The Department of Water, Land and Biodiversity Conservation

Surface Water Assessment of the Upper River Torrens Catchment

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Department of Water, Land and Biodiversity Conservation

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Cover Photographs

DWLBC, Gumeracha Weir and Farm Dams in the Upper River Torrens catchment.

FOREWORD

South Australia's water resources are fundamental to the economic and social wellbeing of the State. Water resources are an integral part of our natural resources. In pristine or undeveloped situations, the condition of water resources reflects the equilibrium between rainfall, vegetation and other physical parameters. Development of surface and groundwater resources changes the natural balance and causes degradation. If degradation is small, and the resource retains its utility, the community may assess these changes as being acceptable. However, significant stress will impact on the ability of a resource to continue to meet the needs of users and the environment. Degradation may also be very gradual and take some years to become apparent, imparting a false sense of security.

Management of water resources requires a sound understanding of key factors such as physical extent (quantity), quality, availability, and constraints to development. The role of the Knowledge and Information Division of the Department of Water, Land and Biodiversity Conservation is to maintain an effective knowledge base on the State's water resources, including environmental and other factors likely to influence sustainable use and development, and to provide timely and relevant management advice.

Bryan Harris
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EXECUTIVE SUMMARY

Since European settlement, large scale land clearing and development within the Upper River Torrens catchment has modified the natural features and drainage of the region, impacting heavily on the aquatic environment. In recent times, there has been a shift from activities such as broad based agriculture to more water intense industries such as horticulture, viticulture and vegetables. Associated with such land use change has been increases in farm dam development. The Department of Water, Land and Biodiversity Conservation (DWLBC), the Torrens Catchment Water Management Board (TCWMB) and the South Australian Water Corporation (SA Water) have become concerned as to the impact of farm dams on the level of water resources available to both the environment and the water supply system for Adelaide. Quantifying the impact that current development of farm dams and reservoirs have had, and that potential future development may have, on the natural streamflow regime, is an important step to providing a more informed and sustainable approach to the management of surface water resources in this catchment.

A detailed assessment of the surface water resources within the Upper River Torrens catchment was therefore undertaken by DWLBC in conjunction with the TCWMB and SA Water. The methodology of this study involved an analysis of available hydrological data (rainfall, evaporation and streamflow) and catchment information (farm dam and water supply data) to allow the construction of an operational hydrological computer model of the catchment. This model was then used to evaluate current and potential impacts from farm dam development. This technical report contains the methodology and results of the assessment and provides for future surface water resource management options for the mainly rural catchment, which extends from the Eastern headwaters to Gorge Weir.

Hydrology The average annual rainfall for the Upper River Torrens catchment is approximately 755 mm/year, but varies between 650 mm/year and 1,000 mm/year over the catchment. There is generally reliable winter rainfall and 80% of total annual rainfall occurs between April and October. Records indicate an overall decreasing trend in annual rainfall totals over the last 100 years, in addition to significant decreases in rainfall during June.

Evaporation data showed a steady increase in annual totals over the last 45 years, corresponding with observed increases in sunshine and temperature. Increases have been particularly significant during February and September.

The assessment of the sustainable water resources of the catchment is complicated by a lack of recorded streamflow data. At many locations where water level is recorded, the data is affected by water supply operations and bulk pipeline transfers from the River Murray. This necessitated the estimation of the resource to be reliant on modelled data. The highest levels of runoff generally occur in July and August, with the majority of total annual runoff occurring between May and November. The median runoff from the catchment has been estimated at 40,500 ML/year. DWLBC has established a gauging station in the River Torrens main channel below Gumeracha Weir to address the lack of recorded streamflow data in part, but diversions to and discharges from water supply reservoirs and pipelines are not adequately quantified. The value of the catchment in supplying water to Adelaide warrants a greater emphasis to be placed on resource measurement, particularly with respect to diversions from and releases into watercourses, and the importation of water from the River Murray.

Farm Dam Development There are approximately 1350 farm dams with a storage capacity of 5,750 ML located within the catchment (based on 1999 data). Overall dam density is approximately 17 ML/km^2, but this varies from 6 ML/km^2 to 36 ML/km^2 between sub-catchments and some individual stream reaches have densities as high as 100 ML/km^2 (equating to 100 mm of runoff). Current development levels have not exceeded the 50:50 development rule limits under the State Water Plan (2000) at a sub-catchment level, but a number of areas are highly developed and are approaching or exceeding these levels at a property scale (McMurray, 2001). This is particularly apparent in the lower rainfall and hence lower runoff areas of the catchment.

