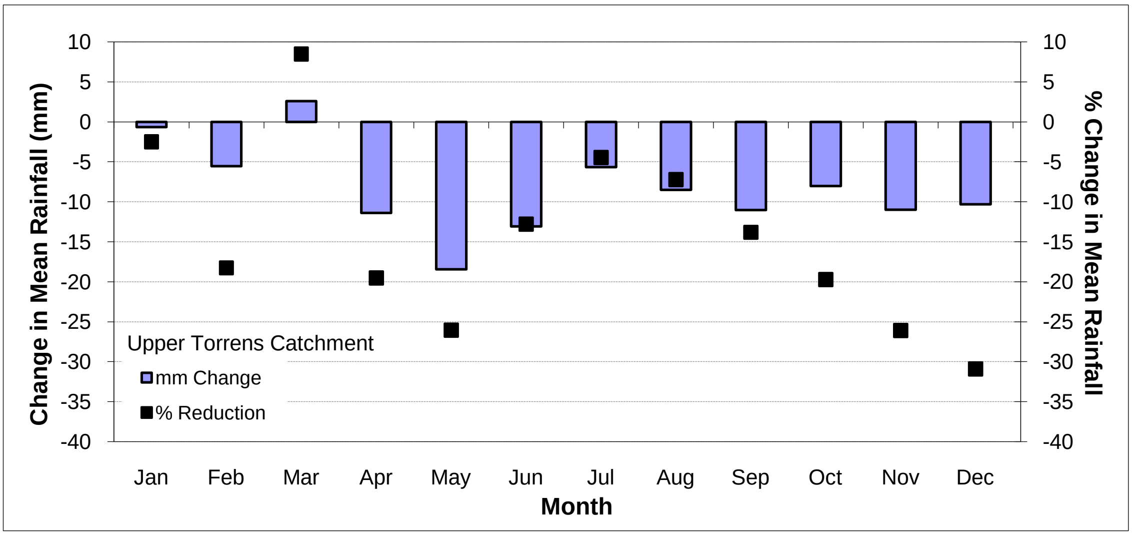

Figure 10 Upper Torrens Catchment: Mean Monthly Rainfall Changes Under Scenario A2

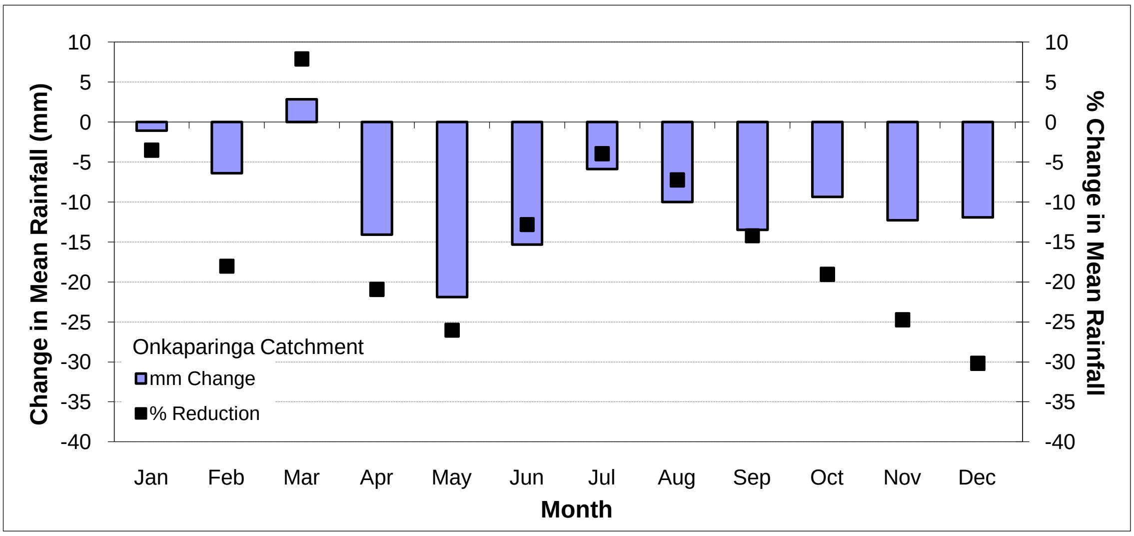

Figure 11 Onkaparinga Catchment: Mean Monthly Rainfall Changes Under Scenario A2

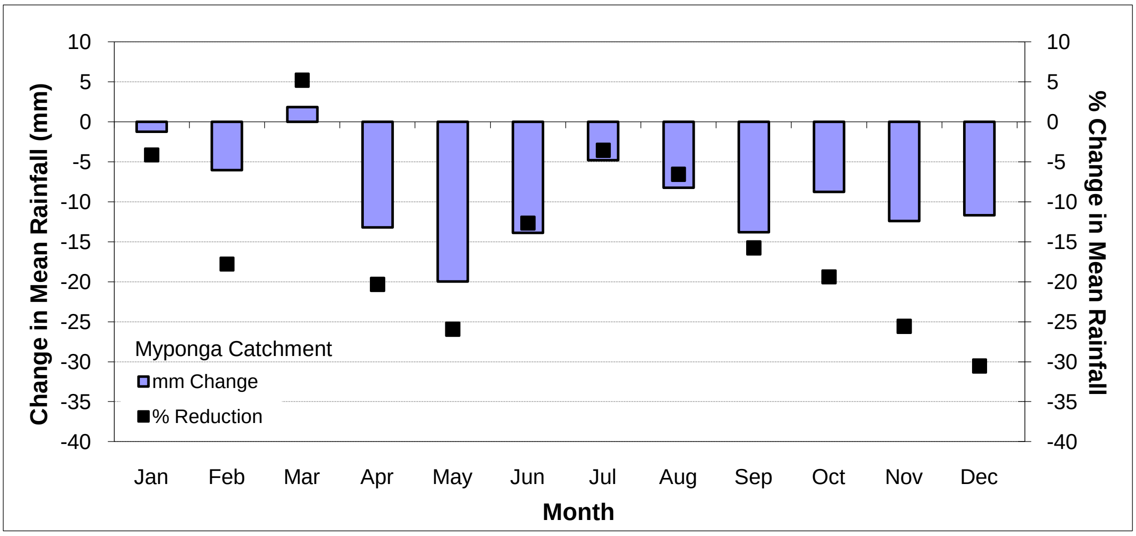

Figure 12 Myponga Catchment: Mean Monthly Rainfall Changes Under Scenario A2

Under the A2 climate change scenario, there was only an increase in monthly rainfall totals during March, although little change in rainfall totals was generally found between January and March. The greatest impact on monthly rainfall totals that is likely to be translated to runoff generation appears to be during the autumn and early winter period from April to June. Rainfall was reduced by as much as 25% over this period. Similar reductions towards the end of the 1900s have been identified previously in other catchment studies, in particular, the Barossa Valley (E&WS 1991), Marne River Catchment (Savadamuthu 2002), Onkaparinga Catchment (Teoh 2003), Finniss River Catchment (Savadamuthu 2003) and Upper Torrens Catchment (Heneker 2003).

Reductions in, or the delay of, early winter rainfall has been found to be responsible for significant reductions in streamflow during previous studies such as those above. However, the results presented here do not show such a delay in rainfall occurrence. The monthly distribution of rainfall is not observed to change significantly but is instead showing a sizeable reduction in rainfall across all winter months through to spring. Rainfall during these months is critical to ensure good surface runoff generation and recharge to groundwater.

### 3.2.5. RESULTS FOR SCENARIO B2

The B2 scenario is based on slower emissions growth as governments and industry move to reduce emissions and employ environmentally and socially sustainable development approaches. The results of downscaling from the CSIRO Mk3 GCM B2 simulation run (Charles & Bates 2006) found that the A2 and B2 scenarios produced very similar trends with similar, consistently reduced monthly rainfall totals. The results also supported the observations that under the A2 scenario there is a greater reduction in very wet winters than under the B2 scenario.

The reductions in the mean and median annual rainfall for each reservoir catchment is presented in Tables 11 and 12 respectively. The distribution of the variation of monthly rainfall totals for each catchment is similar to those in the A2 scenario and as such has not been presented here.

**Table 11 Reductions in Mean Annual Catchment Rainfall Under Scenario B2**

| Catchment | Mean Annual Rainfall (mm) | | % Reduction in Rainfall |
|---|---|---|---|
| | Current Climate Conditions | B2 Climate Change Conditions | |
| South Para | 779 | 681 | 12.7 |
| Little Para | 675 | 590 | 12.6 |
| Upper Torrens | 768 | 672 | 12.5 |
| Onkaparinga | 898 | 788 | 12.3 |
| Myponga | 835 | 732 | 12.2 |

**Table 12 Reductions in Median Annual Catchment Rainfall Under Scenario B2**

| Catchment | Median Annual Rainfall (mm) | | % Reduction in Rainfall |
|---|---|---|---|
| | Current Climate Conditions | B2 Climate Change Conditions | |
| South Para | 778 | 667 | 14.2 |
| Little Para | 675 | 582 | 13.8 |
| Upper Torrens | 768 | 660 | 14.1 |
| Onkaparinga | 900 | 778 | 13.6 |
| Myponga | 831 | 725 | 12.8 |

# 4. WATER RESOURCE PROJECTIONS UNDER CLIMATE CHANGE SCENARIOS

## *4.1. OVERVIEW*

To assess the potential impact of climate change on water supply for Adelaide, the generated current and projected rainfall data were incorporated into existing DWLBC hydrological models of the MLR catchments. The following analysis was then undertaken.

1. Verification of the downscaled rainfall under current conditions was undertaken by comparing the modelled runoff using both observed and downscaled data.
2. The runoff or *total resource* generated from each reservoir and urban catchment was modelled under current conditions and each of the A2 and B2 climate change scenarios, both with and without a 5% increase in evaporation. This represents the total change in water resources generated in each catchment.
3. The ability of each reservoir system to capture and supply the water resources generated in each catchment under each of the A2 and B2 climate change scenarios, assuming each reservoir remains at its current capacity. The volumes generated define the *divertible resource* within each catchment.
4. Assessment of the impact on environmental flows downstream of each reservoir system.

As described in Section 2, an annual maximum interception capacity was allocated to each reservoir. It was calculated as 90% of its capacity in addition to the estimated winter volume diverted to supply. Any inflows from the catchment in excess of this combined volume was assumed to spill from the system. Farm dam development has been assumed at the levels presented in Section 2 for both current and future conditions.

Section 3.2 described the network of 20 rainfall stations within the MLR catchments to which a NHMM was fitted to both the winter and summer seasons. The data generated during the downscaling process produced 100 sets of 30 years of generated daily data for each scenario under both current and future (A2 and B2) conditions. However, the period generated was from May to April and as such only 100 sets of 29 calendar years of data produced for each scenario were used for modelling.

## *4.2. VERIFICATION OF DOWNSCALED RAINFALL UNDER CURRENT CONDITIONS*

The statistical downscaling of current conditions was undertaken for the period from 1975 to 2004. As discussed in Section 3.1.3, when changes to runoff and hence water availability under potential future conditions is examined, comparisons will be made using the current conditions rainfall data generated for the given scenario (A2 or B2) as opposed to actual recorded data. Therefore, to provide a secondary verification of the generated current conditions data, as well as the station substitutions undertaken in Section 0, a comparison was made of the runoff modelled using both observed and generated rainfall data. Table 13 presents the mean annual runoff and Table 14 the three-year minimum annual runoff for each scenario. The results show that, as expected, the modelled mean annual runoff is generally similar for each data set. Some of the difference in modelled runoff could be attributed to the differences between the observed and downscaled rainfall.

**Table 13 Mean Annual Runoff: Observed and Modelled Rainfall Data**

| Catchment | Mean Annual Runoff (GL) | | |
|---|---|---|---|
| | Observed Data | Modelled A2 Data | Modelled B2 Data |
| South Para | 30.2 | 30.6 | 30.9 |
| Little Para | 7.3 | 7.5 | 7.4 |
| Upper Torrens | 45.9 | 43.2 | 42.6 |
| Onkaparinga | 68.2 | 66.1 | 66.4 |
| Myponga | 11.3 | 13.7 | 13.6 |

**Table 14 Three-Year Minimum Annual Runoff: Observed and Generated Rainfall Data**

| Catchment | Three-Year Minimum Annual Runoff (GL) | | |
|---|---|---|---|
| | Observed Data | Modelled A2 Data | Modelled B2 Data |
| South Para | 11.5 | 8.1 | 9.3 |
| Little Para | 1.6 | 1.9 | 2.4 |
| Upper Torrens | 16.8 | 15.7 | 17.2 |
| Onkaparinga | 30.0 | 29.8 | 32.2 |
| Myponga | 2.7 | 3.0 | 3.5 |

## *4.3. POTENTIAL REDUCTION IN WATER RESOURCE AVAILABILITY UNDER SCENARIO A2*

### 4.3.1. OVERVIEW OF RESULTS

This section provides an overview of the results from the assessment of both the total and divertible resource undertaken in each of the five rural catchments and two urban catchments due to climate change under the A2 emission scenario. Current evaporation rates were considered first, with a 5% increase in evaporation then used to test the sensitivity of this parameter.

