The Hydrological Impacts of Climate Change and Variability in the Murray Hotham River Catchment, Western Australia

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Abstract

There is growing evidence that the Earth's climate is changing as a result of natural variability and the enhanced greenhouse effect. This has serious implications for water resources at a regional scale. In south west Western Australia alterations in the rainfall pattern have been observed, with noticeable consequences for streamflow. This paper presents an assessment of how rainfall patterns have changed in the Murray Hotham Catchment during the last century, and how the catchment has responded hydrologically to this change. The LUCICAT catchment hydrological model is employed to investigate how further climate variability and change, as projected by the CSIRO's C-CAM General Circulation Model, may impact stream yields, flood peaks, and salinity processes.

1.0 Introduction

1.1 Climate Change and Variability

Throughout history the Earth's climatic regime has varied naturally over annual, decadal and multi-decadal time scales (IOCI 2002). Natural factors such as variation in solar radiation, land cover change and volcanic eruptions can result in significant change in the long term mean of climate characteristics. These include regional precipitation, evaporation, wind, temperature, fog and sunshine. Climate variability may also cause variation in the standard deviation and extremes of these characteristics without necessarily resulting in a change in mean (BoM 2003).

However, in the last few decades, changes have been observed in the Earth's climate that cannot be explained by natural variability alone. Since the industrial revolution, human activities such as combustion of fossil fuels, land use change and agriculture have caused increases in atmospheric concentrations of greenhouse gases including carbon dioxide, methane and nitrous oxide. Scientists and policy makers alike have growing confidence that these anthropogenic emissions have caused net global warming through the enhanced greenhouse effect, resulting in variation of global atmospheric circulation and regional climate change (IPCC 2007).

The south west of Western Australia (SWWA) is one region which appears to have been influenced by the observed global changes in atmospheric circulation. In the mid 1970s winter rainfall decreased sharply, with autumn and early winter rains remaining 10-15% lower than the preceding 50 year average since then. The decline has not been spatially uniform, with the highest percentage decrease occurring in the drier inland areas, and less severe decrease in wetter coastal areas (IOCI 2002). While the mean decrease in rainfall has been recognised, the effect of climate change on rainfall intensity frequency distribution is less clear, with conflicting opinions as to whether extreme events are increasing or decreasing.

1.2 Hydrological Response to Change

Climate is a key driver of many catchment-scale hydrological processes. River yield is largely determined by the amount of runoff reaching the watercourse after a precipitation event. This process is influenced by not only the total annual precipitation, but also the temporal distribution of rainfall. Storm length, intensity, and inter-storm period all have a significant impact on runoff generation by infiltration excess, saturation excess or subsurface storm-flow, as they affect the soil's ability to convey and store the water. Climate variability may impact upon surface runoff, total river yield, maximum and minimum river discharges, and flood frequency and magnitude.

While debate continues over the cause of changes in rainfall pattern, the consequences on catchment hydrology are already apparent. In SWWA, surface and groundwater systems are dependent on wet years to create a water surplus and on heavy winter rainfall to feed their flow. Since the decline in annual rainfall in the south west began, stream flow and runoff to dams have fallen by a disproportionately large 40% (IOCI 2002). Other effects are less clear; there are conflicting opinions as to whether an increase in extreme rainfall events has occurred, which could result in a rise in flood frequency and severity. The decline in available water resources has implications for urban and rural water supply, agriculture, and the natural environment.

1.3 Aims of Project

This project aims to improve regional level understanding of climate change and variability in SWWA, and of catchment hydrological response to such change. To do so, it focuses on the Murray Hotham Catchment and attempts to answer the following questions;

- How has rainfall intensity frequency distribution changed during the last century?
- How have past rainfall changes affected streamflow, floods and salinity processes?
- How might streamflow, floods and salinity vary under projected climate change?

The study aims to provide the Department of Water with scientific information that will allow them to more confidently meet their responsibility to the people of the Murray Hotham Catchment and Western Australia; to plan, manage and develop the State's water resources so that present and future community requirements are met.