Water Supply Infrastructure and Operations The catchment is a major component of the water supply system for Adelaide and most catchment runoff enters the Millbrook and Kangaroo Creek Reservoirs. There is limited data on water supply operations (such as reservoir and weir releases and reservoir spills) currently recorded, reducing the usefulness of some existing stations that measure water level (Millbrook and Kangaroo Creek Reservoirs and Gorge Weir). The main channel of the River Torrens is used as a transfer aqueduct to facilitate the movement of water from the River Murray to the water supply network. On average, 19,000 ML of water is pumped and discharged from the Mannum-Adelaide Pipeline each year and 14,000 ML of this is released through scours at Mount Pleasant and Angas Creek during the summer months. As a result of this pumping the natural flow variability has been removed, chlorinated water is discharged into the local system and there is a potential for the transfer of non-native fish, invertebrates and parasites.

The major infrastructure associated with water supply has significant benefits for South Australia, and Adelaide in particular. However, the reservoirs and associated weirs and pipelines have the largest impact on native ecosystems because they change the natural flow regime so exclusively. There are also potential biological impacts associated with the release of water from reservoirs, particularly if there are large temperature differentials between the reservoir water and the stream. This can have a severe biological impact on the survival of native fish species. Strategies for reservoir releases are being investigated by DWLBC and SA Water.

Impact of Farm Dams on Catchment Runoff The calibrated hydrological model for the Upper River Torrens catchment was used to evaluate current and potential farm dam development impacts on catchment runoff. An upper limit of runoff captured by farm dams under the 50:50 rule was determined with an assumption that future development will not reduce the current “free to flow” areas (for example, reservoir easements and areas of native vegetation or those used for recreation) and the results presented below are based on this. However, it should be noted that if further development occurs in such free to flow areas, then much larger runoff volumes may be captured and impacts would increase, particularly during summer months when these are generally the only areas contributing to catchment flow. The impact from an increase in farm dam water use without increased development under the 50:50 rule was also examined.

Annual Impacts

Current development has reduced the annual median runoff from the Upper River Torrens catchment from 43,500 ML to 40,500 ML (7% reduction). The impact on annual flows is highest during drier years when over 20% of the total volume may be captured by farm dams. Although the impact reduces during wetter years, the volumes captured may be significantly higher. A further reduction of 6,500 ML is possible under future development (22% total reduction from the pre-farm development runoff), with minimum annual reductions from current flows of over 4,000 ML (10%). During drier years this may be as high as 16,000 ML (40%). Across sub-catchments, reductions in annual runoff vary significantly, with the greatest impact in Mount Pleasant and Footes Creek. Under future development, significant runoff is unlikely to be produced during drier years.

Seasonal Impacts

General trends in the magnitude and impact of intra-annual flow reductions were observed over the catchment. The lowest percentage reduction in flow and hence impact of farm dams occurred between July and October. However, actual volumes captured by dams may be quite high, as much of the annual rainfall and runoff occurs during these months. Between November and March the impact of farm dams on mean flow is at its greatest. While the flow during this period only constitutes a small percentage of the total annual flow, any reductions may be significant and pose a serious threat to water dependent ecosystems. Between April and June the impact is generally lower than during summer but is still significant. Runoff captured during these months delays the onset of winter flows and overall, shortens the length of the higher flow season.

At a sub-catchment scale, the impact is greatest in the Mount Pleasant, Birdwood and Footes Creek sub-catchments. Mount Pleasant is particularly affected and flow does not generally occur during summer. Future development may lead to very little, if any, flow from many sub-catchments between November and June.

Daily Impacts

Daily flow results have shown that current farm dam development has had the most serious impact on the low to medium flows over the catchment. Currently observed flows in this range are most likely produced by the remaining areas with little or no farm dam development. The timing and duration of flows affect important ecological responses and the overall sustainability of aquatic ecosystems. In the absence of water supply infrastructure, the median daily flow from the catchment would be 20 ML, a reduction of 25% from the pre-farm dam development flow of 27 ML. Flows greater than 10 ML/day currently occur for 35 days less per year than under adjusted flow conditions. Given the large catchment area, this implies an extension of the no-flow or dry period during late summer and early winter, when runoff generated after the initial wetting up period is used to fill dams. Similar results were found for each sub-catchment and only areas without farm dams currently contribute to summer flows in a majority of sub-catchments. The median daily runoff from the catchment has the potential to reduce to 17 ML/day and could significantly impact on higher flows.

