# Towards Separation of Climate and Land Use Effects on Hydrology: data analysis of the Googong and Cotter Catchments

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## EXTENDED ABSTRACT

Land use changes associated with agricultural practices can have notable effects on streamflow in rural catchments. Of special concern in many rural catchments are the increase in farm dam density from the 1970s and extensive groundwater extraction for irrigation, contributing to a decrease in streamflow. Changes in streamflow caused by land use changes, however, are easily veiled by fluctuating climate variability because the impacts of land use changes on streamflow can be comparatively small compared with those due to climate variance. Additional factors exacerbating the separation of land use change impacts from the effects of climate variability on streamflow are the lack of good quality streamflow records, especially prior to land use change periods of interest, and the capacity to estimate areal catchment precipitation with sufficient accuracy.

This study focuses on the use of tools to isolate the impacts of land use variations, such as farm dams and other drivers like surface and groundwater extractions, from climate variability to identify effects on streamflow properties. Major subcatchments of the Googong (Queanbeyan River at Tinderry) and Cotter catchments (Cotter River at Gingera) are used as initial test cases. The Googong Catchment is located 50 km south-east of the Australian Capital Territory (ACT) and has an area of approximately 891 $km^2$. Land uses in this catchment are a mixture of nature reserves, low-intensity forestry, rural residential, grazing and recreation areas. Farm dam development and groundwater extraction have intensified in the Burra and Upper Googong catchment since the 1970s. The Cotter catchment (480 $km^2$ ), some 40 km to the west, is far less developed and was selected as a possible control.

In this paper, initial results using data analysis techniques based on rainfall-runoff trend analysis, baseflow filtering, and unit hydrograph response curves are presented. These data analysis techniques are used to explore the hydrologic response characteristics in the Googong and Cotter subcatchments. For estimating areal rainfall, a weighted Theissen polygon method is used along with a long-term (1976-2006) rainfall surface to downscale how the rainfall varied daily and spatially in each polygon.

The Googong and Cotter River catchments show different hydrologic response characteristics in their respective subcatchments, Tinderry and Gingera. A steeper decreasing trend of runoff coefficient was detected in the data for the Queanbeyan River at Tinderry. It dropped remarkably after the 1990's compared with the Cotter River at Gingera. While monthly streamflow declined after 1990 in both catchments, monthly rainfall did not show as noticeable changes over time. This decreasing trend in streamflow was more prominent at Tinderry than Gingera. The nature of each catchment is examined by baseflow filtering, and unit hydrograph response curves. The annual baseflow fraction in individual catchments showed variation over time; however the pattern has not changed remarkably from year to year. The peak unit hydrograph response has declined over the last three decades at Tinderry. The data analysis is not conclusive enough to be certain that streamflow response reductions are not entirely due to climate. Further work based on daily rainfall-runoff modelling will be applied to determine if land use effects can be detected in the streamflow response.

## 1. INTRODUCTION

Land use changes associated with agricultural practices can have notable effects on streamflow in rural catchments. There are several factors which can cause streamflow reduction: land use change such as farm dams, farm forestry, groundwater and river extraction, climate variability and change, and drainage losses. They can impact on streamflow individually or together.

Among land use changes, the sharp and widespread increase in farm dam density of rural catchments from the 1970s and extensive groundwater extraction for irrigation can significantly contribute to a decrease in streamflow. Surface water captured by farm dams and extracted groundwater used for domestic, stock and irrigation purposes are used as an additional water resource during the summer season. Farming risks due to water shortage problems during low rainfall periods can be reduced by farm dam construction and groundwater extraction. However, they can have significant impacts on streamflow reduction and on ecosystems downstream.

In analysing land use changes on streamflow, their effects are easily veiled by fluctuating climate variability because the impacts of land use changes on streamflow can be comparatively small compared to those of climate variance. Additional factors exacerbating the separation of land use change impacts from the effects of climate variability on streamflow are: the lack of good quality streamflow records prior to the development period of interest; the lack of farm dam data relevant to their changing density and volume over time; and the lack of appropriate simulation models (Letcher et al., 2001; Neal et al., 2002; Schreider et al., 2002).