In rural catchments, the non-linearity of the transformation from rainfall to runoff means that significant reductions in runoff may occur for small reductions in rainfall, particularly in the lower rainfall areas. In urban catchments this non-linearity is not as strongly pronounced and therefore percentage runoff reductions may more closely resemble the percentage reduction in rainfall. This is reflected in the results below.

#### 4.3.1.1. Total resource

The total resource produced by each rural catchment has been defined as the total flow volume generated to the lowest diversion point for water supply within the catchment, in particular:

- Upper Torrens: Gorge Weir
- Onkaparinga: Clarendon Weir
- South Para, Little Para, Myponga: most downstream reservoir.

For the urban catchments of the Adelaide Plains, the total resource was defined as the volume of water flowing to sea.

Table 15 shows the reduction in the total resource generated within each of the catchments. For the rural catchments, the potential reduction under the A2 climate change conditions range from 27 to 32%. In urban catchments, the reduction is around 20%.

**Table 15 Reduction in Mean Annual Resource Under Scenario A2 (with Current Evaporation)**

| Catchment | Mean Annual Resource (GL) | | % Reduction in Resource |
|---|---|---|---|
| | Current Climate Conditions | A2 Climate Change Conditions | |
| South Para | 30.6 | 20.8 | 31.9 |
| Little Para | 7.5 | 5.5 | 26.7 |
| Upper Torrens | 43.1 | 30.9 | 28.4 |
| Onkaparinga | 66.1 | 45.4 | 31.3 |
| Myponga | 13.7 | 9.4 | 31.3 |
| Patawalonga | 22.5 | 18.1 | 19.4 |
| Lower Torrens | 23.7 | 19.0 | 19.6 |
| Remaining Urban# | 49.0 | 39.4 | 19.6* |

\# Based on 1.06 x (Patawalonga + Lower Torrens)

* 19.6% reduction assumed (based on Lower Torrens reduction)

#### 4.3.1.2. Divertible resource

The divertible resource was defined as the volume of the total resource that can be captured by the water supply system and provides an initial estimate of the impact that climate change scenarios may have on water resources available to metropolitan Adelaide. The interception capacity within each catchment was defined in Section 2 and results are shown in Table 16.

**Table 16 Reduction in Mean Annual Divertible Resource Under Scenario A2 (with Current Evaporation)**

| Catchment (rural only) | Mean Annual Divertible Resource (GL) | | % Reduction in Divertible Resource |
|---|---|---|---|
| | Current Climate Conditions | A2 Climate Change Conditions | |
| South Para | 29.9 | 20.7 | 30.8 |
| Little Para | 7.5 | 5.5 | 26.3 |
| Upper Torrens | 35.7 | 27.9 | 21.7 |
| Onkaparinga | 57.7 | 42.6 | 26.1 |
| Myponga | 13.1 | 9.3 | 29.4 |

For both the total and divertible resources, the magnitude of the reductions generally increased as the annual rainfall decreased. Based on this trend, the effect of low rainfall or drought years, and particularly sequences of these years, is likely to lead to more severe reductions in water resources available than the percentage reduction of the mean total and divertible resources suggests.

#### 4.3.1.3. Evaporation increase

Changes in evaporation rates were not modelled as part of the downscaling process. It is generally accepted that there will be an increase in evaporation based on temperature increases forecast by the GCMs. However, variations in evaporation are likely to be extremely complex and depend on how the weather patterns passing across South Australia are altered under future climate scenarios.

The application of a 5% increase in evaporation produced a reduction in the total resource produced within each catchment of approximately 3 to 4% as shown in Table 17 (comparison with Table 15). The cause of this is likely due to the majority of runoff within the MLR occurring during winter months when evaporation is low. However, if future weather patterns lead to significant winter temperature increases, potentially caused by longer periods of northerly air flows and therefore resulting in evaporation increases, the impact of evaporation on water resource availability may increase significantly.

**Table 17 Reduction in Mean Annual Resource Under Scenario A2 (with 5% Evaporation Increase)**

| Catchment | Mean Annual Resource (GL) | | % Reduction in Resource |
|---|---|---|---|
| | Current Climate Conditions | A2 Climate Change Conditions + 5% Evaporation | |
| South Para | 30.6 | 19.7 | 35.5 |
| Little Para | 7.5 | 5.2 | 30.7 |
| Upper Torrens | 43.1 | 29.6 | 31.4 |
| Onkaparinga | 66.1 | 43.4 | 34.4 |
| Myponga | 13.7 | 8.8 | 35.5 |

The following sections provide detailed analysis of the potential changes in water resource availability in each catchment. Since the impact of increased evaporation shown above is relatively low and limited modelling currently exists to accurately define the potential changes, current evaporation conditions were assumed for all subsequent modelling. Hence, all results provided below only assume changes in rainfall.

### 4.3.2. SOUTH PARA CATCHMENT

The mean annual total resource availability in the South Para Catchment reduced from 30.6 to 20.8 GL under A2 climate change conditions, representing a reduction of almost 32%.

The South Para Reservoir is large with respect to its contributing catchment area and hence the total resource generated. As a result, the reservoir spills infrequently (approximately one in every seven years) and the divertible resource closely matches the total resource. Reservoir spills provide very little water for the maintenance of downstream environments. The mean annual divertible resource under current conditions is estimated to be 29.9 GL. This reduces by 31% to 20.7 GL under A2 climate change conditions.

Figures 13 and 14 show the frequency curves for the total resource and divertible resource respectively. The maximum divertible resource shown in Figure 14 plateaus at 55 GL as defined by the interception capacity of the system and hence its ability to store and divert runoff (refer Section 2.2).

Figure 14 shows that under current conditions, spills from the South Para Reservoir occur less than one in ten years. The difference between this modelled estimate and the recorded spill frequency of one in seven years is likely due to the actual management of the South Para Reservoir system. It is expected that greater volumes of water are retained over the winter period than has been assumed. This would lead to increased spills, which may be in part due to the use of the Warren Reservoir as part of the BIL scheme and because limited flows are able to be provided to the South Para Reservoir system via the River Murray pipelines. Under A2 climate change conditions this frequency of spill was significantly reduced.

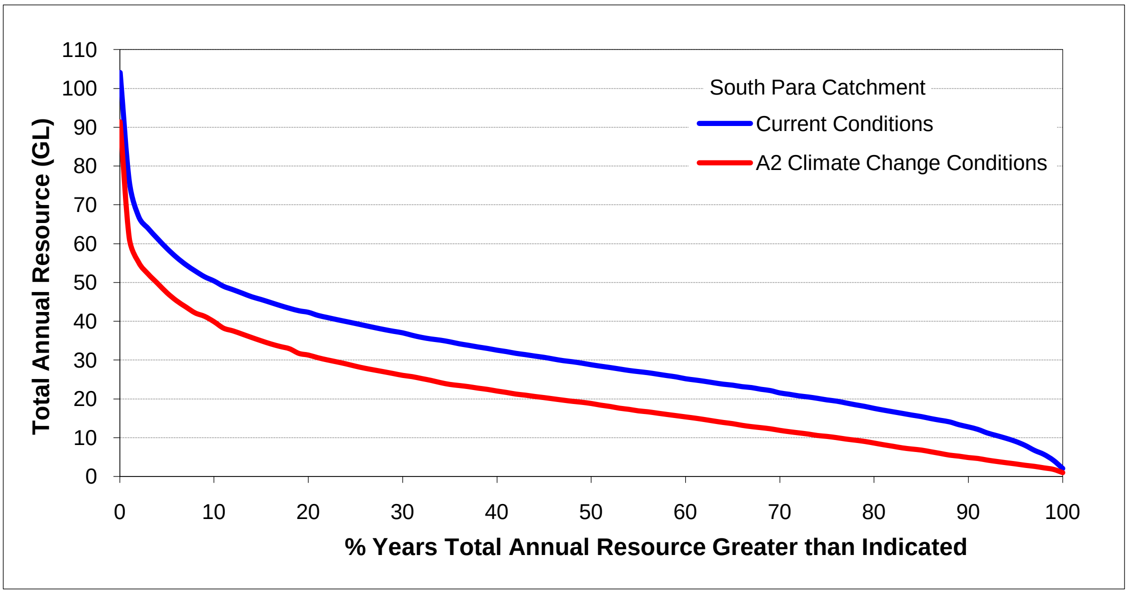

**Figure 13** South Para Catchment: Total Annual Resource Frequency Curve Change (Scenario A2)

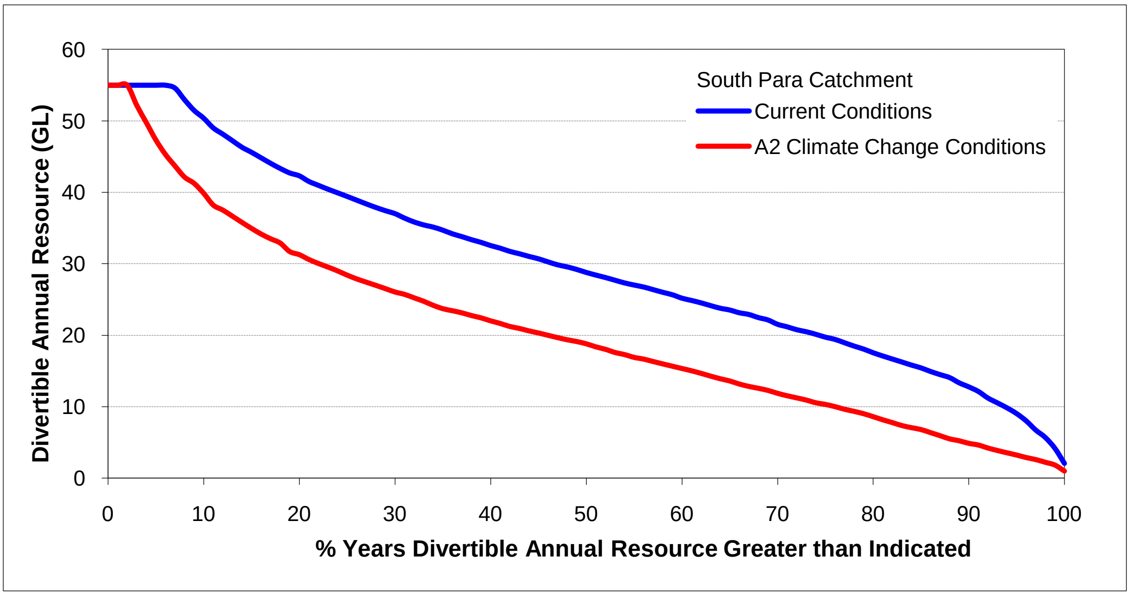

**Figure 14** South Para Catchment: Divertible Annual Resource Frequency Curve Change (Scenario A2)

Table 18 shows the change in the exceedance frequencies of the total annual resource volumes shown in Figure 13. The flow percentiles indicate the percentage of years during which the associated total resource volume is exceeded, for example, under current conditions the total annual resource was greater than or equal to 50.4 GL in 10% of all years. Under the A2 climate change conditions this reduces by 21% to around 40 GL. As the flow percentiles increase, the percentage reduction increases, for example, a total annual resource of at least 12.8 GL was generated in 90% of all years under current conditions is reduced by almost 62% under A2 climate change conditions. The 50th percentile or median total annual resource potentially reduces by 35% from 28.8 to 18.8 GL.