Increased Dam Usage

An increase to a 70% dam usage rate, as compared with an assumed rate of 30%, may produce an additional 1,700 ML reduction in median annual flows (4% of current flow). At a monthly scale, the impact is likely to be greatest in April and May when more runoff is required to replace water used for irrigation. At a sub-catchment level, the impact of increasing dam usage was highly dependant on the current level of farm dam development. The Mount Pleasant and Footes Creek sub-catchments are currently highly developed and there is less potential for further development under the 50:50 rule. Therefore, an increase in usage from existing farm dams, as distinct from further farm dam development, is likely to have a more significant impact in these sub-catchments and more runoff is likely to be needed to replace water used for irrigation than for filling increased sized or new dams. The impact is considered less under increased dam usage than is likely from increased farm dam development in other sub-catchments. This finding has implications for water allocation planning, because management controls on water use cannot be exerted through development control alone.

Key Conclusions, Recommendations and Management Options The model and results that have been generated from this study form the basis for the implementation of management options to ensure the sustainable use of water resources within the catchment. A number of key recommendations are presented below, with the full recommendations contained in Section 6. These will help to further refine the water resource availability forecasts and hence enable the system to be managed sustainably.

1. While the current impact is a 7% reduction in median annual flow and still relatively low, controls on further farm dam development in areas that contribute runoff directly to the stream network (free to flow areas) and are not currently affected by dams should be the highest priority.
2. Because of the importance of low flows on the sustainability of aquatic ecosystems, it would be prudent to incorporate low-flow bypass structures on all new dam developments.
3. The management of water use from dams may be just as important as the management of dam development. Therefore, future water allocation planning will need to give careful consideration to dam water use, which includes conjunctive surface water and groundwater use.
4. The 50:50 rule for farm dam capacity and water capture needs further examination as it may not be conservative enough for long term water resource sustainability. Water supply infrastructure and operations have a much more significant impact on flow than do farm dams.
5. Ongoing assessment and monitoring of the ecological impact of changes to the flow regime due to farm dams and water supply infrastructure is crucial to enable the establishment of strategies to prevent further degradation, and for the future planning of environmental water allocations.
6. Further studies of the impact of water supply infrastructure and operations on the ecological value of the aqueduct zone are required. In particular, methods to ensure the direct transfer of water to the Millbrook Reservoir need to be explored.
7. This study has produced the best estimates possible with the limited data that is currently available. Additional information is required to gain a better estimation of the natural runoff from the catchment and hence a more solid appreciation of the availability and sustainability of water resources. In particular, an extension of the streamflow monitoring network, better estimation of farm dam volume and use, and sufficient continuously recorded data of water supply operations are vital.

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1. INTRODUCTION

1.1 Purpose

An assessment of the surface water resources within the River Torrens catchment was undertaken by the Department of Water, Land and Biodiversity Conservation (DWLBC) in conjunction with the Torrens Catchment Water Management Board (TCWMB) and the South Australian Water Corporation (SA Water), as part of the Mount Lofty Ranges Assessment Program. This technical report contains the methodology and results of this assessment and provides future surface water resource management options for the mainly rural Upper River Torrens catchment that extends from the eastern headwaters to Gorge Weir.

1.2 Background

The River Torrens is a significant waterway and a premier tourist attraction for Adelaide and South Australia. Forming part of the Mount Lofty Ranges, the water resources from the river and its contributing catchment provide for many purposes including domestic drinking supplies, agricultural industries (both stock supplies and irrigated horticulture and agriculture), recreation, rural living and the environment.

Since European settlement, large scale development within the River Torrens catchment has modified the natural features and drainage of the region, impacting heavily on the aquatic environment. River regulation and the development of the upper catchment as a component of the water supply system for Adelaide has caused one of the biggest changes to the natural flow regime. Catchment runoff provides a major input to the Millbrook and Kangaroo Creek reservoirs, which severely depletes seasonal flows and creates unnatural flow conditions in the River Torrens. The main channel is used as a transfer aqueduct to facilitate the movement of water from the River Murray to the reservoirs and the water supply system, creating artificial flows for the aquatic environment.