The capacity to estimate areal rainfall is another limitation. Having sufficiently accurate rainfall is obviously one of the most important elements in rainfall-runoff analysis. Rainfall data are provided as a point measurement within a catchment and need to be averaged over the catchment to be used as input data in a spatially lumped rainfall-runoff model. Streamflow impacts due to land use changes can be hidden by errors in areal rainfall estimates, when those errors are larger than the effect of land use changes on reducing streamflow. The effects of errors in areal rainfall estimates can be amplified specially when rainfall patterns change markedly over time and space or point measurement rainfall data themselves have errors.

Various algorithms and simulation models have been used to analyse the effects of land use change on streamflow. In the special case of farm dam development effects on streamflow, Letcher et al. (2001) and Schreider et al. (2002) conducted trend analyses based on the Estimated Generalized Least Squares (EGLS) and the Generalized Additive Model (GAM) methods. The calibrated IHACRES conceptual rainfall-runoff model (Jakeman and Hornberger, 1993) was used to simulate daily streamflow over the entire period of analysis. SKM (2000; 2001), Neal et al. (2002), and Egis (2002) estimated impacts on streamflow caused by farm dam developments and land use changes by applying the TEDI (Tool for the Estimation of Dam Impacts) model which is a lumped water balance model using a monthly time-step. In McMurray (2006) a GIS-based annual rainfall-runoff model was used to incorporate the effects of streamflow reduction by farm dam interception. The WaterCress (Water-Community Resources Evaluation and Simulation System) modelling platform (Clark et al., 2002; Cresswell, 2002) was also used to assess impacts of farm dam development (Heneker, 2003; Savadamuthu, 2002; 2004; Teoh, 2002). Farm dam development over the entire Googong catchment was investigated using high-resolution ortho-rectified aerial photography and temporal trends in rainfall and streamflow were compared with biomass, using NDVI (Normalised Difference Vegetation Index) extracted from multi-temporal low resolution NOAA (National Oceanographic and Atmospheric Administration) and SPOT VI satellite imagery (AGRECON, 2005). These studies generally showed reductions of runoff in the individual catchments considered. These model-based approaches for analysing impacts of farm dam development on streamflow are based on testing statistical significance between observed and simulated runoff volume using fixed parameter values. Therefore, there is a potential limitation in the capacity to separate the impacts of land use change from climate variability (the model parameters are assumed to be independent of the observed variation in climate).

The objectives of this research are to identify relationships between climate and land use effects on streamflow, and to develop a model to predict the effects of climate, farm dams and other drivers on the hydrological response. In this paper, initial results using data analysis techniques will be presented. These data analysis techniques are used to explore the hydrologic response characteristics in the Googong catchment and the same methodology is applied in the less-developed Cotter River catchment as a comparison.

## 2. STUDY SITE

The Googong catchment is located 50 km south-east of the Australian Capital Territory (ACT). The main drainage is the Queanbeyan River and the catchment has an area of approximately 891 km$^2$ with moderately steep terrain. The elevation within the Googong catchment ranges from 1,370 to around 650 m at the reservoir. The catchment consists of three major parts having different catchment characteristics. One is a lower, extensively grazed north western landscape covering the Burra catchment and the lower reaches of the Queanbeyan River. The second is a central undulating landscape with strongly incised drainage systems, little floodplain development, and is surrounded by mountain ranges on either side. The third is an upper river landscape characterised by an undulating terrain surrounded by mountainous ranges (Ecowise, 2006b). Land use in this catchment is a mixture of nature reserves, low-intensity forestry, rural residential, grazing and recreation areas. Farm dam development and groundwater extraction are highly concentrated in the Burra and Upper Googong catchment (AGRECON, 2005).

The Cotter River catchment covers about 480 km$^2$ and is located in the west and south west of the ACT. Most of the catchment is within the ACT and elevation ranges from 500 through to 1,900 m and there are three main parts having different catchment characteristics. One is a lower northern landscape with extensive undulations, surrounded by a mountainous range to the west. The second is a central deeply incised valley system flanked by steep ranges to the east and west. The third is an upper river landscape characterised by a series of alluvial valley flats surrounded by mountainous ranges, feeding respectively into the Cotter, Bendora and Corin Dams (Ecowise, 2006a).

