

# Modelling of streamflow reduction due to climate change in Western Australia – A case study

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## EXTENDED ABSTRACT

The population of the Perth-Bunbury region in Western Australia is 1.1 million and is predicted to increase to 3.1 million by 2050. At present about 40% of the Perth's water supply comes from surface water resources. Due to below-average rainfall for several decades, streamflow to reservoirs supplying the Perth metropolitan area has declined more than 40%. General Circulation Models (GCMs) predict that rainfall in this region is likely to decrease further due to projected climate change. The availability of water resources may diminish further and pose a significant threat to water supply, environment and biodiversity.

This paper presents a case study of the effect of a projected change in climate on the water yield of the Stirling Dam catchment, located in the south west of Western Australia. The study applied 40 realisations of current (1975 to 2004) and future (2035 to 2064) daily rainfall generated by statistically downscaling a single CSIRO Mk3 GCM simulation based on the IPCC SRES A2 emission scenario. The Land Use Change Incorporated Catchment Model (LUCICAT) was calibrated for the Stirling Dam catchment under

existing conditions. The projected change in catchment runoff was then simulated using the downscaled rainfall. No change in land use, potential evaporation or evapotranspiration potential was assumed to occur when moving from the current to future climate.

The study found that when the IPCC SRES A2 emission scenario is applied to the CSIRO Mk3 GCM to produce two 30-year realisations, annual rainfall in the south west of Western Australia is projected to decrease 11% by the middle of this century. Taking into account the assumptions and limitations of the study, the projected reduction in rainfall would likely result in a 31% reduction in annual water yield from the catchment. A sensitivity analysis revealed that a 10% increase in potential evaporation, coupled with the 11% decrease in rainfall, could result in water yield reductions of greater than 40%. Conversely a 10% decrease in potential evaporation with same rainfall decrease resulted in only a 9% reduction in water yield.

Confidence in the predictions of rainfall and runoff could be improved by using: (i) multiple GCMs and CO<sub>2</sub> emission scenarios, (ii) multiple catchments and (iii) better estimates of the Leaf Area Index (LAI) and potential evapotranspiration.

## 1 INTRODUCTION

In recent decades, increasing concern has developed over global climate change, trends and projections and the implication of these in areas such as water resources management. An Australian context of climate variability and climate change is well described in publications by the Australian Bureau of Meteorology (2003) and the Australian Greenhouse Office (2003).

At present, General Circulation Models (GCMs) have been used to estimate changes in precipitation and temperature globally (IPCC 2001). These models are able to project different climate regimes by accounting for changing levels of CO<sub>2</sub> and other gases in the atmosphere, and determining the resulting atmospheric conditions brought about by changes in circulation patterns. GCM outputs are most reliable at large scales, which can lead to problems when the intended use of GCM outputs is for regional scale applications, such as simulation of rainfall and temperature data for small catchments. The use of statistically downscaled GCM outputs to produce more spatially defined projections of rainfall and temperature is an emerging science that holds great promise for applications on such local scales (Wilby et al. 2004).

This study aims to apply statistically downscaled rainfall to a water resource catchment in south-west Western Australia to assess the impact of projected climate change on catchment water yield. The methodology adopted involves the coupling of statistically downscaled GCM climate projections with a catchment hydrology model. The Australian Greenhouse Office supported this study as a combined project between Western Australia's Department of Environment (formerly known as the Water and Rivers Commission), CSIRO Land and Water and Western Australia's Water Corporation.

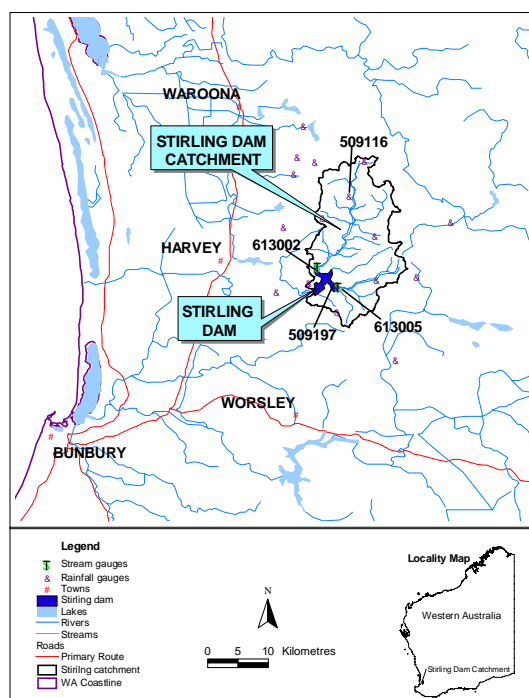
Several decades of below average rainfall and a recent succession of dry years has focused attention on water resource reliability in south-west Western Australia. Rodgers and Ruprecht (1999) assessed the impact of climate variability on surface water resources of the region, finding that major changes occurred in the hydrology of the forested catchments. This region has experienced a decline in winter rainfall of up to 20% over the past 30 years, which has resulted in a 40% or greater reduction in runoff to reservoirs supplying the Perth metropolitan area (Rodgers and Ruprecht 1999; IOCI 2001). The Perth-Mandurah Integrated Water Supply System (IWSS) has traditionally utilised the Darling Range

Catchments as a potable water source, however the decline in catchment water yield has resulted in a greater dependence on Perth's regional groundwater resources and has increased the potential for impact on coastal groundwater dependent ecosystems.