2.0 Catchment Description

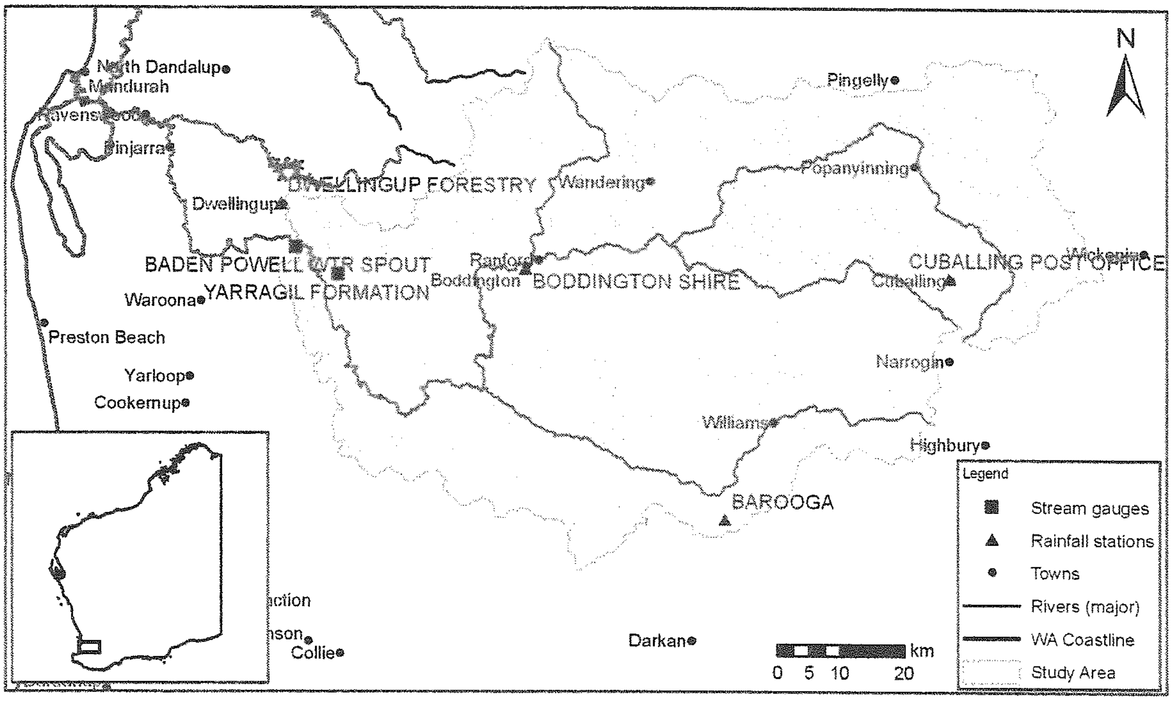

Figure 1. Murray Hotham Catchment study area, gauging sites, and major rivers of the Murray Basin

The Murray Hotham Catchment is located within the Peel-Harvey subregion in SWWA (Fig. 1). The study area covers an area of 6757km^2 upstream of the Baden Powell Water Spout, and varies from gently undulating slopes in the east where the Williams and Hotham Rivers begin, to hilly landforms where the Murray River enters the Darling Escarpment. The western portion of the catchment remains under native jarrah and marri forest with some mining around Boddington. To the east, approximately 57% of the catchment has been cleared for low intensity agriculture. The region has a temperate climate, experiencing hot dry summers and cool wet winters. Mean annual rainfall ranges from 1300mm at Dwellingup in the west to 400mm at Wickepin to the east of the catchment, decreasing with distance from the coast. Pan evaporation ranges from above 1800mm in the NE corner of the basin to below 1600mm towards the SW.

3.0 Methodology

3.1 Rainfall Analysis

The aim of the first stage of the project was to determine whether rainfall intensity frequency distribution has changed in the Murray Hotham Catchment during the last century, and to quantify these changes if possible. Of particular interest was to determine if a change was apparent in comparing data from before 1975 (pre-75) with data from after 1975 (post-75), when a step-change in annual rainfall has been observed in studies of other SWWA catchments.

Four rainfall stations within the catchment were chosen for analysis, based on their length and completeness of record, and their even spatial distribution through the study area. Daily rainfall records were obtained for Dwellingup Forestry, Boddington Shire, Barooga, and Cuballing Post Office from before 1934 until 2006. Annual rainfall datasets were assessed for trends in the total precipitation. Mean monthly rainfall for pre-75 and post-75 were compared to evaluate any change in seasonal distribution. Daily rainfall analysis focused on identifying changes in intensity frequency distribution. Tests were conducted of the frequency distribution of daily rainfall intensity into 10 mm intensity bands pre-75 and post-75, the distribution of rain volume 10 mm intensity bands pre-75 and post-75, and annual and seasonal one-day and five-day maximum rainfall.