In this paper, the subcatchments located in the upper part of the Queanbeyan and Cotter River are selected to avoid effects from the regulation of storages in the Googong and Cotter River catchments. Stream gauges for the Queanbeyan River at Tinderry (410734) and the Cotter River at Gingera (410730) are chosen for analysis and details are listed in Table 1.

**Table 1.** Stream gauge station information for the Googong and Cotter River subcatchments

| Station ID | Area (km$^2$) | Elev. (m) | Period | Missing rate (%) |
|---|---|---|---|---|
| 410734 | 506* | 785** | 04/08/66~ 08/05/06 | 0.4 |
| 410730 | 148** | 958** | 03/01/64~ 12/06/03 | 0.2 |

* Source: AGRECON (2005)
** Source: Bureau of Meteorology: http://www.bom.gov.au/hydro/wrsc

There are more than 200 rainfall gauging stations around the study areas available from the Bureau of Meteorology (BoM) and Ecowise. Among these, 62 rainfall stations have more than 30 years of record. The Canberra Airport rainfall gauging station has the longest record with no missing data (data are available from 1939 through to the present). Rainfall is on average 615 mm/y and the mean annual maximum and minimum rainfall are around 1,063 and 262 mm at the Canberra Airport station. The location of the catchments and stream gauge stations, and the mean annual rainfall surface are shown in Figure 1.

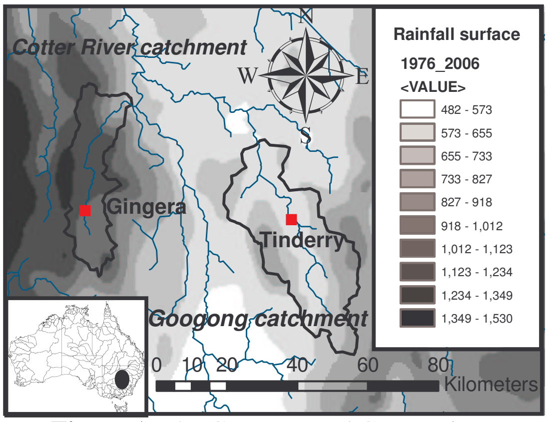


**Figure 1**. The Googong and Cotter River catchments with mean annual rainfall surface and stream gauging stations chosen for analysis

## 3. METHODOLOGY

Analysis and results presented in this paper are based on trend analysis, baseflow filtering, and estimation of unit hydrograph response curves.

Trend analysis of runoff coefficients is used here as a simple means of estimating the proportional runoff volume expected from a catchment for a given amount of rainfall. It is useful for comparing catchments having different rainfall-runoff characteristics, or for identifying change in a catchment over time. A moving average (or running mean) has been used to detect variations in rainfall and streamflow.

There are several methods for estimating the baseflow component in a record of observed streamflow. The simplest method of determining the baseflow component of observed streamflow is to use mathematical filters. There also are many filtering techniques for baseflow separation using assumptions about the structure of the baseflow hydrograph or physical processes based on baseflow recession curves (Chapman, 1999; Croke et al., 2002; Furey and Gupta, 2001; Gustard et al., 1992). The baseflow separation method used is the running minimum filter (Croke et al., 2001) which makes no assumption about physical processes causing the form of baseflow. This filter is an alternative to the BFI (Gustard et al., 1992) using a running minimum filter of variable width (typically 5 days is used) followed by a running average filter with the same width (Croke, 2005).

An estimate of the average unit hydrograph response curve is a useful means of comparing hydrologic response characteristics in different catchments and their change over time. A simple method for obtaining a non-parametric estimate of the unit hydrograph is through Fourier deconvolution of the auto-correlation of rainfall and cross correlation of streamflow with rainfall (Croke, 2005). The advantage of using the correlation functions over the time series is that the variability inherent in catchment response is averaged before deconvolving the signal. This approach is particularly useful for investigating the peak of the unit hydrograph.