In recent times, there has been a continuing shift from broad based agricultural activities to more water intense industries such as horticulture, viticulture and vegetables. Associated with such land use changes has been an increase in farm dam development. Farm dams capture upstream runoff generated from the catchment, delaying natural downstream flows until a dam is full and overflows. In particular, large dams constructed across streams have significantly contributed to the decreasing levels of streamflow within many areas of the catchment.

Quantifying the impact that current development levels have had, and that potential future development may have, on the natural streamflow regime is an important step to providing a more informed and sustainable approach to the management of surface water resources in this catchment. Surprisingly, few studies have been undertaken in the Upper River Torrens catchment to determine the availability of water resources, the effect that water supply operations have had on the natural flow regime or to quantify the influence of farm dams based on their spatial position within the catchment. Those that have been undertaken, have generally only investigated monthly reservoir catchment yield (Tomlinson, 1996) and not yields from smaller sub-catchments. Others, such as the background reports for the Torrens Catchment Water Management Plan (Tonkin Consulting, 2000b; 2000c; 2000d) did not explicitly account for the spatial distribution of farm dams within the catchment.

1.3 Study Objectives and Methodology

The overall objective of this study is to provide an improved understanding of the surface water hydrology of the Upper River Torrens catchment that can form a technical foundation for the consideration of future management options and policy decisions. Such an understanding allows a more informed approach to ecologically sustainable development so that the surface water resources within the catchment are used to maximise the economic, social and environmental returns on a sustainable basis.

Hydrological computer models that can adequately describe catchment rainfall-runoff processes and incorporate current development levels offer the most flexible means of determining the availability of surface water resources and the impact of development on the natural flow regime. At the same time, such models provide scope to conduct environmental flows assessment, analyse the impact of potential future development and facilitate the assessment of various water management options.

The methodology for this study involved two stages, the first being the construction of an operational hydrological computer model, which involved:

- an analysis of available hydrological and climatological data relating to rainfall, evaporation and streamflow;
- consideration of development levels and infrastructure within the catchment that influences the surface water hydrology such as farm dams (capacity and location), land use and irrigation, and bulk water transfers and water supply operations;
- sub-division of the entire catchment into major sub-catchments based on a combination of primary streams, streamflow gauging stations, reservoirs and flow diversion structures, and then into minor sub-catchments based on secondary streams, topography, farm dam density, rainfall patterns and land use information;
- representation of the rural and urban areas, farm dams and bulk water transfer infrastructure in a surface water model; and
- calibration of model parameters using observed daily streamflow, rainfall, evaporation and bulk water transfer data.

The second stage of this study then used the calibrated model to generate synthetic runoff for a number of scenarios. These were:

- quantifying the effect that current levels of farm dam development have had on catchment runoff, by removing all farm dams from the model, calculating the pre-farm dam development or "adjusted" runoff[1] and then comparing this with recorded data;
- predicting the impact that increased farm dam development, up to the maximum allowed under the 50:50 rule[2], would have on pre-farm dam development runoff levels;
- quantifying the impact that farm dam development may have on the water supply system for Adelaide;
- predicting the impact that increased water usage from farm dams would have on current runoff levels, assuming a current usage level of 30% and increased levels of 50% and 70%; and
- predicting the joint impact of farm dams and below average rainfall periods on runoff.

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[1] The adjusted runoff is defined (State Water Plan, 2000) as "the annual catchment discharge with the impact of farm dams removed".

[2] The 50:50 rule (State Water Plan, 2000) restricts the allowable size of a farm dam for a given property to 50 percent of the median annual adjusted runoff from that property.

2. CATCHMENT DESCRIPTION

2.1 Overview

The Upper River Torrens catchment is immediately east of the city of Adelaide (Figure 1) and is part of the Mount Lofty Ranges Watershed. Extending from the eastern headwaters near Mount Pleasant to Gorge Weir, the catchment has an area of approximately 350km^2 and contains extensive and varied urban and rural areas. Major towns in the catchment include Mount Pleasant, Birdwood, Gumeracha, Mount Torrens, Kersbrook and Foreston.