3.2 Hydrological Analysis

The next stage of the project involved quantifying any changes to the catchment streamflow characteristics, again for pre-75 and post-75 periods. Only two stations were chosen, due to the lack of other stations with a long period of complete and reliable data. Baden Powell Water Spout is located on the Murray River at the discharge point of the study area. Its record shows processes occurring throughout the Murray Hotham Catchment from 1952 to 2006. The Yarragil gauge is located on Yarragil Brook, a small experimental subcatchment draining to the Murray River. It provides a comparison area limited land use change, a necessary condition for homogeneity. Flow duration curves were constructed to look at changes in low flow periods, whilst flood frequency curves were used to look at probabilistic changes in extreme streamflow events, using the annual flood series method from Australian Rainfall and Runoff (IEAust 2001).

3.3 Catchment Modelling

Hydrological models are useful tools to help improve understanding of catchment runoff processes, based on mathematical descriptions of the physical systems that transform rainfall into streamflow. They can also be used to predict catchment response to an imposed change in internal or external forcing factors. One such model is LUCICAT, the Land Use Change Incorporated Catchment hydrological model, designed to represent catchment scale daily water and salt balance processes under various land use or climatic scenarios.

LUCICAT was applied to the Murray Hotham Catchment in order to determine how the catchment might respond to future changes in climate. To prepare for modelling, the catchment was divided into 135 subcatchment "response units" and the stream channel network was defined using a digital elevation model (DEM) of the land surface in ArcGIS. Catchment attributes including impervious area, topsoil depth, soil profile depth, stream length, elevation change were estimated in attribute files, whilst conceptual groundwater level was input as an initial condition. Aerial photographs and LANDSAT images were used to define the land use history and vegetation cover of the catchment over time. Rain information collected at numerous regional stations was used to generate a daily subcatchment rainfall dataset.

The model was calibrated by trial and error, to match predicted streamflow and stream salinity to observed data for the period 1960 to 2005. This was done primarily by modifying catchment attributes and global parameters such as the biological factors for minimum and maximum rainfall. A field visit to the Murray Hotham Catchment was used to ground-truth the calibrated model, comparing what had been generated by computers with what actually exists on the ground. Once set up and calibrated, the LUCICAT model is run in Microsoft Developer Studio. Projected climatic conditions were used as input to illustrate the potential catchment hydrological response to future climate change. The model outputs daily, monthly and annual streamflow, salinity and salt load for specified nodes of the stream channel network. The present (1975-2004) and future (2035-2064) streamflow and salinity outputs are statistically compared to determine if the projected future scenario is significantly different to present hydrological characteristics.

3.4 Climate Projection

General Circulation Models (GCMs) are a major class of climate models, developed to simulate climate system behaviour, long term trends, and to project climatic response to applied change. When given an input scenario, such as future atmospheric CO_2 concentration, GCM programs model physical climate processes by solving equations for conservation of mass, momentum and energy at each point in a three dimensional grid covering the Earth's surface to project future conditions. While the accuracy of GCMs is highest projecting mean climate change at the global scale, results can be statistically downscaled for use at local and regional scales (BoM 2003).

For this project C-CAM, the Conformal-Cubic Atmosphere Model, was chosen to project future climate under the A2 scenario, based on the results of a previous study which compared results from several GCMs for the Serpentine Dam Catchment (Kitsios, Bari & Charles 2006). C-CAM is a regional climate model, nested within the CSIRO's Mk3 GCM, with 60km resolution over Australasia (McGregor 2005). The A2 emission scenario from the International Panel on Climate Change corresponds to constantly increasing population with a regional economic focus, with steadily increasing CO_2 emission rates leading to a 1.7-fold rise in concentration by 2050 (IPPC 2007). Rainfall input datasets for LUCICAT were obtained from the CSIRO for 40 present (1975-2004) and 40 future (2035-2064) statistically down-scaled C-CAM realisations.