There are several methods to estimate daily areal rainfall such as the arithmetic-mean, Thiessen polygons, isohyetal, trend surface analysis, finite element and Kriging methods. In this paper, a weighted Theissen polygon method is used. In this approach, an average rainfall surface from 1976-2006 is used to represent the spatial variation of rainfall in each polygon. This compensates for the influence of the location of the gauge(s) within (or nearby) the catchment (gauges tend to be located in the valley floor where there is typically a lower rainfall than on the more elevated parts of the catchment). The surface is based on fitting splines (Hutchinson, 1995) to the monthly totals at each rainfall station.

## 4. RESULTS

The long term rainfall surface is shown in Figure 1. The associated average monthly rainfall and the measured streamflow for each subcatchment are shown in Figure 2.

Even though the Cotter River catchment at Gingera is close to the Googong catchment (approximately 40 km to the west of the Googong catchment), the plot captures some of their very different climate patterns and hydrologic response characteristics. Tinderry has less variation in mean monthly rainfall patterns than Gingera. Moreover, mean monthly streamflow increases from the autumn and has a peak during the winter season at Tinderry, while mean monthly areal rainfall decreases during the autumn and winter season. Mean areal rainfall and streamflow for Gingera increase from the winter season and have a peak during the spring season. In contrast to Gingera, the Tinderry flow peak is out of phase with the rainfall because of the effects of evapotranspiration and lower catchment moisture storage.

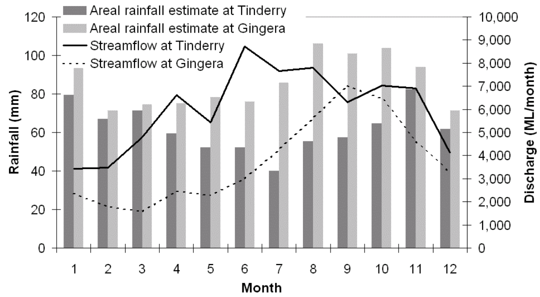


**Figure 2**. Mean monthly estimated areal rainfall and observed streamflow for Tinderry and Gingera

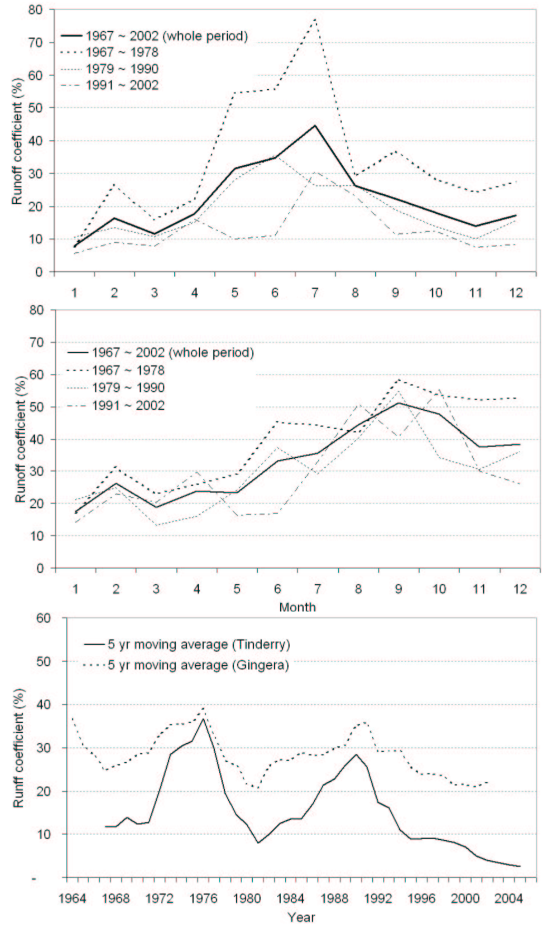


**Figure 3**. Mean monthly runoff coefficient for Tinderry (top panel), for Gingera (middle), and annual runoff coefficient for both catchments (bottom)

Figure 3 shows the mean monthly and annual runoff coefficients for the two subcatchments. The annual values are calculated as 5-year moving averages. Note that the mean monthly runoff coefficient drops significantly at Tinderry through time, while Cotter River catchment at Gingera does not show this kind of remarkably declining pattern. The annual runoff coefficient shows a similar pattern for both catchments, with high variability over time. However, while runoff coefficients are similar during wet periods, the runoff coefficient drops more steeply during dry periods at Tinderry because of comparatively low storage capacity to discharge ratio. In that case, we have two interpretations about the steep decrease in mean monthly and annual runoff coefficients for the Queanbeyan River at Tinderry. One is that it is caused by the effects of climate such as low rainfall in the catchment. The other is the nature of the catchment such as storage capacity (the combined surface and sub-surface storage capacity of the catchment) and land use changes in the catchment. Both factors could be important.