To further add to the challenges now faced by water resources managers, future climate projections indicate a further decrease in rainfall in the south-west of Western Australia. The risks that such a decrease poses for the environment, water supply and water resources management are significant, especially with a steady increase in demand for water and the diminishing availability of traditional source options. This study investigates the impact of a projected climate change on inflows to the Stirling water supply dam in south-west Western Australia and will contribute toward a reassessment of surface water supply planning in the State.

## 2 CATCHMENT DESCRIPTION

Stirling Dam catchment (Figure 1) is located approximately 120 km south of Perth in the Darling Range and is used for irrigation and as a component of the Perth-Mandurah Integrated Water Supply Scheme.



**Figure 1.** Location of Stirling Dam catchment

The Stirling Dam catchment covers an area of 250 km<sup>2</sup>, and the mean annual inflow to Stirling

Reservoir for the period 1975 to 1994 was 49 GL (Gigalitres). The catchment forms part of state forest and is managed by the Department of Conservation and Land Management (CALM). The dominant species in the area are jarrah (*Eucalyptus marginata*) and marri (*Corymbia calophylla*) which form an upperstorey vegetation cover to a height of 20 to 35 m. There is also a well-defined understorey formed by trees and shrubs. Pine plantations exist around some parts of the dam area. The Forest Products Commission and CALM conduct logging and controlled burning as part of normal forestry operation, but on the whole, minimal clearing has taken place in the catchment. Dieback is also present within the catchment.

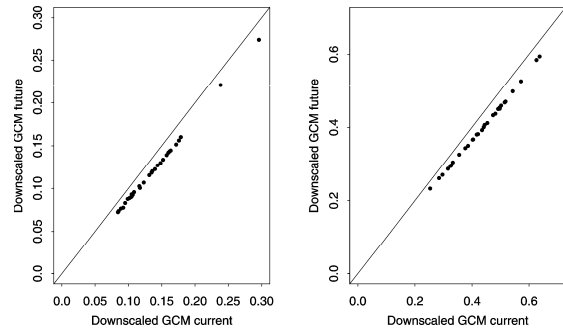
### 3 METHODOLOGY

#### 3.1 Statistical Downscaling

The downscaling procedure provides multi-station, daily rainfall and temperature data for a network of 31 stations across south-west Western Australia (Berti et al. 2004). The Non-homogeneous Hidden Markov Model (NHMM) of Hughes et al. (1999) was used to downscale atmospheric predictors to multi-site, daily precipitation occurrence and then conditional multiple linear regression was used to simulate multi-site, daily precipitation amounts (Charles et al. 1999). The CSIRO GCM used in this study is denoted as the Mark 3 (Mk 3) version (Gordon et al. 2002). Two 30-year time-slices of daily GCM output representing a current and future period were extracted from a single continuous (transient) run using the IPCC A2 medium economic growth emissions scenario with steadily increasing greenhouse gas concentrations. The current period is centered on 1990 and runs from 1975 to 2004. The future period is centered on 2050 and runs from 2035 to 2064. This future period experiences a climate with approximately 1.7 times the equivalent CO<sub>2</sub> concentration of the present day. The statistical downscaling models were validated on observed data (Berti et al. 2004). Both summer and winter mid-21<sup>st</sup> century downscaled climate projections indicate an overall drying trend with fewer rain days (Figure 2), lower seasonal and extreme rainfall amounts, and higher maximum and minimum daily temperatures.

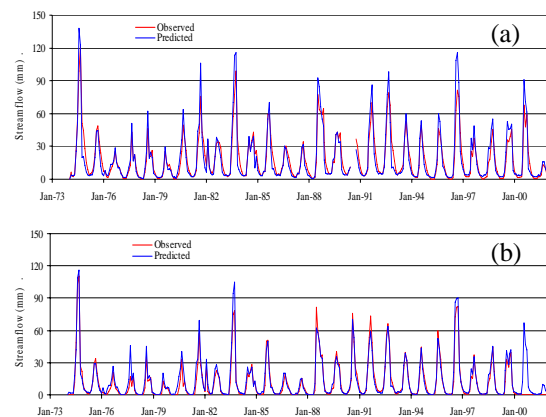
#### 3.2 Application of the LUCICAT Model

The LUCICAT (Land Use Change Incorporated CATCHment) model was used to investigate the impact of the statistically downscaled GCM projections on catchment yield (Berti et al. 2004).