**Table 18 South Para Catchment: Total Resource Volume Frequency Change (Scenario A2)**

| Flow Percentile | Total Resource (GL) | | % Reduction |
|---|---|---|---|
| | Current Climate Conditions | A2 Climate Change Conditions | |
| 10th | 50.4 | 39.9 | 20.9 |
| 25th | 39.4 | 28.4 | 27.9 |
| 50th | 28.8 | 18.8 | 34.7 |
| 75th | 19.8 | 10.3 | 47.6 |
| 90th | 12.8 | 4.9 | 61.7 |

Figure 15 shows the potential changes to the mean monthly total resource volumes under A2 climate change conditions. Total resources generated during the peak inflow months of July to September are reduced by around 30%. Over the remainder of the year, the majority of mean total monthly resource volumes are reduced by at least 40%, and in some months as much as 55%.

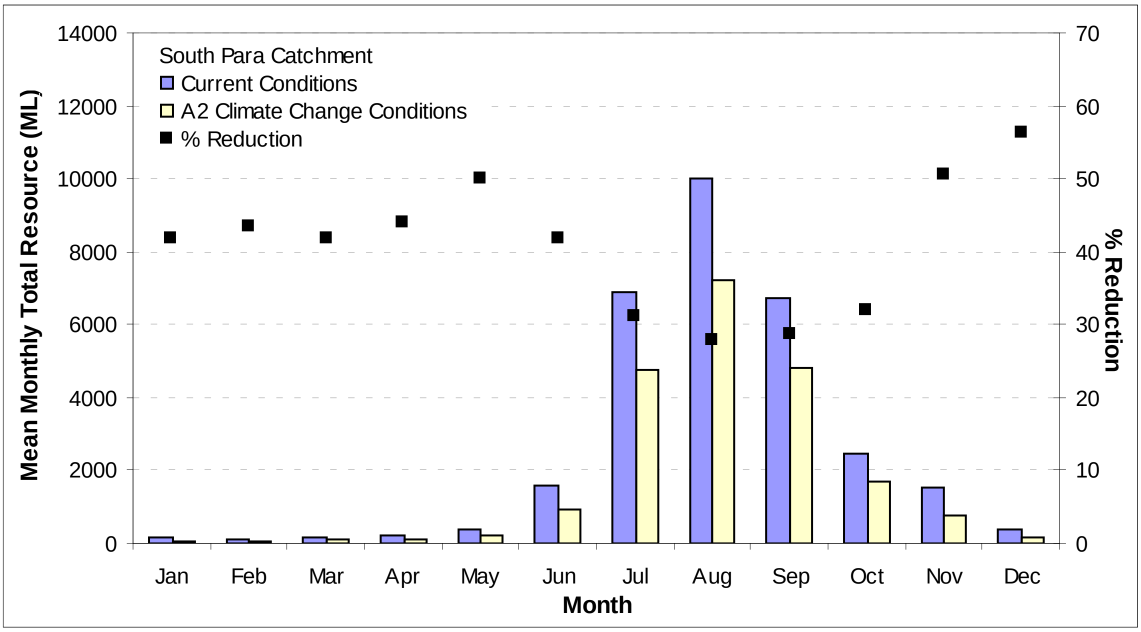

**Figure 15 South Para Catchment: Mean Monthly Total Resource Change (Scenario A2)**

### 4.3.3. LITTLE PARA CATCHMENT

The mean annual total resource availability in the Little Para Catchment reduced from 7.5 to 5.5 GL under A2 climate change conditions. This represents a reduction of 27%.

As with the South Para Reservoir, the Little Para Reservoir is also large with respect to its contributing catchment area and hence the total resource generated. Since its construction in 1978, it has only spilled twice and as such the divertible resource closely matches the total resource. The mean annual divertible resource under current conditions is estimated to be 6.5 GL. This reduces by 28% to 4.7 GL under A2 climate change conditions.

When the Little Para Reservoir was constructed it was recognised that flows downstream were an important component of recharge for aquifers immediately adjacent the Little Para River through the Northern Adelaide Plains. To meet the ongoing recharge requirements, an environmental release management rule of 3.2 GL/year was implemented (Dillon 1983; Dillon & Mittiga 2001). This release rate has not been met in recent years and future management of the system should expect that these volumes will be released. Given that releases have been reduced in part due to below average runoff and hence risks to the security of domestic water supply, potential reductions in inflow due to climate change may lead to more frequent instances of the lack of these environmental releases.

Figures 16 and 17 show the frequency curves for the total resource and divertible resource respectively. The maximum divertible resource shown in Figure 17 plateaus at 21 GL as defined by the interception capacity of the system and hence its ability to store and divert runoff (refer Section 2.3).

Table 19 shows the change in the exceedance frequencies of the total annual resource volumes shown in Figure 16. Under current conditions the total annual resource was greater than or equal to 13.2 GL in 10% of all years. Under the A2 climate change conditions this reduces by 20% to 10.6 GL. The 50th percentile, or median total annual resource, potentially reduces by 28% from 6.5 to 4.7 GL.

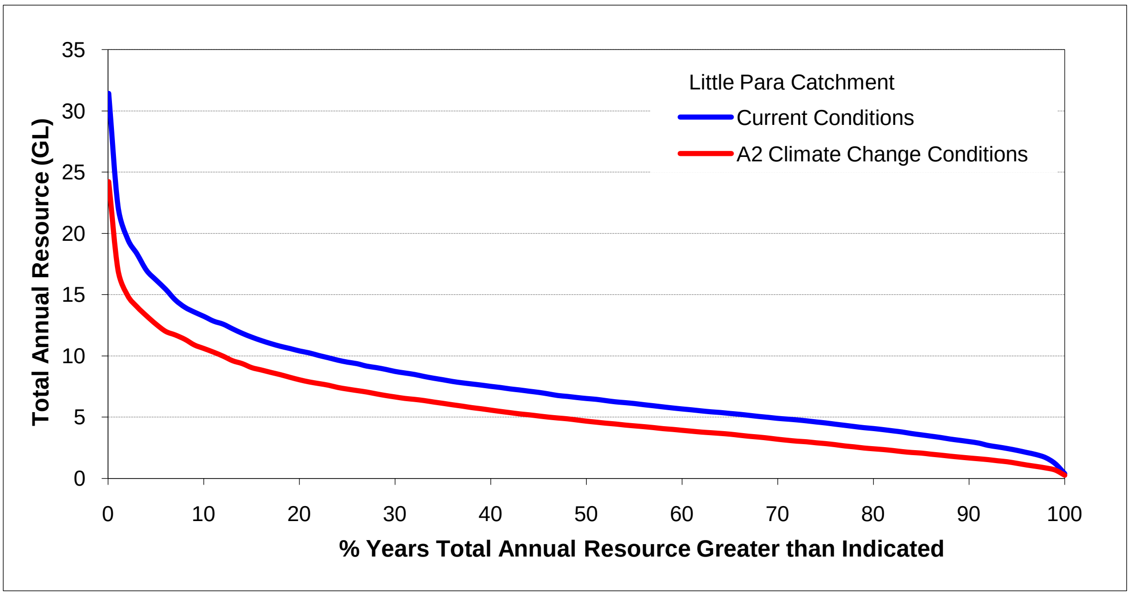

Figure 16 Little Para Catchment: Total Annual Resource Frequency Curve Change (Scenario A2)

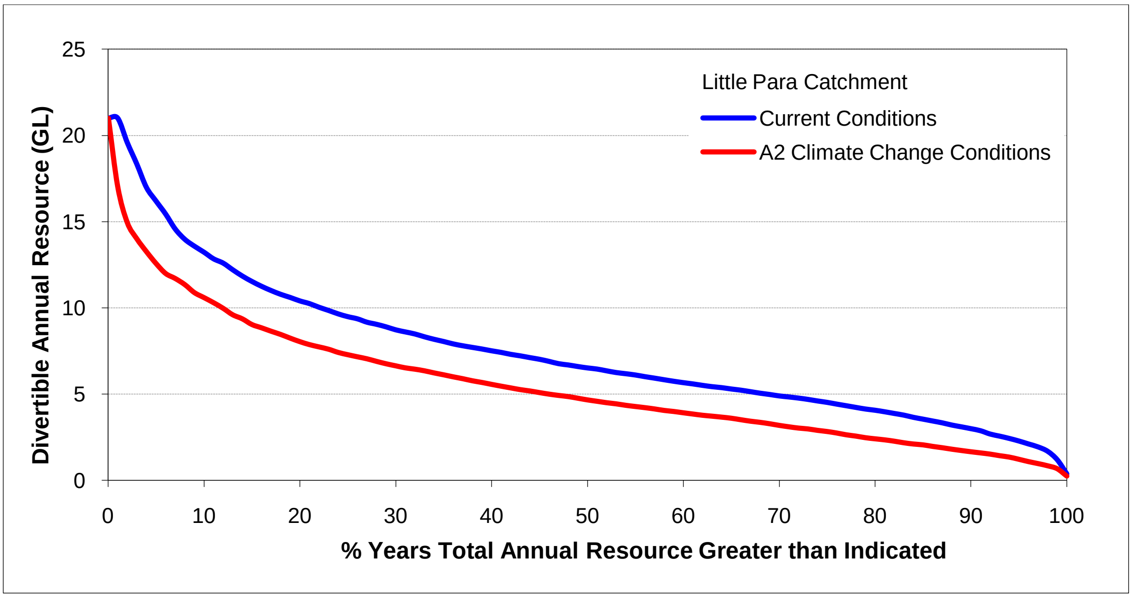

Figure 17 Little Para Catchment: Divertible Annual Resource Frequency Curve Change (Scenario A2)

**Table 19 Little Para Catchment: Total Resource Volume Frequency Change (Scenario A2)**

| Flow Percentile | Total Resource (GL) | | % Reduction |
|---|---|---|---|
| | Current Climate Conditions | A2 Climate Change Conditions | |
| 10th | 13.2 | 10.6 | 19.8 |
| 25th | 9.5 | 7.3 | 23.2 |
| 50th | 6.5 | 4.7 | 28.3 |
| 75th | 4.5 | 2.8 | 37.2 |
| 90th | 3.0 | 1.7 | 44.5 |

Figure 18 shows the potential changes to the meanly month total resource volumes under A2 climate change conditions. Total resources generated during the peak inflow months of July to September are reduced by around 25%. Over the remainder of the year, the majority of mean total monthly resource volumes are reduced by around 30%, but in one month by as much as 55%.

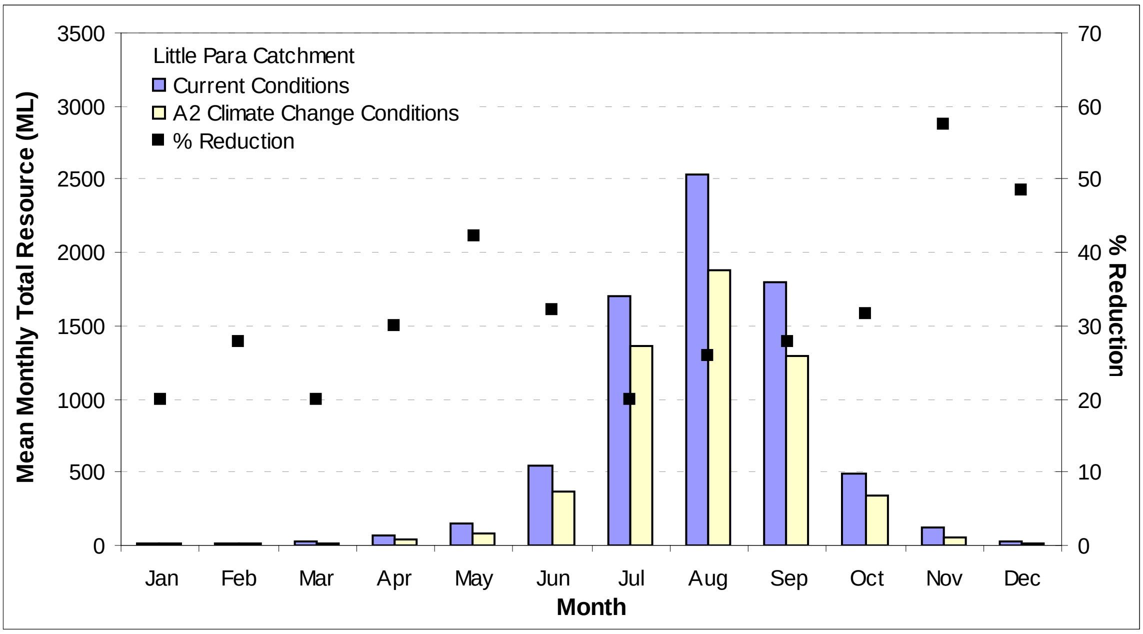

**Figure 18 Little Para Catchment: Mean Monthly Total Resource Change (Scenario A2)**

## 4.3.4. UPPER TORRENS CATCHMENT

The mean annual total resource availability in the Upper Torrens Catchment reduced from 43.1 to 30.9 GL under A2 climate change conditions, representing a reduction of 28%.