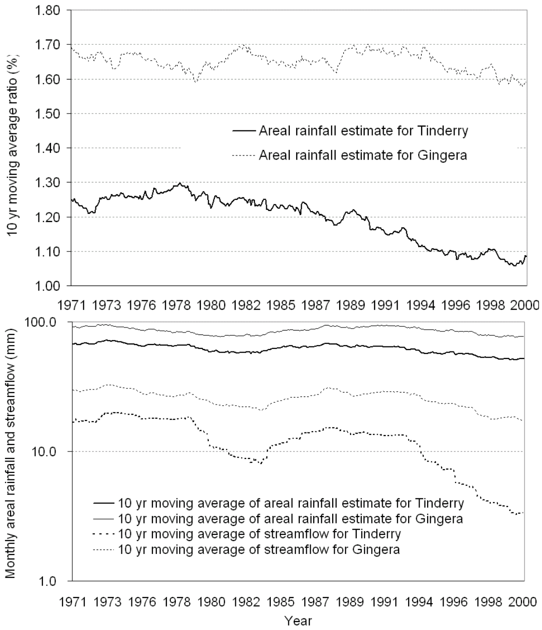


**Figure 4**. Using 10 year moving averages, ratio of areal rainfall for Tinderry and Gingera relative to rainfall at Canberra airport (top panel), and trends of monthly estimated areal rainfall and observed streamflow for Tinderry and Gingera (bottom)

To investigate the trends further, the ratio of Tinderry and Gingera subcatchment rainfall to that at Canberra airport is shown in the top panel of Figure 4. The numerator and denominator in the ratio are 10-year moving averages. Areal rainfall estimates for Gingera look very similar, in proportion, to records at Canberra Airport. But Tinderry rainfall shows a strong relative decline, particularly during the 1990s. Monthly streamflow shows a declining pattern after 1990 in both catchments, whereas monthly rainfall does not show as noticeable changes over time. Moreover, streamflow in the Queanbeyan River at Tinderry has declined in a spectacular manner compared to the Cotter River catchment at Gingera. These facts prompt the question: is the steeper decline of Tinderry runoff coefficient totally due to drying of the climate. There is some possibility that the nature of moisture storage in the soils and vegetation of Tinderry is so much lower than Gingera that a decrease in rainfall causes a much larger decrease in stream yield.

Figure 5 is an attempt to illustrate the potential storage capacity to discharge ratio in the two catchments. Annual baseflow fractions of total discharge were computed using the running minimum filter for this purpose. Note that they have not changed over time for each catchment, even though the baseflow fraction for Tinderry is smaller and shows a comparatively marked annual variation. Gingera has much more impact on baseflow, and quick flow response is much higher at Tinderry compared to that at Gingera.

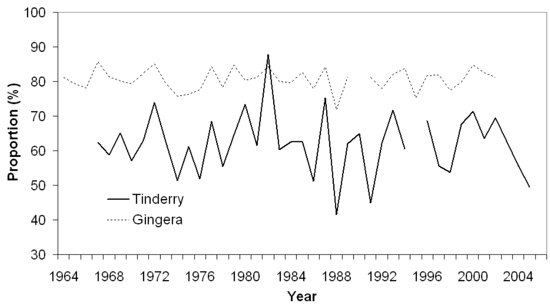


**Figure 5**. Annual baseflow fraction of total discharge for Tinderry and Gingera.

Estimates of an average unit hydrograph response for Tinderry and Gingera are shown in Figure 6. They are plotted based on three time periods so as to consider changes in streamflow response in each period. The unit hydrographs for each period are normalized by the peak flow from 1967 to 1978. As seen in Figure 6, the peak of the unit hydrograph for Tinderry has declined over time, while that for Gingera has increased slightly. Moreover, recession curves in the unit hydrograph are steeper at Tinderry than Gingera. Further analysis of the uncertainty in these curves, based on bootstrapping for example, will be needed here to assess if these changes through time are significant.