The topography (Figure 2) of the catchment ranges from undulating hills in the eastern sub-catchments to steep gullies in the south-western sub-catchments. Elevation of the main channel ranges from 500 metres at Mount Pleasant down to 110 metres at Gorge Weir. For this study, the Upper River Torrens catchment was divided into 13 major sub-catchments based on a combination of primary streams, streamflow gauging stations, reservoirs and flow diversion structures (Figure 3). The elevation at the headwaters of these sub-catchments range from 500 to 600 metres.

Rainfall over the catchment varies significantly. Along the main river channel, the upper reaches around Mount Pleasant are the driest (650 mm/year), with the rainfall increasing down the catchment to the Cudlee Creek area (850 mm/year) before decreasing again towards Gorge Weir (670 mm/year). Rainfall increases through each sub-catchment from the main River Torrens channel to the upper reaches at higher elevations, with the highest rainfall occurring around the Uraidla area (1,000 mm/year).

The major land uses at a catchment scale are broadscale grazing (65% of total area), native vegetation and protected areas (12% of total area) and protected and recreation areas (8% of total area). Forestry (exotic vegetation) (3.5% of total area), vines (3.1% of total area), horticulture and floriculture (2.8% of total area) and intensive grazing (2.5% of total area) are also significant land uses. The proportions of each land use at a sub-catchment scale varies significantly. Irrigation from farm dams and ground water bores is assumed to be predominantly for vines, horticulture and floriculture and intensive grazing.

Farm dam development is significant, particularly in the eastern sub-catchments. Based on 1999 aerial surveys, it is estimated that there are 1,354 farm dams with a storage capacity of 5,750 ML within the catchment. Dam density is approximately 17 ML/km^2, but varies significantly at a sub-catchment level between 6 ML/km^2 to 36 ML/km^2.

The catchment has been developed as a major component of the water supply system for Adelaide. Catchment runoff provides input to the Millbrook and Kangaroo Creek Reservoirs, which have storage volumes of 16,000 ML and 19,000 ML respectively. The main channel of the River Torrens is used as transfer aqueduct to facilitate the movement of water from the River Murray to the water supply system. Water is released from the Mannum-Adelaide Pipeline through scours at Mount Pleasant, Angas Creek and Millbrook Reservoir.

Total mean runoff from the catchment is estimated at 45,980 ML/year, varying at a sub-catchment level from 1,220 ML/year (McCormick Creek) to 8,410 ML/year (Sixth Creek). However, there are few gauging stations within the catchment that allow an accurate estimate of total water resources that are not influenced by water supply operations.

The following sections provide detailed information on the Upper River Torrens catchment, both at a catchment and major sub-catchment scale.

2.2 Major Sub-Catchments

The purpose of dividing a catchment into a series of major sub-catchments is to allow a meaningful comparison of highly variable physical catchment attributes and behaviours such as topography, farm dam development, land use, rainfall levels and rainfall-runoff characteristics over large areas. Subsequently, it increases the efficiency of catchment modelling by allowing the straightforward application of variable parameter sets to represent localised hydrological conditions. It then enables informed conclusions as to localised impacts and effects of current and future farm dam development or specific land uses and hence, identifies areas that may be under significant environmental stress. At a catchment scale, such areas may not be easily identified.

The Upper River Torrens catchment was sub-divided into a series of major sub-catchments (Figure 3) based on a combination of primary streams, streamflow gauging stations, reservoirs and flow diversion structures. Table 1 details these sub-catchments and their respective areas. The Mount Pleasant, Birdwood, Gumeracha and Kangaroo Creek sub-catchments traverse the length of the catchment and contain the main channel of the River Torrens. The remaining sub-catchments drain into the main channel.

Table 1 Major Sub-Catchments in the Upper River Torrens Catchment

Sub-Catchment	Sub-Catchment Area (km^2)
Mount Pleasant	26.1
Birdwood	50.9
Hannaford Creek	15.1
Angas Creek	27.2
Gumeracha	28.4
Footes Creek	9.5
McCormick Creek	9.3
Kenton Valley	12.8
Millers Creek	22.8
Cudlee Creek	20.1
Kangaroo Creek	38.6
Kersbrook Creek	36.1
Sixth Creek	44.2
Total	341.1

The sub-division of major sub-catchments into minor sub-catchments is carried out during catchment model construction, allowing the most realistic representation of each sub-catchment possible to be modelled. It is based on on-stream farm dams, secondary streams, rainfall patterns and land use information and is discussed further in Section 4.2.1.