Unlike the South Para and Little Para Catchments, the Upper Torrens Catchment generates a total annual resource that is generally greater than the system interception capacity. Spill from this system occurs approximately four in every ten years and hence provides valuable water to environments downstream. The mean annual divertible resource under current conditions is estimated to be 35.7 GL. This reduces by 22% to 27.9 GL under A2 climate change conditions.

Figures 19 and 20 show the frequency curves for the total resource and divertible resource respectively. The maximum divertible resource shown in Figure 20 plateaus at 44 GL as defined by the interception capacity of the system and hence its ability to store and divert runoff (refer Section 2.4). The frequency of spills from this system is seen to reduce to less than two in every ten years under A2 climate change conditions.

Table 20 shows the change in the exceedance frequencies of the total annual resource volumes shown in Figure 19. Under current conditions the total annual resource was greater than or equal to 70.7 GL in 10% of all years. Under the A2 climate change conditions this reduces by 22% to 55.3 GL. The 50th percentile or median total annual resource potentially reduces by 30% from 39.2 to 27.6 GL.

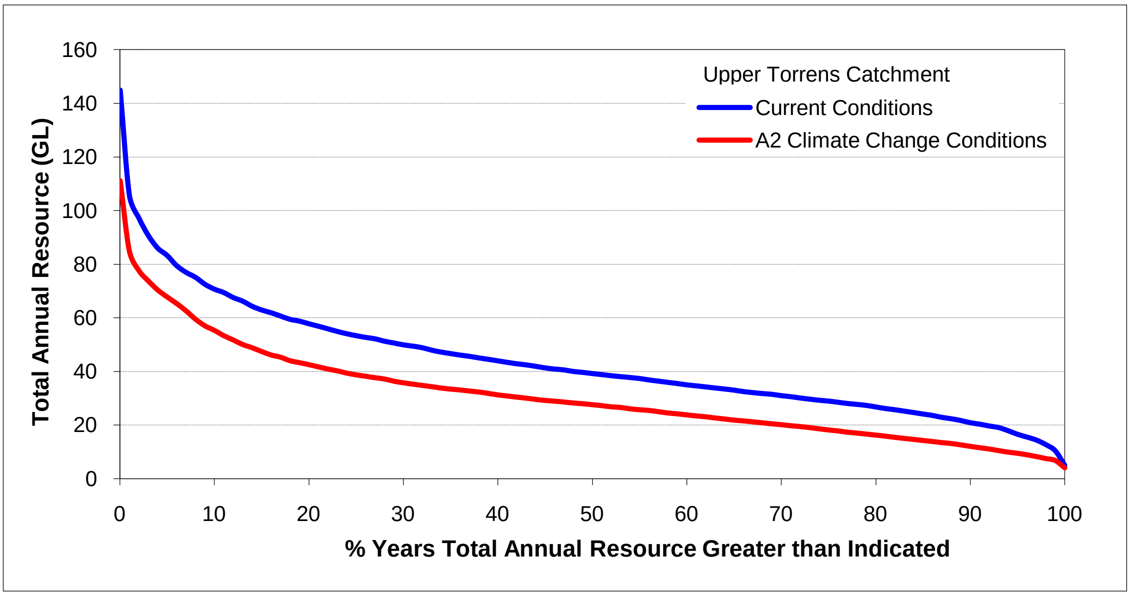

**Figure 19 Upper Torrens Catchment: Total Annual Resource Frequency Curve Change (Scenario A2)**

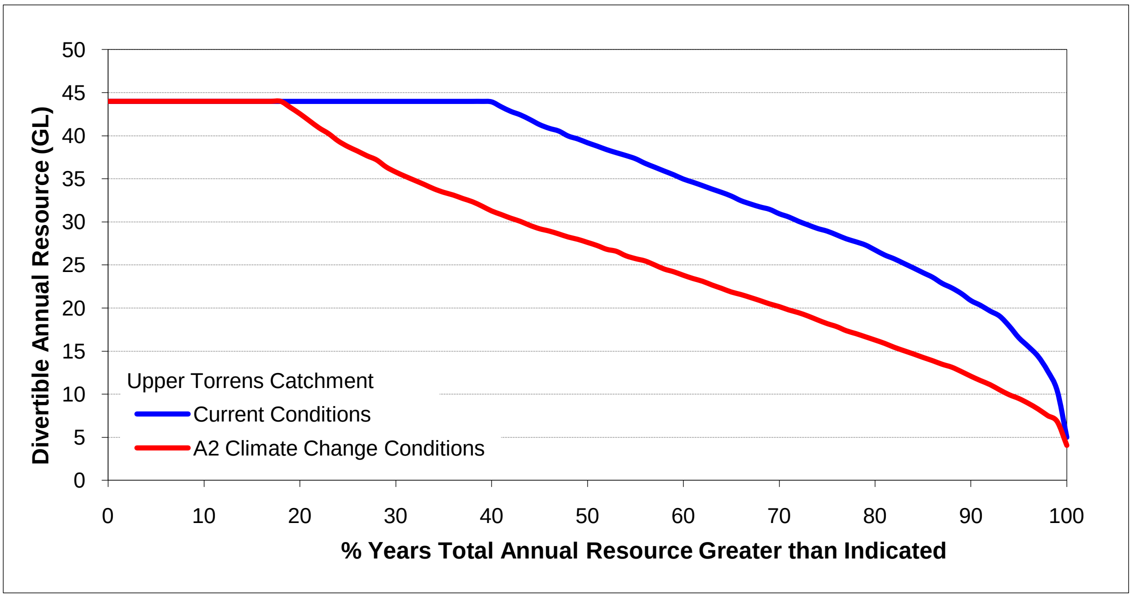

Figure 20 Upper Torrens Catchment: Divertible Annual Resource Frequency Curve Change (Scenario A2)

**Table 20 Upper Torrens Catchment: Total Resource Volume Frequency Change (Scenario A2)**

| Flow Percentile | Total Resource (GL) | | % Reduction |
|---|---|---|---|
| | Current Climate Conditions | A2 Climate Change Conditions | |
| 10th | 70.7 | 55.3 | 21.7 |
| 25th | 53.3 | 38.7 | 27.3 |
| 50th | 39.2 | 27.6 | 29.5 |
| 75th | 28.9 | 18.2 | 37.1 |
| 90th | 20.9 | 12.1 | 42.0 |

Figure 21 shows the potential changes to the mean monthly total resource volumes under A2 climate change conditions. Total resources generated during the peak inflow months of June to September are reduced by around 25 to 35%. Over the remainder of the year, the mean total monthly resource volumes are reduced by between 10 and 40%.

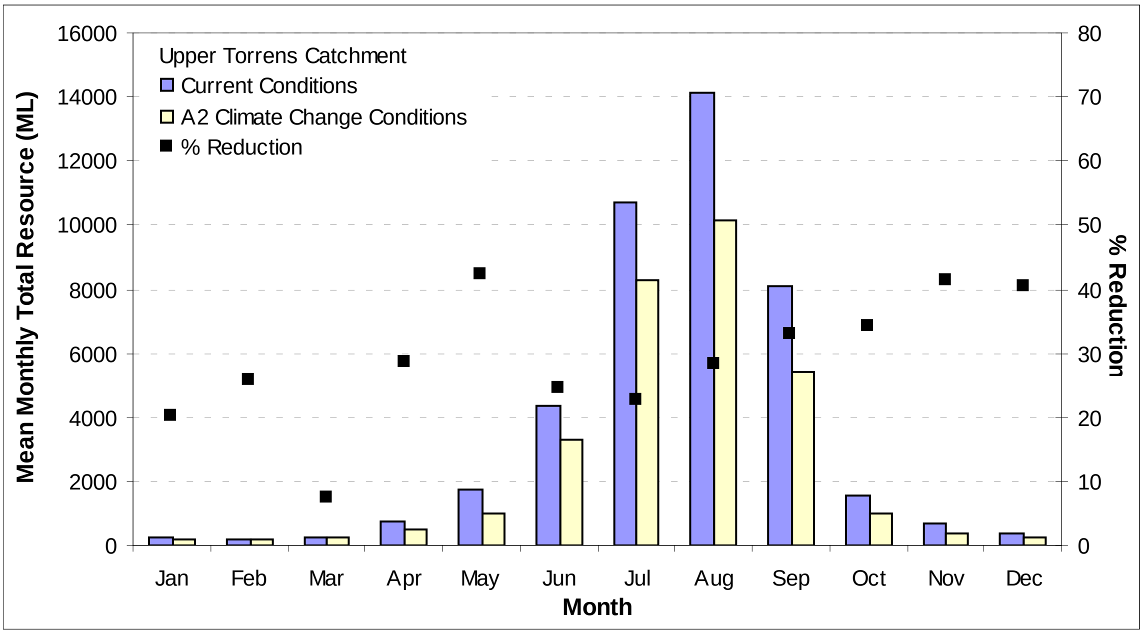

**Figure 21 Upper Torrens Catchment: Mean Monthly Total Resource Change (Scenario A2)**

## 4.3.5. ONKAPARINGA CATCHMENT

The mean annual total resource availability in the Onkaparinga Catchment reduced by 31% under A2 climate change conditions, from 66.1 to 45.4 GL.

The Onkaparinga Catchment is similar to the Upper Torrens Catchment in that the catchment generates an total annual resource generally greater than the system interception capacity. Spill from this system occurs approximately one in every two years and provides valuable flow to environments downstream of the Mount Bold Reservoir. The mean annual divertible resource under current conditions is estimated to be 57.7 GL (87% of the total resource available). This reduces by 26% to 42.6 GL under A2 climate change conditions.

Figures 22 and 23 show the frequency curves for the total resource and divertible resource respectively. The maximum divertible resource shown in Figure 23 plateaus at 69 GL as defined by the interception capacity of the system and hence its ability to store and divert runoff (refer Section 2.5). Figure 23 also indicates that under current conditions, spills from the Onkaparinga Reservoir system occur in just over four in every ten years. The difference between this modelled estimate and the observed spill frequency of one in every two years is likely due to the actual management of the Onkaparinga Reservoir system. Based on the management assumptions used, the frequency of spill was significantly reduced to only 1.5 in every ten years under A2 climate change conditions.