## 5. DISCUSSION AND CONCLUSIONS

Several data analysis techniques were used to examine the changes in the relationship between rainfall and runoff in the two catchments. Monthly streamflow declined noticeably after 1990 in both catchments, in nonlinear proportion to the rainfall. This decreasing trend was more prominent in the Queanbeyan River at Tinderry. The nature of each catchment, for instance storage capacity and land use changes, was examined by use of baseflow filtering and unit hydrograph response curves. The potential storage to discharge in individual catchments showed variation over time on an annual basis, but it has not changed remarkably over time.

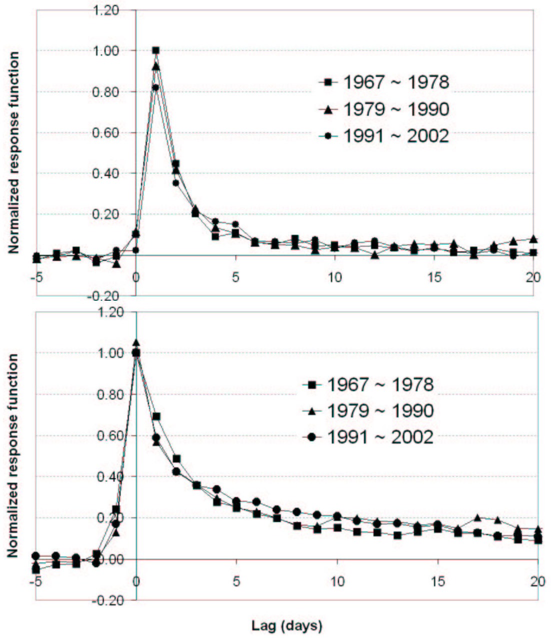


**Figure 6**. Estimates of an average unit hydrograph response through time for Tinderry (top panel) and Gingera (bottom) subcatchments.

The hydrologic response characteristics in the Googong catchment suggest that it is more vulnerable to land use changes such as farm dam development and groundwater extraction, and that these could be accelerating the significant reduction in runoff volume.

Further work will however be needed to separate the effects of climate and land use in the Googong catchment. This work must include complementary model-based analysis of the dynamic relation between rainfall and runoff using daily records. Such modelling should make minimal assumptions and aim to capture the changes in response characteristics of the catchment through time. The aim would be to assess if there is a systematic change in the response characteristics that relates to land use changes. Uncertainty characterisation of the parameters in the model used will be needed so as to assess the significance of any observed change in its parameter values. The influence of input uncertainties will be evaluated using the method describe by Croke (2007). Moreover, we will investigate improvements in streamflow prediction based on different areal rainfall estimation methods, identification and correction of rainfall errors and patching of missing rainfall records.

Other catchments with similar seasonal rainfall patterns and hydrologic response to Googong will be selected for analysis. Each will have varying degrees of land use change over the last 30 years. It is hoped that such systematic analyses and modelling will lead to further improvements in the ability to separate land use effects from those of climate on hydrologic response.

## 6. ACKNOWLEDGMENTS

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## 7. REFERENCES

AGRECON, 2005, MDBC Hillside farm dams investigation, MDBC Project 04/4677DO, Draft Report, July 2005.

Chapman, T.G., 1999, A comparison of algorithms for stream flow recession and baseflow separation, *Hydrological Processes*, 13(5), 701-714.

Clark, R.D.S., Pezzaniti, D. and Cresswell, D., 2002, WaterCress - Community Resources Evaluation and Simulation System - A tool for innovative urban water systems planning and design, Hydrology and Water Resources Symposium, Melbourne, Victoria, pp. 21-23.

Cresswell, D.J., 2002, WaterCress: Water - Community Resource Evaluation and Simulation System; Unpublished reference manual, Department of Water, Land and Biodiversity Conservation, Government of South Australia.