4.0 Results and Discussion

4.1 Rainfall Analysis

Annual rainfall records in the Murray Hotham Catchment suggest that the catchment is drying, with a drop in the post-75 mean rainfall compared to the pre-75 data. The decrease varies from 12% in the high rainfall zone, to over 30% in the low rainfall zone. There have also been less very wet years in the last three decades. From 1934 to 1974 there were ten years with >1500mm at Dwellingup, however since 1975 no years have had >1500mm recorded. Also, three of the five lowest years on record have occurred since 1999.

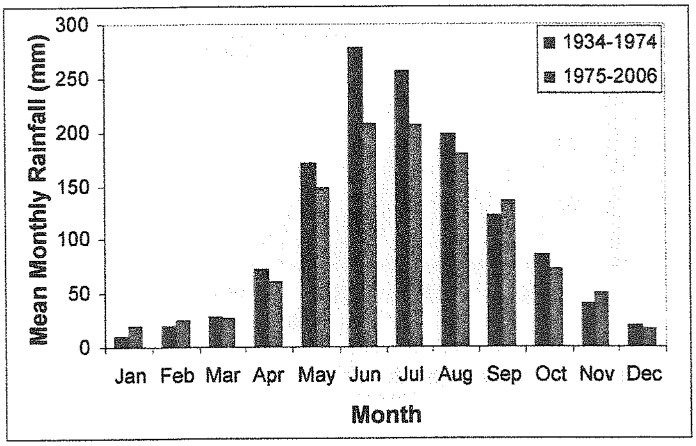

Figure 2. Mean monthly rainfall at Dwellingup Forestry

From the monthly rainfall analysis a trend is apparent of decreased rainfall from March to August compared to pre-1975. Autumn and early winter months are drier, indicating a seasonal shift in rainfall, with the season breaking later. Fig. 2 shows an example of this from the Dwellingup Forestry station.

Analysis of daily rainfall intensity frequency distribution shows no obvious trends in the one-day and five day maximum annual rainfall, or in the one-day maximum summer and winter rainfalls. Rainfall intensity results are inconsistent across the catchment, with some stations registering as increase in the number of low intensity (<10mm/day) events per year, and others registering a decrease. However, there does appear to have been a general decrease in the frequency of higher intensity events, and of the volume of total rainfall falling in these higher intensity events. This supports the argument that there has not been an observable increase in extreme rainfall events. There are no clear trends in observed change from west to east.

4.2 Streamflow Analysis

For both Baden Powell and Yarragil stream gauging sites there has been a decrease in the total stream yield from pre-75 to post-75. Flow duration curves show that there has been a distinct decrease in low flows. This is particularly apparent in Yarragil, due to its smaller catchment size resulting in higher sensitivity to change in inputs, with mean flow duration decreasing from 69% to 44% of the time.

Flood frequency curves use statistical analysis of recorded extreme flow events to estimate the magnitude of floods with a certain probability of exceedance. The flood frequency curves generated for both Baden Powell (Fig 3) and for Yarragil suggest that the probability of extreme flood events occurring has decreased in the post-75 period, with curves significantly different at the 5% confidence level. This is consistent with the decrease in extreme rainfall events.

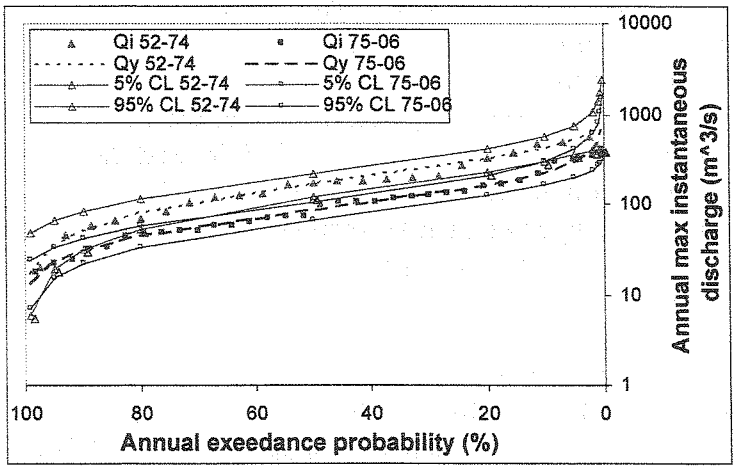

Figure 3. Flood frequency curves for Baden Powell Water Spout (Qi=observed AEP, Qy=statistically predicted AEP)

4.3 Hydrological Modelling

LUCICAT set up and calibration were successfully carried out through an iterative process to achieve an acceptable level of error between observed and modelled streamflow, flow duration curves, salinity and salt load for the five major stream gauging sites selected on the channel network. The difference achieved between observed and modelled values ranged from -0.8% to +2.7% for streamflow, and between -3.9% and -0.5% for total dissolved solutes load. Fig. 4 and Fig. 5 demonstrate the flow duration curve and streamflow respectively for the Baden Powell Water Spout at the catchment outlet. Similar plots were generated for each gauging station.