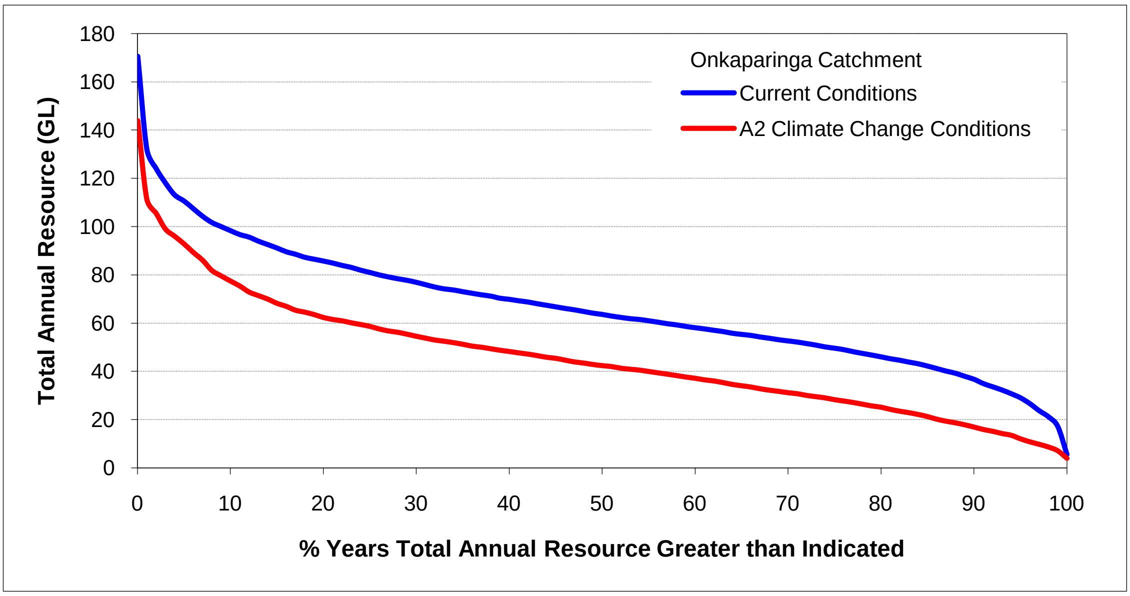

**Figure 22 Onkaparinga Catchment: Total Annual Resource Frequency Curve Change (Scenario A2)**

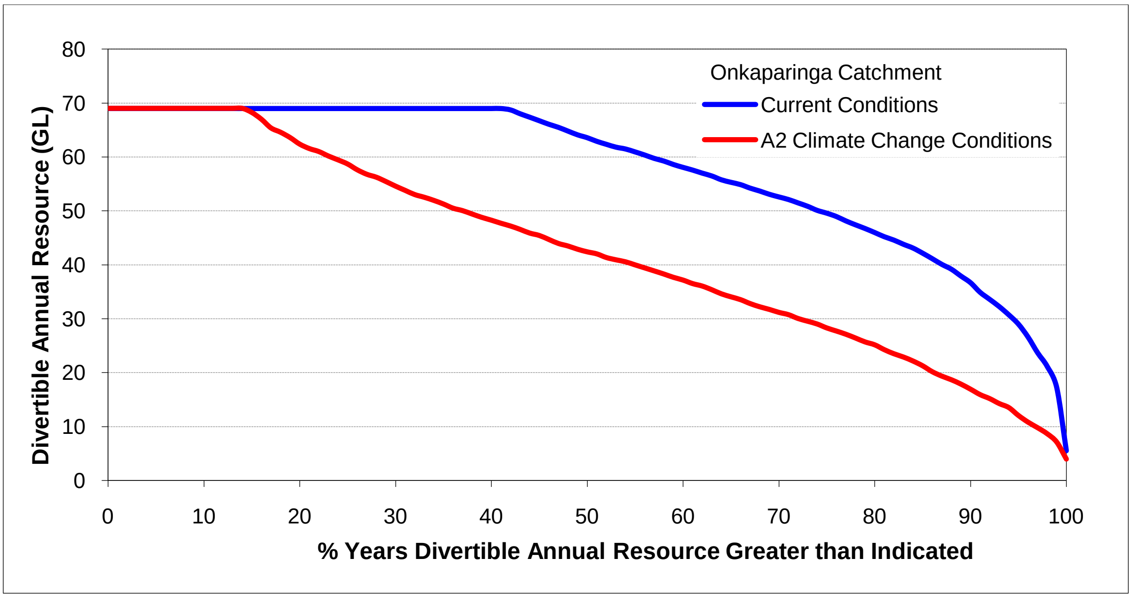

**Figure 23 Onkaparinga Catchment: Divertible Annual Resource Frequency Curve Change (Scenario A2)**

Table 21 shows the change in the exceedance frequencies of the total annual resource volumes shown in Figure 22. Under current conditions the total annual resource was greater than or equal to 98.3 GL in 10% of all years. Under the A2 climate change conditions this reduces by 21% to 77.5 GL. The 50th percentile or median total annual resource potentially reduces by 33% from 63.6 to 42.4 GL.

Figure 24 shows the potential changes to the mean monthly total resource volumes under A2 climate change conditions. Total resources generated during the peak inflow months of July to October are reduced by around 30%. Over the remainder of the year, the mean total monthly resource volumes are reduced by between 25 and 55%.

**Table 21 Onkaparinga Catchment: Total Resource Volume Frequency Change (Scenario A2)**

| Flow Percentile | Total Resource (GL) | | % Reduction |
|---|---|---|---|
| | Current Climate Conditions | A2 Climate Change Conditions | |
| 10th | 98.3 | 77.5 | 21.2 |
| 25th | 81.0 | 58.7 | 27.5 |
| 50th | 63.6 | 42.4 | 33.3 |
| 75th | 49.6 | 28.3 | 42.9 |
| 90th | 36.7 | 17.0 | 53.8 |

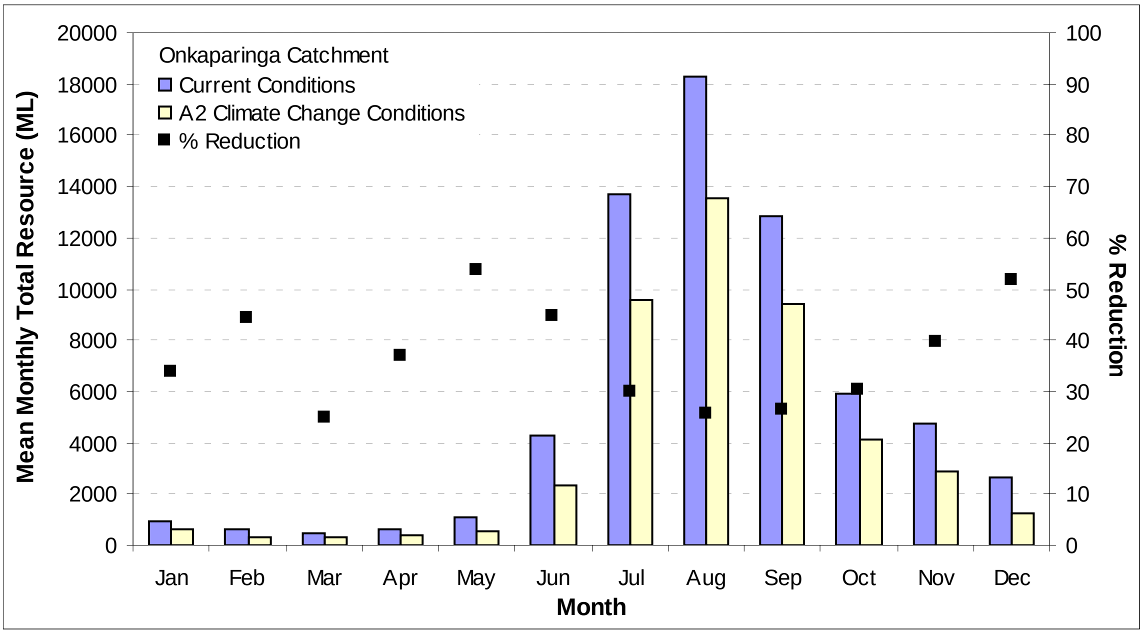

**Figure 24 Onkaparinga Catchment: Mean Monthly Total Resource Change (Scenario A2)**

## 4.3.6. MYPONGA CATCHMENT

The mean annual total resource availability in the Myponga Catchment reduced by 31% under A2 climate change conditions, from 13.7 to 9.4 GL.

The Myponga Reservoir is large with respect to its contributing catchment area and hence the total resource generated. As a result, the reservoir spills infrequently (approximately one in every five years) and the divertible resource closely matches the total resource. Reservoir spills could potentially provide little water for the maintenance of downstream environments, however, distribution constraints that ensure reliable supply currently allow for the availability of sufficient water for this purpose. The mean annual divertible resource under current conditions is estimated to be 13.1 GL. This reduces by 29% to 9.37 GL under A2 climate change conditions.

The potential reduction in inflows due to climate change may significantly impact on its ability to meet the increasing demands of the southern coast towns, particularly the expanding area of Victor Harbor, as well as EWPs.

Figures 25 and 26 show the frequency curves for the total resource and divertible resource respectively. The maximum divertible resource shown in Figure 26 plateaus at 20 GL as defined by the present interception capacity of the system and hence its ability to store and divert runoff (refer Section 2.6).

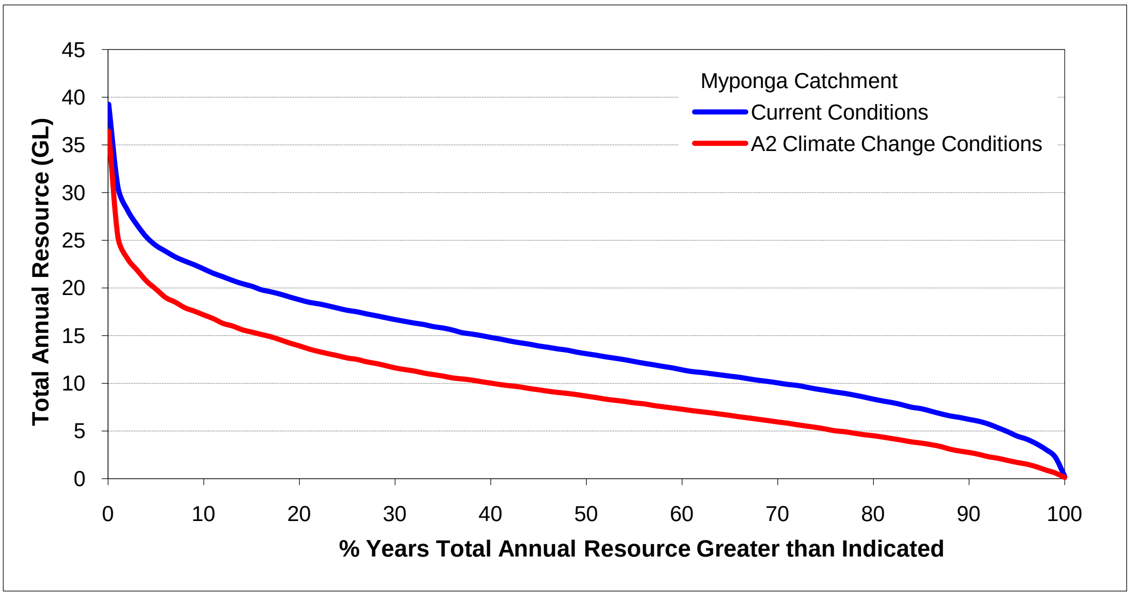

**Figure 25 Myponga Catchment: Total Annual Resource Frequency Curve Change (Scenario A2)**

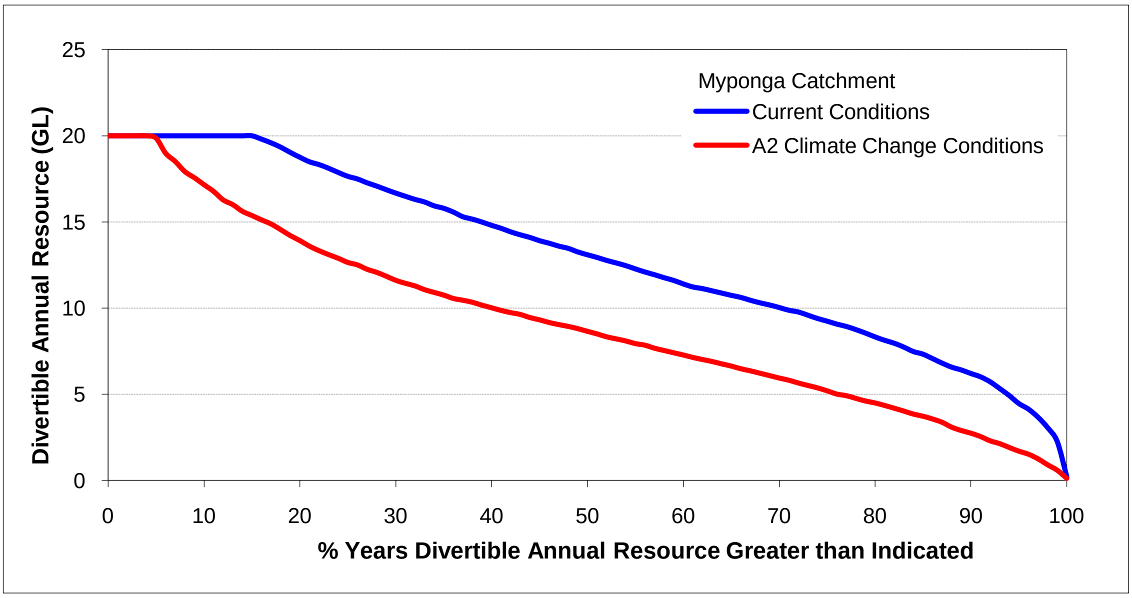

**Figure 26 Myponga Catchment: Divertible Annual Resource Frequency Curve Change (Scenario A2)**

Table 22 shows the change in the exceedance frequencies of the total annual resource volumes shown in Figure 25. Under current conditions the total annual resource was greater than or equal to 22 GL in 10% of all years. Under the A2 climate change conditions this reduces by 22% to 17.2 GL. The 50th percentile or median total annual resource potentially reduces by 34% from 13.1 to 8.7 GL.

Figure 27 shows the potential changes to the mean monthly total resource volumes under A2 climate change conditions. Total resources generated during the peak inflow months of July to October are reduced by around 30%. Over the remainder of the year, the mean total monthly resource volumes are reduced by between 35 and 60%.