**Figure 2.** Precipitation probabilities for current and mid-21st century Summer (left) and Winter (right)

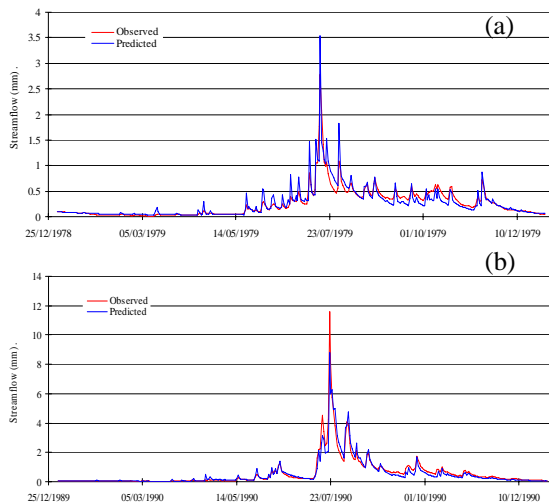
The Stirling Dam catchment was divided into 33 subcatchments ranging from 2.4 to 12 km<sup>2</sup> in size. The model generally provided an accurate prediction of observed streamflow. At the Harvey River Dingo Road and Blackbutt Point gauging stations, there was less than 1% and 7% difference respectively between the predicted and observed annual flow for the period 1974 to 1999. A statistical t-test shows that this difference is not significant at the 99% confidence limit. At both the gauging stations, a tendency toward over-prediction can be seen in the modelling of the monthly peak flows (Figure 3). The correlation between the monthly observed and predicted flows was approximately 0.9 for Dingo Road and approximately 0.95 for Blackbutt Point.



**Figure 3.** Observed and predicted monthly streamflow at (a) Dingo Road and (b) Blackbutt Point

The daily simulation of the low-flow year (1979) was compared to the observed streamflow at Dingo Road (Figure 4a). During the period January to May, when the base flow component was dominant, the model prediction was very close to the observed. For May and June the model generally over-predicted the daily flow. Over all,

the trend in observed and predicted daily flow was very consistent. Comparing the observed and predicted daily flow at the Blackbutt Point for the average-flow year 1990, it can be seen that the two matched reasonably well (Figure 4b). The model predicted the daily peak flow very well, while slightly under-predicting the streamflow during the period October to December when the interflow and base flow component was dominant.



**Figure 4.** Observed and predicted streamflow at (a) Dingo Road and (b) Blackbutt Point

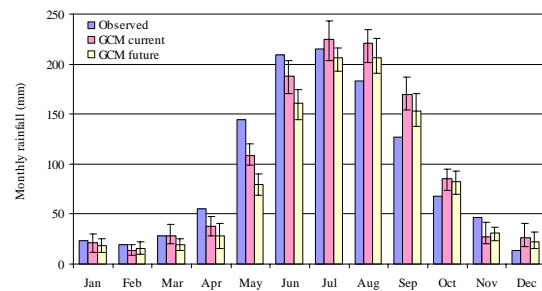
The predicted monthly inflow to the Stirling Dam compared well to the figures derived using the Water Corporation’s reverse water balance calculation. A correlation coefficient greater than 0.9 supports the accuracy of the LUCICAT calibration. The predicted average (1972-1998) annual catchment yield of 53.9 GL compares well with the reverse water balance figure of 52.2 GL. Both inflow series have relatively low coefficients of variation, similar means and similar values at the 10<sup>th</sup> percentile range. The main difference occurs at the higher flow end with the calibrated LUCICAT inflows being greater than the reverse water balance figures at the 90<sup>th</sup> percentile. This may occur as the LUCICAT figures do not take into account dam overflows, scour and evaporation from the dam surface.

## 4 RAINFALL DOWNSCALING AND YIELD PREDICTION

### 4.1 Rainfall

One thousand realisations of current and future daily rainfall and temperature were generated through the downscaling of the current and future atmospheric predictors. To capture the range and

variability while reducing the LUCICAT running-time, it was calculated that analysing 40 randomly selected realisations would be statistically valid. The GCM downscaled mean monthly rainfall, for both the current and future, exhibit differences to the observed mean monthly rainfall (Figure 5). Despite the shift in intra-annual peak, the catchment average current GCM downscaled rainfall is only 2% greater than that calculated using the observed data. This margin of error is within the limits found in previous studies (Wood et al, 1997) and will tend to overestimate runoff response.



**Figure 5.** Comparison of mean monthly rainfalls

The downscaled annual rainfall for the future is on average 11% lower than the current downscaled annual rainfall. This is consistent with previous projections of rainfall decrease due to climate change for south-west Western Australia. Except for February and November, the mean monthly rainfall under future climate would be lower than the current state (Figure 5). The largest change in mean monthly rainfall total (mm) is predicted to occur in May. An early winter (May/June) decrease is consistent with the observed mid-1970s rainfall decrease experienced by the region (IOCI, 2001).

### 4.2 Dam Inflow

To assess the change in yield that could occur following a change in climate, the LUCICAT model was run using the current and future GCM downscaled rainfall. A slight bias toward over-prediction of inflow can be seen when using the current GCM downscaled rainfall (Figure 6). This can be attributed to the higher average annual rainfall produced under the current GCM climate.

Comparing the annual 10<sup>th</sup> and 90<sup>th</sup> percentile flow volumes reveals that the current downscaled rainfall produces a smaller streamflow range, and thus a smaller annual variation, than the observed case (Table 1). On average the current predicted inflow is about 9% greater than the annual inflow generated using observed rainfall. The shift in