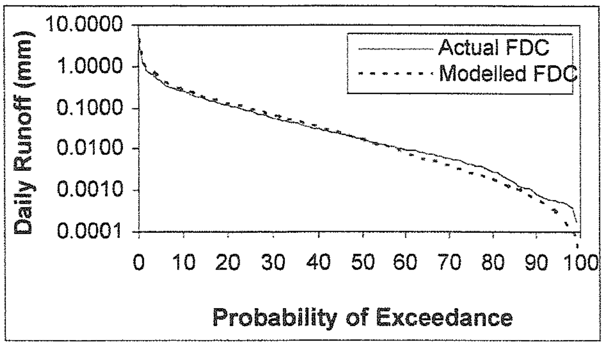

Figure 4. Flow duration curve for Baden Powell

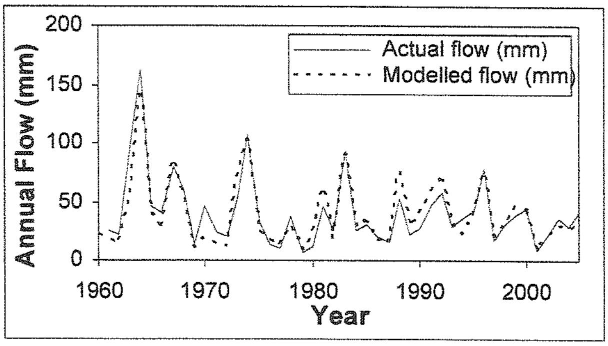

Figure 5. Actual and modelled flows for Baden Powell

The C-CAM climate projections have been used to create present and future rainfall sets for each of the subcatchments, with continuing decrease in rainfall predicted for the period 2035-2064 (Fig 6). At the time of writing, processing of the LUCICAT output catchment response to the projected climate change had not been finalised. When results become available they will give an indication of the direction and magnitude of change to stream yields, flood characteristics and salinity loading that may be expected in the future.

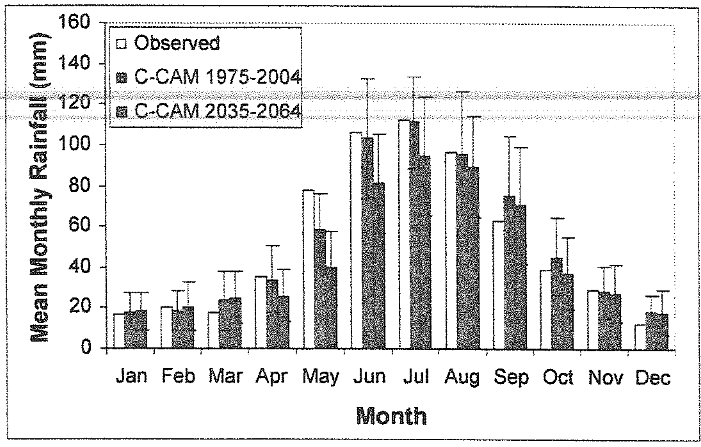

Figure 6. Mean catchment monthly rainfall, generated by LUCICAT from observed data and modelled present and future C-CAM realisations

5.0 Conclusions and Future Work

It has been shown that in the last century annual rainfall in the Murray Hotham Catchment has decreased, with a shift in seasonal distribution. However, there does not appear to be a trend in rainfall intensity frequency distribution at the daily scale. Hydrological systems have responded to the reduced input with lower total yield, and decreases in both low and high flow events. At the completion of the project there will be a clearer picture of how projected climate change will influence the hydrological systems of the catchment, adding to the knowledge gained from work already done in other catchments in south west Western Australia, including the Stirling Dam Catchment and Serpentine Catchment.

6.0 References

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