**Table 22 Myponga Catchment: Total Resource Volume Frequency Change (Scenario A2)**

| Flow Percentile | Total Resource (GL) | | % Reduction |
|---|---|---|---|
| | Current Climate Conditions | A2 Climate Change Conditions | |
| 10th | 22.0 | 17.2 | 21.9 |
| 25th | 17.7 | 12.6 | 28.3 |
| 50th | 13.1 | 8.7 | 33.9 |
| 75th | 9.2 | 5.2 | 43.7 |
| 90th | 6.2 | 2.7 | 55.8 |

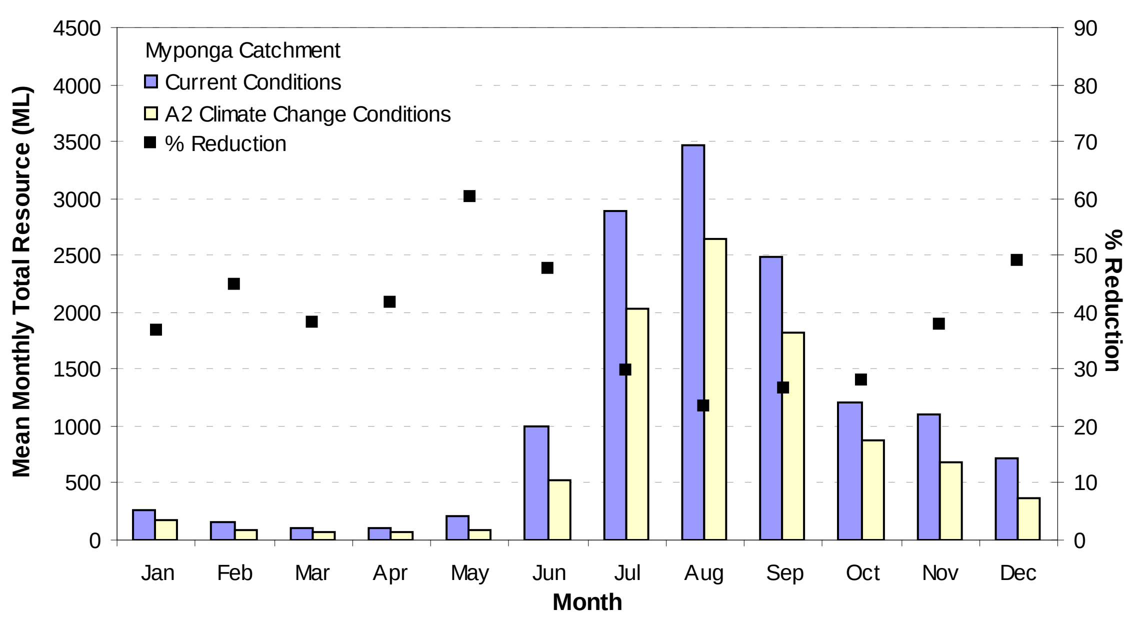

**Figure 27 Myponga Catchment: Mean Monthly Total Resource Change (Scenario A2)**

## 4.3.7. URBAN CATCHMENTS

Urban runoff or stormwater is generally derived from impervious pavements and is widely calculated using rainfall as input to an initial loss and continuing loss (IL–CL) model. In general, runoff from impervious areas can be accurately estimated using this method, provided that the estimations of the impervious areas are accurate. The application of an IL–CL model for the urban catchments show that the decrease in runoff due to rainfall reductions under the A2 climate change conditions is significantly less than from largely rural catchments, primarily because of the more linear relationship between rainfall and runoff in urban catchments.

Table 23 shows the potential reduction in the total resource available from the metropolitan Adelaide urban catchments. While the total resource available in rural areas may reduce by around 30% under A2 climate change conditions, urban runoff is likely to decrease by 20%.

In addition to the runoff generated within the urban catchments themselves, significant reservoir spills are estimated to flow through the urban catchment areas. Under potential climate change scenarios, it is likely that these “non-captured” flows could decrease to a point where they will be required to be supplemented by reservoir releases in order to satisfy minimum EWPs.

**Table 23 Urban Catchments: Total Resource Volumes Under Scenario A2 (with Current Evaporation)**

| Catchment | Mean Annual Total Resource (GL) | | % Reduction in Resource |
|---|---|---|---|
| | Current Climate Conditions | A2 Climate Change Conditions | |
| Patawalonga | 22.5 | 18.1 | 19.4 |
| Lower Torrens | 23.7 | 19.0 | 19.6 |
| Remaining Urban# | 49.0 | 39.4 | 19.6 * |

\# Based on 1.06 x (Patawalonga + Lower Torrens)

* 19.6% reduction assumed (based on Lower Torrens reduction)

Figures 28 and 29 show the potential changes to the mean monthly total resource volumes under A2 climate change conditions. These highlight the higher monthly volumes of urban stormwater generated outside of the peak winter months of June to September as a proportion of the total annual resource. The potential to use aquifer storage to smooth out the intra-annual variability will be a key in using this resource. There is also less difference between the percentage reductions for individual months across the year than seen previously for the rural catchments.

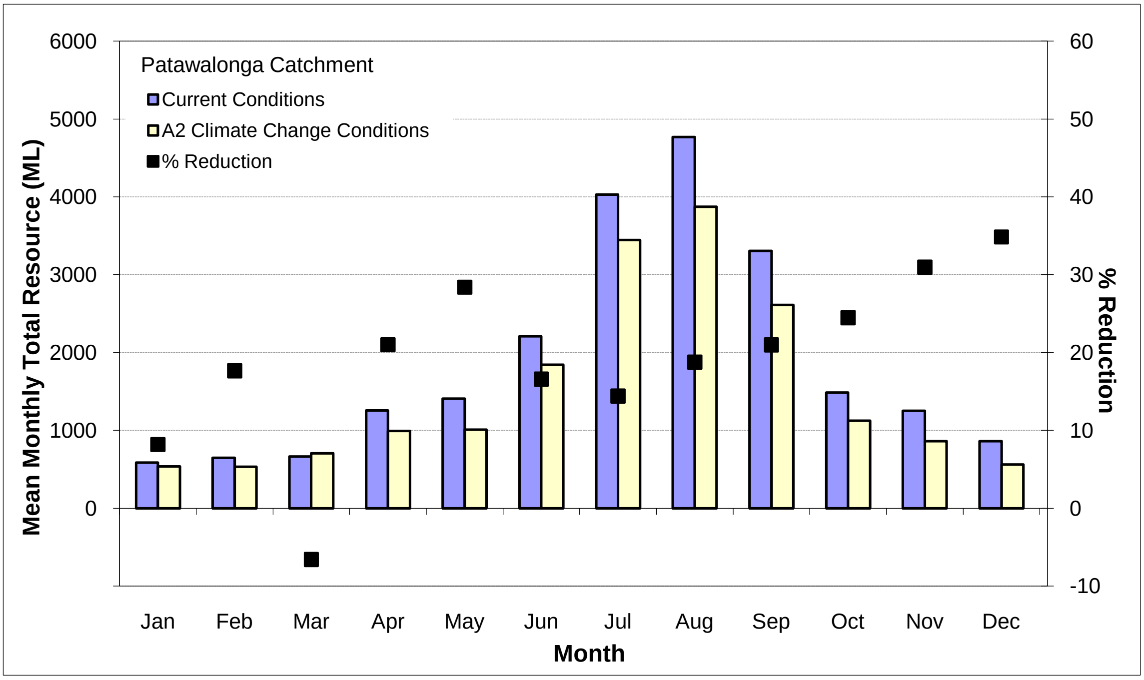

**Figure 28 Patawalonga Catchment: Mean Monthly Total Resource Change (Scenario A2)**

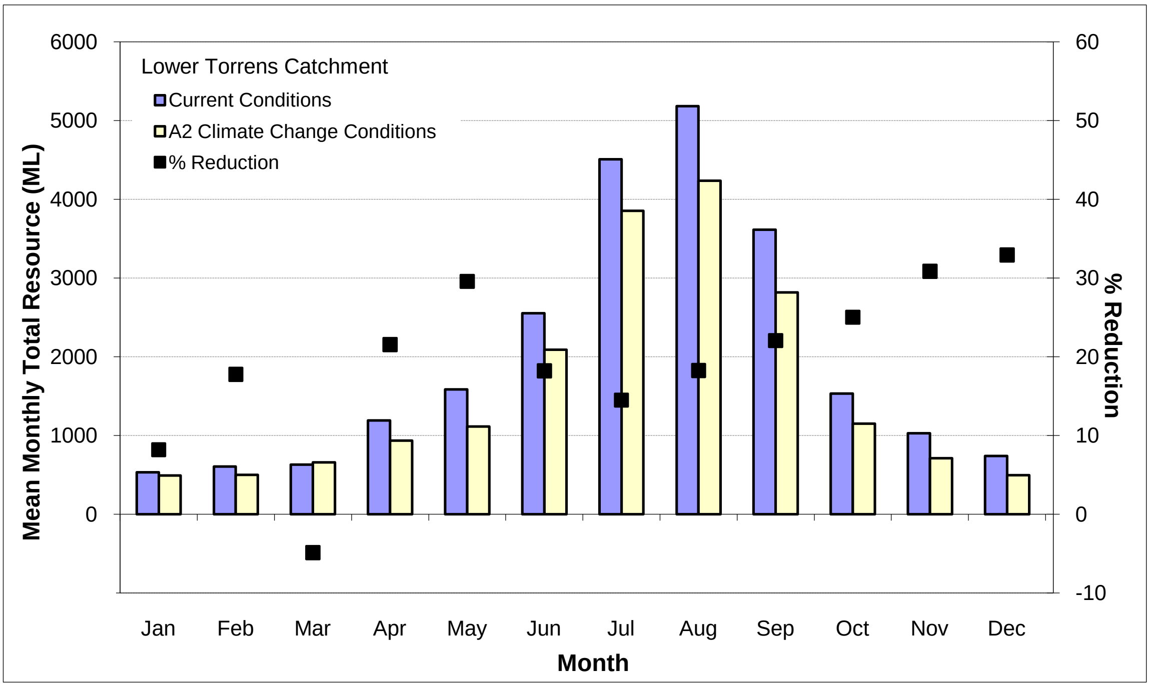

**Figure 29 Lower Torrens Catchment: Mean Monthly Total Resource Change (Scenario A2)**

Urban stormwater resources will likely increase as the demand for water increases due to a parallel increase in the areas of impervious surfaces associated with population and economic growth. Table 24 provides an estimate of the potential changes to the generation of stormwater given the assumptions on generation rates and changes to the population of Adelaide in conjunction with A2 climate change conditions.

The estimates indicate that given a continuation of current climate conditions and an increase in population, stormwater generation could increase from 95.2 to 124 GL/year. Applying the A2 climate conditions reduction leads to 102 GL of stormwater generated annually by 2050. Assuming it was possible to intercept and then redistribute 70% of stormwater generated under both current and A2 climate conditions, the total available resource would increase from 67 to 71 GL/year.

**Table 24 Urban Stormwater Availability in 2050 (Scenario A2)**

| Product and Population Dynamics | Mean Annual Resource (GL) | |
|---|---|---|
| | Current Climate Conditions | A2 Climate Change Conditions |
| Total urban stormwater—no population change | 95.2 | 76.5 |
| Total urban stormwater—increase to 1.4 million | 124.0 | 102.0 |

Assumptions

1. Stormwater is generated at a rate of 225 kL per constructed dwelling (Clark 2007).
2. Constant population increase of 0.5% per annum for Adelaide would lead to an increase in the total number of dwellings from 475,000 to 613,000.
3. Stormwater volumes generated reduced by 19.6% to incorporate A2 climate change conditions.

## *4.4. POTENTIAL REDUCTION IN WATER RESOURCE AVAILABILITY UNDER SCENARIO B2*

The B2 scenario is based on slower emissions growth as governments and industry move to reduce emissions and employ environmentally and socially sustainable development approaches. However, whilst most of the differences between the scenarios in terms of the concentration of greenhouse gases occurs in the latter half of the 21st century, there is only a small difference in the projected changes to rainfall and subsequently runoff. Given the small differences, the annual changes in water resource availability are presented below and then the A2 emissions scenario is used for all further analysis.

Tables 25 and 26 show the reductions in the total and divertible resources generated respectively within each of the catchments. The potential reduction in both the total and divertible resource under the B2 climate change conditions ranges from 24 to 32%. Comparison with the results for the A2 climate change conditions (Section 4.3.1) indicates only fractionally less reductions for the B2 emissions scenario.