Figure 1 Location of the Upper River Torrens Catchment.

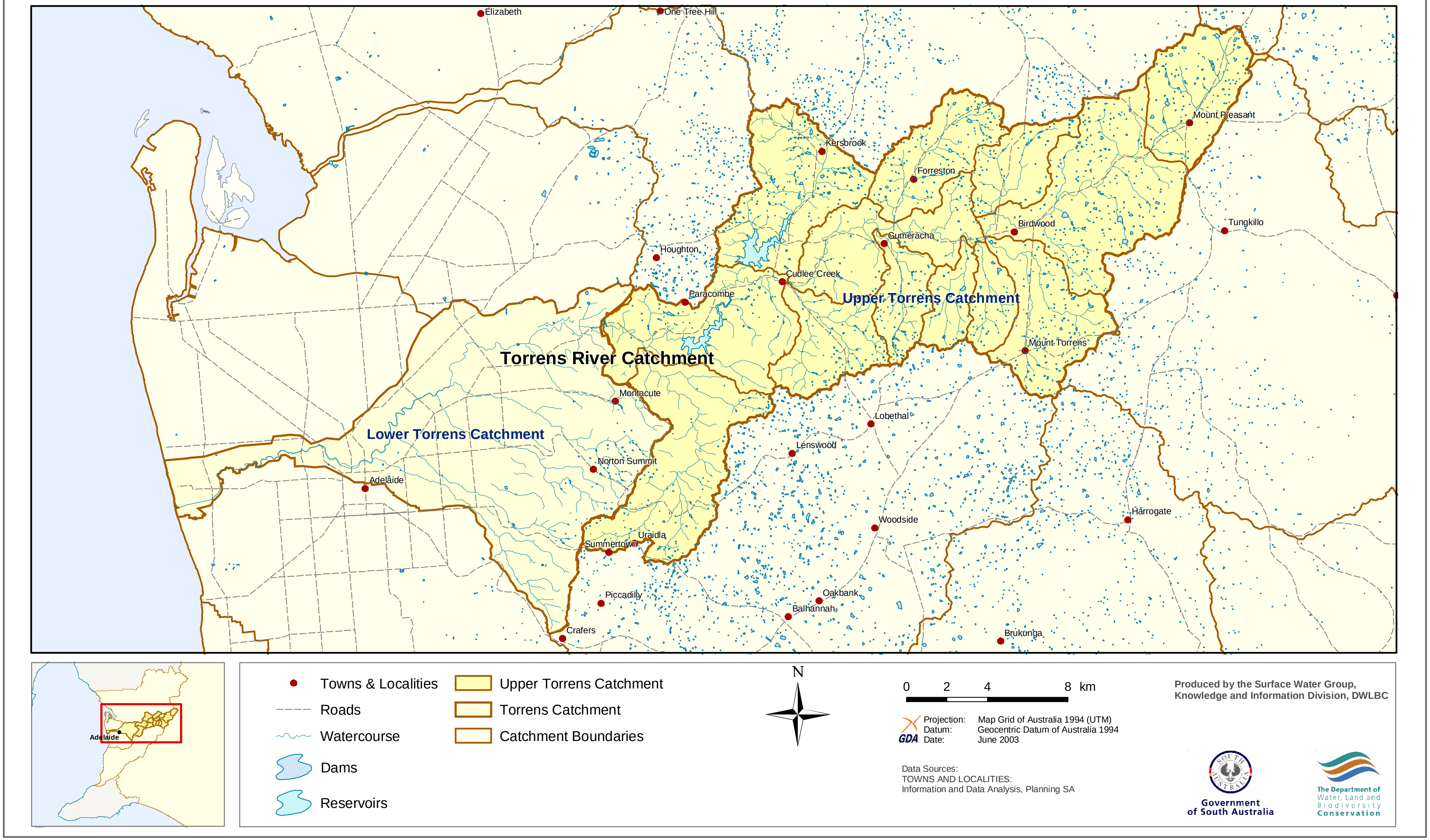


Figure 2 Topography of the Upper River Torrens Catchment.