Croke, B.F.W., 2005, Land use impacts on hydrologic response in the Mae Cheam catchment, Northern Thailand, Proceedings of the 2005 International Conference on Simulation and Modelling, V. Kachitvichyanukul, U. Purintrapiban, P. Utayopas, eds., Bangkok, Thailand, January 17-19, 2005, pp434-439 (http://www.mssanz.org.au/simmod05/papers/C5-03.pdf).

Croke, B.F.W., 2007, The role of uncertainty in design of objective functions, MODSIM 2007, Christchurch, NZ (this volume).

Croke, B.F.W., Evans, W.R., Schreider, S.Y. and Buller, C., 2001, Recharge estimation for Jerrabomberra Creek catchment, the Australian Capital Territory, In: International Congress on Modelling and Simulation, Canberra, 10-13 December 2001, eds F. Ghassemi, P. Whetton, R. Little and M. Littleboy, ISBN 0 86740 525 2, vol 2, p555-560.

Croke, B.F., Smith, A.B. and Jakeman, A.J., 2002, A one-parameter groundwater discharge model linked to the IHACRES rainfall-runoff model, In: A.E. Rizzoli and A.J. Jakeman (Eds), Proceedings International Environmental Modelling and Simulation Society (iEMSs), Biennial Conference, Lugano Switzerland, pp. 428-433.

Ecowise, 2006a, February 2006, Cotter catchment fire recovery mapping; Lower Cotter catchment draft management project, ACTEW Corporation and Evironment ACT, Ecowise Environmental project number AG100065.

Ecowise, 2006b, Googong water supply catchment land cover and land use, 2005/2006, ACTEW Corporation and Evironment ACT, Ecowise Environmental project number AG100073.

Egis, 2002, Estimation of impact of farm dams on streamflow: Little Yarra River, Melbourne Water, Victoria.

Furey, P.R. and Gupta, V.K., 2001, A physically based filter for separating base flow from streamflow time series, *Water Resource Research*, 37(11), 2709-2722.

Gustard, A., Bullock, A. and Dixon, J.M., 1992, Low flow estimation in the United Kingdom, Institute of Hydrology, Report 108, UK.

Heneker, T.M., 2003, Surface Water Assessment of the Upper River Torrens Catchment, Department of Water, Land and Biodiversity Conservation, Report DWLBC 2003/23, South Australia.

Hutchinson, M.F., 1995, Interpolating mean rainfall using thin plate smoothing splines, *International journal of geographical information systems*, 9(4), 385.

Jakeman, A.J. and Hornberger, G.M., 1993, How much complexity is warranted in a rainfall-runoff model? *Water Resource Research*, 29(8), 2637-2649.

Letcher, R.A., Schreider, S.Y., Jakeman, A.J., Neal, B.P. and Nathan, R.J., 2001, Methods for the analysis of trends in streamflow response due to changes in catchment condition, *Environmetrics*, 12(7), 613-630.

McMurray, D., 2006, Impact of farm dams on streamflow in the Tod River Catchment, Eyre Peninsula, South Australia, Department of Water, Land and Biodiversity Conservation, Report DWLBC 2006/22, South Australia.

Neal, B.P., Nathan, R.J., Schreider, S.Y. and Jakeman, A.J., 2002, Identifying the separate impact of farm dams and land use changes on catchment yield, *Australian Journal of Water Resources*, 5(2), 165-175.

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

Savadamuthu, K., 2004, Surface water assessment of the Tookayerata Catchment, Department of Water, Land and Biodiversity Conservation, Report DWLBC 2004/23, South Australia.

Schreider, S.Y. Jakeman, A.J., Letcher, R.A., Nathan, R.J., Neal, B.P., and Beavis, S.G. 2002, Detecting changes in streamflow response to changes in non-climatic catchment conditions: farm dam development in the Murray-Darling basin, Australia, *Journal of Hydrology*, 262(1-4), 84-98.

SKM, 2000, The impact of farm dams on Hoddles Creek and Diamond Creek Catchments, Melbourne Water, Final Report 2, Victoria.

SKM, 2001, Assessment of farm dam impact on the Plenty River Catchment, Melbourne Water, Final 1, Victoria.

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