**Table 25 Reduction in Mean Annual Resource Under Scenario B2 (with Current Evaporation)**

| Catchment | Mean Annual Resource (GL) | | % Reduction in Resource |
|---|---|---|---|
| | Current Climate Conditions | B2 Climate Change Conditions | |
| South Para | 30.9 | 21.1 | 31.9 |
| Little Para | 7.4 | 5.6 | 24.0 |
| Upper Torrens | 42.6 | 30.9 | 27.5 |
| Onkaparinga | 66.4 | 47.0 | 29.1 |
| Myponga | 13.6 | 9.9 | 27.7 |

**Table 26 Reduction in Mean Annual Divertible Resource Under Scenario B2 (with Current Evaporation)**

| Catchment | Mean Annual Divertible Resource (GL) | | % Reduction in Divertible Resource |
|---|---|---|---|
| | Current Climate Conditions | B2 Climate Change Conditions | |
| South Para | 30.5 | 20.8 | 31.7 |
| Little Para | 7.4 | 5.6 | 24.1 |
| Upper Torrens | 36.5 | 27.9 | 23.6 |
| Onkaparinga | 58.6 | 44.1 | 24.7 |
| Myponga | 13.1 | 9.6 | 26.4 |

## *4.5. ENVIRONMENTAL WATER PROVISIONS*

The MLR major water supply catchments currently provide approximately 60% of Adelaide's water needs, as well as supporting agriculture, industry and valuable eco-systems. Based on the relative position of competing users within the catchments, it is likely that agriculture, through farm dam capture and groundwater use, currently have first option on the limited resources, followed by SA Water through the capture and storage in the reservoir system and the environment last. Potential reductions in rainfall and streamflow due to climate change would significantly impact on total water resource availability. The combination of current and future pressures on the balance of water resources available to these competing users has meant that regulation is essential if water is to be managed and shared equitably.

In October 2004, a *Notice of Intent to Prescribe* and a *Notice of Prohibition* was placed on the surface water, watercourses and underground water of the WMLR, the area which includes the five major water supply catchments. This has led to Prescription in October 2005, triggering the development of a water allocation plan (WAP) for the water resources of this area. The requirements of a WAP are set out in the *Natural Resources Management Act 2004*, and provide for the allocation (including the quantity of water that is to be available for allocation) and use of water so that an equitable balance is achieved between social, economic and environmental needs for the water and to ensure that the rate of use of the water is sustainable.

Water supply for Adelaide is essentially drawn from four catchments: the Onkaparinga, Upper Torrens, South Para and Little Para. The Myponga catchment predominantly supplies the South Coast region and has therefore not been included in the analysis to follow. In terms of EWPs, only the Little Para Reservoir system is currently required to provide releases (3.2 GL/year), in this case to maintain recharge to the Northern Adelaide Plains aquifer.

Table 27 shows that meeting the present demand for metropolitan Adelaide of approximately 200 GL/year under A2 climate change conditions (with no assumed increase in demand) would result in the current local catchment to River Murray supply proportions of 55 and 45% reversing to 38 and 62%.

**Table 27 Annual Available Resource under Current and A2 Climate Change Conditions**

| **Annual Divertible Resource (GL)** | **Current Conditions** | **A2 Conditions** |
|---|---|---|
| South Para | 29.9 | 20.7 |
| Little Para[1] | 4.3 | 2.3 |
| Upper Torrens | 35.7 | 27.9 |
| Onkaparinga | 57.7 | 42.6 |
| Total Divertible Resource | 127.6 | 93.5 |
| Total Divertible Resource Less Evap[2] | 110.6 | 76.5 |
| Requirement from River Murray | 89.4 | 123.5 |
| **%Present Demand Supplied[3]** | | |
| Local Catchments | 55 | 38 |
| River Murray | 45 | 62 |

[1] Little Para resource reduced by 3.2 GL/year for environmental release

[2] Evaporation losses from reservoirs estimated at 17 GL/year

[3] Present demand estimated at 200 GL/year

Evaporation losses from the reservoirs have been assumed to average 17 GL/year, however, this does not assume any increases due to climate change. Under potential climate change conditions it is expected that the evaporation rate will increase and this may represent an additional annual loss of 1 GL directly from the reservoirs.

EWPs are currently under development as part of the MLR WAP process. Although not complete, preliminary EWPs have been defined (SA Water 2006) for river reaches at four locations within the South Para, Torrens and Onkaparinga Catchments. The EWPs are defined as flow regimes that have been specifically designed for each individual reach, based on hydrological modelling and ecological objectives. The annual release volumes are as follows:

- South Para: 2.24 GL/year from the Barossa Diversion Weir (immediately downstream of South Para Reservoir)
- Upper Torrens: 4.11 GL/year from Gumeracha Weir
- Upper Torrens: 0.89 GL/year from Gorge Weir
- Onkaparinga: 9.24 GL/year from Clarendon Weir

The release from Gumeracha Weir is considered a 4.11 GL/year EWP but because the flows are essentially re-regulated and recovered to SA Water in Kangaroo Creek Reservoir, they are not lost to water supply. Therefore, the preliminary annual total EWP is equal to 12.4 GL/year. The existing EWP from the Little Para Reservoir is assumed to remain at 3.2 GL/year and hence an additional release is not required.

Modelling using the SA Water's HOMA showed that the 12.4 GL/year releases are effectively equal to an 8 GL/year loss to water supply (SA Water 2006). This reduction is due to the one in every two year frequency of spill from the Mount Bold Reservoir. Any releases, and hence loss to water supply, made in the year prior to a spill would be negated by the refilling of the reservoir. However, if the frequency of spill from Mount Bold Reservoir is halved, as is indicated under the A2 climate change scenario, the EWP loss to water supply may be closer to 10 GL/yr.

Table 28 shows that water resources diverted from water supply to EWPs will likely lead to additional pumping from the River Murray or the provision of water supply from alternative sources such as desalination.

**Table 28 Water Supply Balance under Current and A2 Climate Change Conditions including EWPs**

| **Available Resource (GL)** | **Current Conditions** | **A2 Conditions** |
|---|---|---|
| Divertible Resource from Local Catchments[1] | 110.5 | 76.5 |
| Divertible Resource less EWR[2] | 102.5 | 66.5 |
| River Murray / Other sources | 97.5 | 133.5 |
| **% Demand Supplied[3]** | | |
| Local Catchments | 51 | 33 |
| River Murray / Other source | 49 | 67 |

[1] From Table 27

[2] EWR assumed to be 8 GL under both current and A2 climate change conditions

[3] Demand assumed to remain at 200 GL/year, and from both traditional and alternative sources

Water supply reservoirs intercept and store significant volumes of flow, impacting on aquatic ecosystems downstream. Under potential climate change scenarios this impact is likely to increase due to reductions in reservoir spills. A measure of the change in spill is the difference between the modelled total resource and divertible resource as presented in Section 4.3.1. This showed that for the South

Para, Little Para, Upper Torrens and Onkaparinga Catchments, the mean annual total resource under current conditions is approximately 147 GL and the initial estimate of the divertible resource 131 GL. This constitutes a mean annual spill of 16 GL. Under A2 climate change conditions this spill may reduce to 6 GL/year.

Under potential climate change conditions and increasing water supply demands there is a risk that EWP may be foregone. Therefore, it is important that the preliminary EWPs above are continually reviewed and incorporated into the ongoing planning of Adelaide's water supply systems to ensure the desired ecological objectives for downstream aquatic ecosystems can be met.

# 5. SUMMARY OF RESULTS, CONCLUSIONS AND RECOMMENDATIONS

## *5.1. POTENTIAL IMPACTS OF CLIMATE CHANGE ON WATER RESOURCE AVAILABILITY*

### 5.1.1. CLIMATE CHANGE SCENARIO DOWNSCALING

The A2 emissions scenario assumes a continued high rate of greenhouse gas emissions, resulting from focusing on regional economic development rather than technological change and global environmental concerns. The results of downscaling from the CSIRO Mk3 GCM A2 simulation run (Charles & Bates 2006) showed that:

- The projected winter weather state mean trends indicate an increase in the drier patterns and a decrease in the wetter patterns.
- There are only slight changes in the station daily rainfall distributions between the current and projected future downscaled simulations.
- Projected monthly totals are consistently reduced.

In comparison to the B2 scenario, there were also indications that the A2 scenario produces a greater reduction in very wet winters.

In terms of the potential reductions in rainfall, it was shown that:

- The increasing drier climate patterns and decreasing wetter patterns during winter are shown by the reductions in the mean and median annual rainfall for each catchment.
- Overall, a 13% reduction in rainfall totals within the water supply catchments was identified, with similar reductions seen in the hills and plains catchments.
- Both scenarios appeared to produce similar seasonal reductions across the year.
- The greatest impact on monthly rainfall totals that is likely to be translated to runoff generation appears to be during the autumn and early winter period from April to June. Rainfall was reduced by as much as 25% over this period.
- The only increase in monthly rainfall totals occurred during March, although little change in rainfall totals was generally found between January and March.

Reductions in, or the delay of, early winter rainfall has been found to be responsible for decreases in streamflow in previous studies by DWLBC. The monthly distribution of rainfall is not observed to change significantly but is instead showing a sizable reduction in rainfall across all winter months through to spring. Rainfall during these months is critical to ensure good surface runoff generation and recharge to groundwater. The result may be only moderate runoff during the spring months, which traditionally have been the months of greatest runoff in low rainfall years.

### 5.1.2. WATER RESOURCE AVAILABILITY MODELLING

In rural catchments, the non-linearity of the transformation from rainfall to runoff means that reductions in runoff may occur for small decreases in rainfall, particularly in the lower rainfall areas. In urban catchments this non-linearity is not as strongly pronounced and therefore percentage runoff reductions more closely resemble the percentage reduction in rainfall.

It is generally accepted that there will be an increase in evaporation based on temperature increases forecast by the GCMs. However, variations in evaporation are likely to be extremely complex and depend on how the weather patterns passing across South Australia are altered under future climate scenarios. Current evaporation rates were considered first, with a 5% increase in evaporation then used to test the sensitivity of this parameter.

In terms of the potential reductions in reservoir inflows to the MLR reservoirs under A2 climate change conditions, it was shown that:

- The mean annual inflows or total resource availability reduced from 161 to 112 GL (refer Section 4.3.1), representing a reduction of 30%.
- The potential reductions for individual rural catchments ranged from 27 to 32% as shown in Table 29 below.
- Increasing the evaporation by 5% led to a further 3 to 4% reduction in resource availability.
- The percentage reduction in total resource over the peak inflow months of July to September was generally in the order of the percentage reduction in mean annual totals.
- As was anticipated in Section 5.1.1, larger percentage reductions in monthly resource availability occurred between April to June. During these months, rainfall totals were heavily impacted and hence the time taken for a catchment to become saturated and produce runoff increased.
- The recurrence of reservoir spills is likely to decrease significantly, even for those reservoirs that currently frequently spill.

The runoff from the impervious pavements of urban catchments is less affected by antecedent soil moisture conditions, and consequently the potential decrease in runoff from these catchments will likely be less than that from rural catchments. For the urban catchments of metropolitan Adelaide under A2 climate change conditions it was shown that:

- The reduction in the total resource generated was approximately 20% as shown in Table 29.
- The percentage reductions in monthly volumes were more uniform across the year.

The changes under the B2 climate change conditions were similar to those above under A2 conditions. Refer to Section 4.4 for further details.

**Table 29 Reduction in Mean Annual Resource Under Scenario A2 (with Current Evaporation)**

| Catchment | Mean Annual Resource (GL) | | % Reduction in Resource |
|---|---|---|---|
| | Current Climate Conditions | A2 Climate Change Conditions | |
| South Para | 30.6 | 20.8 | 31.9 |
| Little Para | 7.5 | 5.5 | 26.7 |
| Upper Torrens | 43.1 | 30.9 | 28.4 |
| Onkaparinga | 66.1 | 45.4 | 31.3 |
| Myponga | 13.7 | 9.4 | 31.3 |
| Patawalonga | 22.5 | 18.1 | 19.4 |
| Lower Torrens | 23.7 | 19.0 | 19.6 |
| Remaining Urban | 49.0 | 39.4 | 19.6 |

### 5.1.3. INITIAL WATER SUPPLY AVAILABILITY MODELLING

The *divertible resource* defines the ability of the reservoir systems to capture and supply the water resources generated in each catchment. For this investigation, the interception capacity was defined as 90% of the total reservoir volume in addition to the estimated winter usage (diversion to supply). Any inflow that exceeded this combined volume was assumed to spill from the system. It should be noted that the modelling undertaken provides an initial estimate of interception capacity only and that future modelling is proposed using the generated runoff estimates as input to the SA Water operated HOMA model. This will ensure that accurate representation of the reservoir system and operations including inter-annual variability in demand, dead storage, emergency supply, and water quality considerations and transfers.

Using these assumptions, the mean annual divertible resource reduced from 144 GL under current rainfall conditions to 106 GL under the A2 climate change scenario, a reduction of 27%. The reduction in divertible resource is less than the reduction in total resource generated since the reservoir capacities effectively become larger in relation to the reduced inflows. Table 30 shows the changes in the mean annual divertible resource within each catchment.

**Table 30 Reduction in Mean Annual Divertible Resource Under Scenario A2 (with Current Evaporation)**

| Catchment (rural only) | Mean Annual Divertible Resource (GL) | | % Reduction in Divertible Resource |
|---|---|---|---|
| | Current Climate Conditions | A2 Climate Change Conditions | |
| South Para | 29.9 | 20.7 | 30.8 |
| Little Para | 7.5 | 5.5 | 26.3 |
| Upper Torrens | 35.7 | 27.9 | 21.7 |
| Onkaparinga | 57.7 | 42.6 | 26.1 |
| Myponga | 13.1 | 9.3 | 29.4 |

The reduced impact on the divertible resource results in a reduction in the recurrence of system spills, particularly from the Upper Torrens and Onkaparinga systems. Under current conditions, mean annual spill from the South Para, Little Para, Upper Torrens and Onkaparinga Catchments was approximately 16 GL. This was reduced by around 63% to 6.1 GL/year under A2 climate change conditions.

### 5.1.4. ENVIRONMENTAL CONSIDERATIONS

Water supply reservoirs intercept and store significant volumes of flow, impacting on aquatic ecosystems downstream. Under potential climate change conditions that are likely to reduce the volume and frequency of reservoir spills, in addition to increasing water supply demands, there is a risk that EWPs may be foregone. Therefore, it is important that the preliminary EWPs presented here are continually reviewed and incorporated into the ongoing planning of Adelaide's water supply systems such that acceptable EWPs are available to aquatic ecosystems downstream of major water supply infrastructure at all times.

## 5.2. RECOMMENDATIONS

The assessment undertaken here provides estimates of the impacts of likely future climate change scenarios based on the best available information presently available. However, given that climate change has the potential to place additional pressure on the already variable water resources of the MLR, it is recommended that:

1. A more comprehensive range of emission scenarios, and hence climate change projections, be considered and modelled to determine changes to water resource availability. This would require significant resources to enable the further development of the CSIRO models but would enable a better estimation of the likely risk to water supply in the MLR.
2. Consider the output from a wider range of GCMs, particularly those that are considered to be appropriate for southern Australia.
3. Use the generated runoff estimates under current and future conditions as input to the SA Water operated HOMA model. This will ensure accurate representation of the reservoir system and operations including inter-annual variability in demand, dead storage, emergency supply, and water quality considerations and transfers.
4. Assess the possible long-term reduction in resource capacity and the subsequent changes required of the EWP for the groundwater and surface water resources of the MLR.
5. Incorporate the findings of parallel studies being carried out by the Murray–Darling Basin Commission regarding the reduction of resources within the Murray–Darling Basin and examine the probability of conjunctive dry periods in both the MLR and River Murray catchments.

# UNITS OF MEASUREMENT

## Units of measurement commonly used (SI and non-SI Australian legal)

| Name of unit | Symbol |
|---|---|
| day | d |
| gigalitre | GL |
| hectare | ha |
| kilolitre | kL |
| kilometre | km |
| litre | L |
| megalitre | ML |
| metre | m |
| millimetre | mm |
| second | s |
| year | yr |

# GLOSSARY

**Aquatic ecosystem** — The stream channel, lake or estuary bed, water, and/or biotic communities, and the habitat features that occur therein

**BIL** — Barossa Infrastructure Limited

**Catchment** — That area of land determined by topographic features within which rainfall will contribute to runoff at a particular point

**Farm dams development** — The surveyed 1999 farm dams data

**DWLBC** — Department of Water, Land and Biodiversity Conservation

**Ecosystem** — Any system in which there is an interdependence upon, and interaction between, living organisms and their immediate physical, chemical and biological environment

**Environmental water provisions** — That part of environmental water requirements that can be met; what can be provided at a particular time after consideration of existing users' rights, and social and economic impacts

**Environmental water requirements** — The water regimes needed to sustain the ecological values of aquatic ecosystems, including their processes and biological diversity, at a low level of risk

**EWP** — see *environmental water provisions*

**GCM** — General circulation model: a sophisticated computer program that simulates the physical processes of the atmosphere and oceans

**HOMA** — Headworks Optimisation Model—Adelaide

**IL–CL** — initial loss and continuing loss model

**Irrigation** — Watering land by any means for the purpose of growing plants

**MLR** — Mount Lofty Ranges

**Model** — A conceptual or mathematical means of understanding elements of the real world that allows for predictions of outcomes given certain conditions. Examples include estimating storm runoff, assessing the impacts of dams or predicting ecological response to environmental change

**Monitoring** — (1) The repeated measurement of parameters to assess the current status and changes over time of the parameters measured (2) Periodic or continuous surveillance or testing to determine the level of compliance with statutory requirements and/or pollutant levels in various media or in humans, animals, and other living things

**NHMM** — Non-homogeneous hidden Markov model

**PPD** — Patched Point Dataset

**SA Water** — South Australian Water Corporation

**Stormwater** — Runoff in an urban area

**Surface water** — (a) water flowing over land (except in a watercourse), (i) after having fallen as rain or hail or having precipitated in any another manner, (ii) or after rising to the surface naturally from underground; (b) water of the kind referred to in paragraph (a) that has been collected in a dam or reservoir

**WAP** — Water allocation plan

**Watercourse** — A river, creek or other natural watercourse (whether modified or not) and includes: a dam or reservoir that collects water flowing in a watercourse; a lake through which water flows; a channel (but not a channel declared by regulation to be excluded from the this definition) into which the water of a watercourse has been diverted; and part of a watercourse

# REFERENCES

Charles SP and Bates BC, 2006, *Stochastically downscaled precipitation projections for the Mount Lofty Ranges and Upper South East Region of South Australia*, Draft final report, Prepared by CSIRO Land and Water for the Department of Water, Land and Biodiversity Conservation, Adelaide

Charles SP, Bates BC, Fleming PM, 2005, *Analysis of weather patterns and climate variables for the Mount Lofty Ranges and Adelaide Hills Region of South Australia*, Prepared by CSIRO Land and Water for the Department of Water, Land and Biodiversity Conservation, CSIRO Land and Water Report (in press)

Charles SP, Bates BC, Hughes JP, 1999, 'A spatio–temporal model for downscaling precipitation occurrence and amounts', in *Journal of geophysical research,* 104: pp. 31657–31669

Charles SP, Bates BC, Smith IN and Hughes JP, 2004. 'Statistical downscaling of daily precipitation from observed and modelled atmospheric fields', in *Hydrological processes*, 18, pp. 1373–1394

Charles SP, Heneker TM and Bates BC, 2008, 'Stochastically downscaled rainfall projections and modelled hydrological response for the Mount Lofty Ranges, South Australia', in *Proceedings of water down under 2008*, pp. 428-349.

Clark RDS, 2007, *Water proofing Adelaide—modelling the dynamic processes*, Richard Clark and Associates, Adelaide

Cresswell D, 2000, 'WaterCress 2000 User Manual', unpublished

Dillon PJ, 1983, *Little Para recharge study—final report*, Department of Civil Engineering, University of Adelaide, South Australia

Dillon PJ and Mittiga L, 2001, *Aquifer recharge from Little Para River*, Draft report, Department for Water Resources, for the Government of South Australia

E&WS – see Engineering and Water Supply Department

Engineering and Water Supply Department, 1991, *Integrated management of farm dams in the Barossa Valley*, Report EWS 91/7, Engineering and Water Supply Department, for the Government of South Australia

Gorden HB, Rotstayn LD, McGregor JL, Dix MR, Kowalczyk EA, O'Farrell SP, Waterman LJ, Hirst AC, Wilson SG, Collier MA, Watterson IG and Elliott TI, 2002, *The CSIRO Mk3 climate system model*, CSIRO Atmospheric Research Technical Paper No. 60, Aspendale, Victoria.

Heneker TM, 2003, *Surface water assessment of the Upper River Torrens catchment*, DWLBC Report 2003/24, Department of Water, Land and Biodiversity Conservation, for the Government of South Australia

Hennessy K, Fitzharris B, Bates BC, Harvey N, Howden SM, Hughes L, Salinger J and Warrick R, 2007, 'Climate change 2007: impacts, adaptation and vulnerability—Australia and New Zealand', in Parry ML, Canziani, OF, Palutikof JP, PJ van der Linden and CE Hanson (eds), *Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change,* Cambridge University Press, Cambridge, UK, pp. 507–540

Hughes JP, Guttorp P and Charles SP, 1999, 'A non-homogeneous hidden Markov model for precipitation occurrence', in *Applied Statistics*, 48 pp. 15–30

Jeffrey SJ, Carter JO, Moodie KB and Beswick AR, 2001, 'Using spatial interpolation to construct a comprehensive archive of Australian climate data', in *Environmental Modelling and Software*, 16 pp. 309–330

McMurray D, 2003, *Assessment of water use from farm dams in the Mount Lofty Ranges, South Australia*, Report DWLBC 2004/2, Department of Water, Land and Biodiversity Conservation, for the Government of South Australia

# REFERENCES

Nakicenovic N, Alcamo J, Davis G, de Vries B, Fenhann J, Gaffin S, Gregory K, Grüble A, Jung TY, Kram T, La Rovere EL, Michaelis L, Mori S, Morita T, Pepper W, Pitcher H, Price L, Riahi K, Roehrl A, Rogner H-H, Sankovski A, Schlesinger M, Shukla P, Smith S, Swart R, van Rooijen S, Victor N, Dadi Z, 2000, *IPCC special report on emissions scenarios*, Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA

Perkins SE, Pitman AJ, Holbrook NJ and McAneney J, 2007, 'Evaluation of the AR4 climate models' simulated daily maximum temperature, minimum temperature and precipitation over Australia using probability density functions, in *Journal of climate*, 20 pp. 4356–4376

Savadamuthu K, 2002, *Impact of farm dams on streamflow in the Upper Marne Catchment*, Report DWR 02/01/0003, Department for Water Resources, for the Government of South Australia

Savadamuthu K, 2003, *Streamflow in the Upper Finniss Catchment*, Report DWLBC 2003/18, Department of Water, Land and Biodiversity Conservation, for the Government of South Australia

SA Water, 2006, *Environmental water trials for the Western Mount Lofty Ranges: summary report*, Adelaide and Mount Lofty Ranges Natural Resources Management Board, Department of Water, Land and Biodiversity Conservation and SA Water, Adelaide

Teoh K, 2003, *Estimating the impact of current farm dam development on the surface water resources of the Onkaparinga River Catchment*, DWLBC Report 2002/22, Department of Water, Land and Biodiversity Conservation, for the Government of South Australia

Teoh K, 2006a, *The impact of farm dam development on the surface water resources of the South Para River Catchment*, DWLBC Report 2003/19, Department of Water, Land and Biodiversity Conservation, for the Government of South Australia

Teoh K, 2006b, *Assessment of surface water resources of Patawalonga Catchment and the impact of farm dam development*, DWLBC Report 2007/09, Department of Water, Land and Biodiversity Conservation, for the Government of South Australia

Teoh K and Kotz S, 2007, 'Surface water assessment and the impact of farm dam development in the Lower Torrens Catchment', Unpublished DWLBC Report, Department of Water, Land and Biodiversity Conservation, for the Government of South Australia

Viney NR and Bates BC, 2004, 'It never rains on Sunday: the prevalence and implications of untagged multi-day rainfall accumulations in the Australian high quality data set'. In *International Journal of Climatology*, 24 pp. 1171–1192

Williams T, 2007, 'Surface water assessment of the Little Para Catchment', DWLBC Report in prep., Department of Water, Land and Biodiversity Conservation, for the Government of South Australia