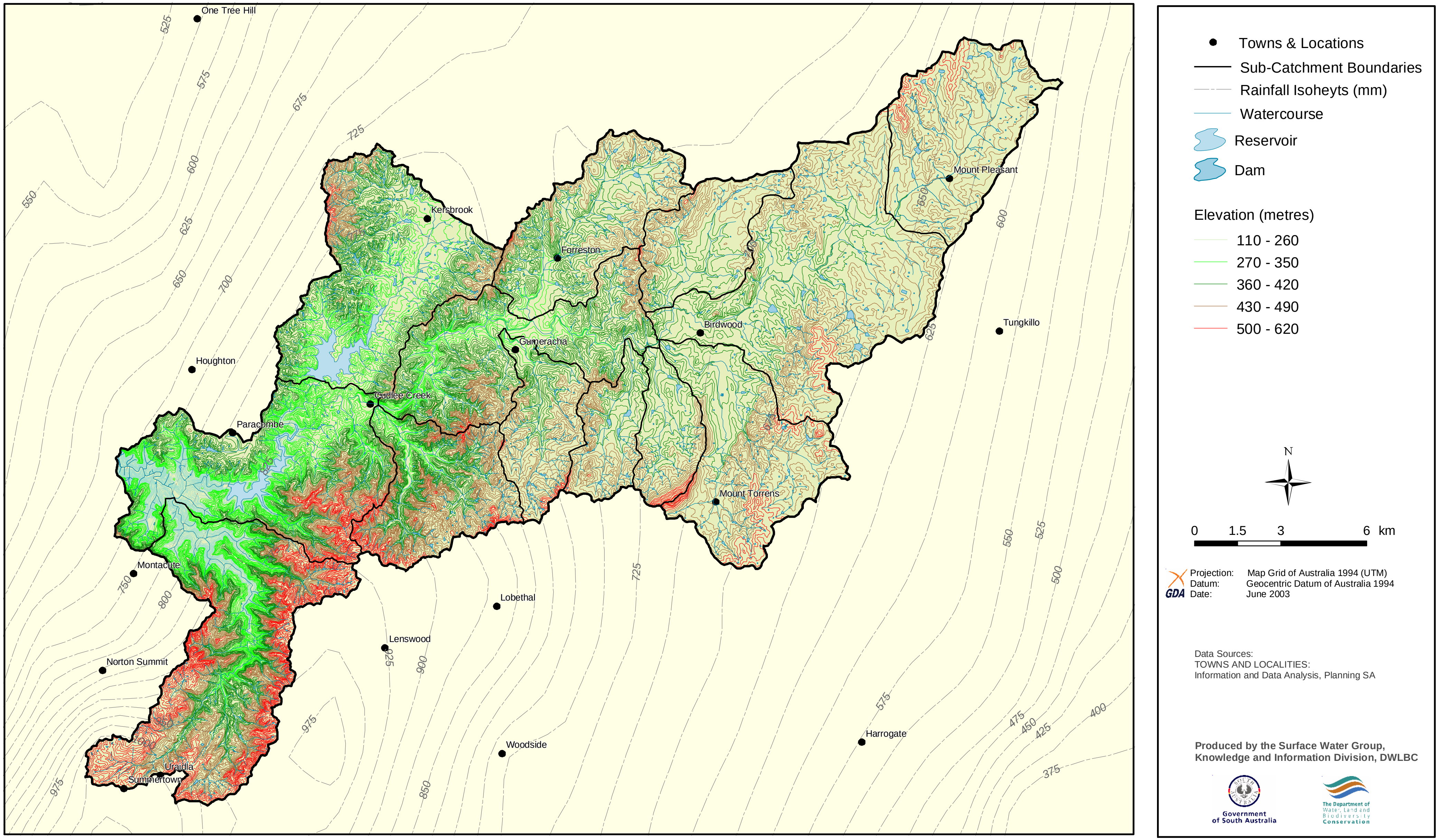
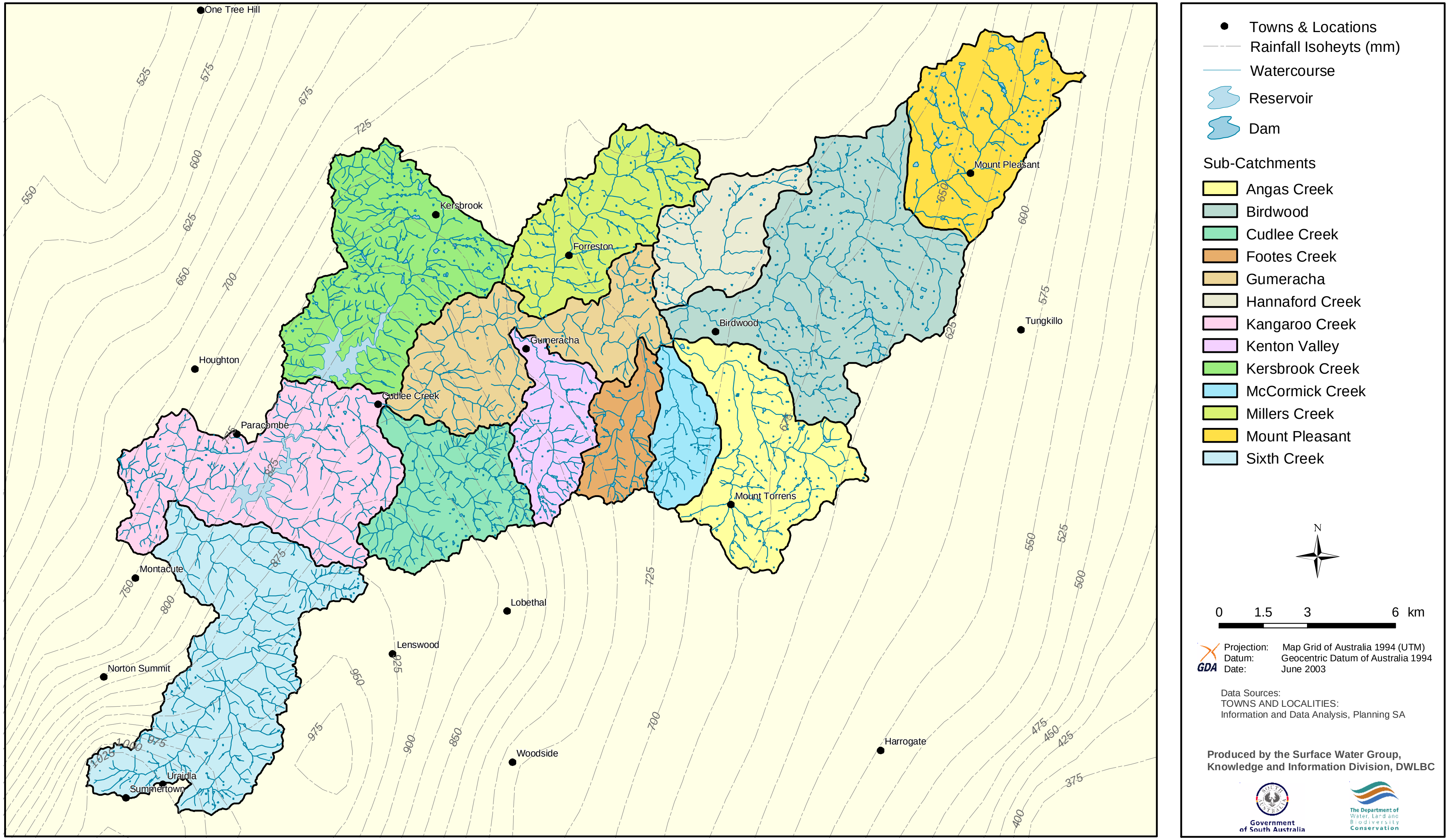


Figure 3 Major Sub-Catchments of the Upper River Torrens Catchment.



2.3 Farm Dam Development

Farm dams are water storage structures that are generally constructed in rural areas to capture surface runoff generated from the catchment areas upstream. The water stored in farm dams provides an additional source of water (to rainfall and pumped groundwater) for domestic water supplies, stock watering and irrigation, and enables security of supply during the drier, summer months. Dams used for stock and domestic purposes are generally smaller (often less than 5ML) than those used for irrigation. With a recent and continuing shift from broad based agricultural activities to more water intense industries such as horticulture, viticulture and vegetables there has been an increase in farm dam development. Examples of these increases include the Barossa Valley where there was a ten fold increase in total farm dam storage capacity between the 1970s and the 1990s (Cresswell, 1991) and the Upper Marne River Catchment where the total capacity has doubled between 1991 and 1999 (Savadamuthu, 2002).

Farm dams delay natural downstream flows until the dam is full and overflows. This directly impacts on the availability of water to users, including the environment, downstream of the dam, particularly when a large dam is constructed across the stream. The other negative impact of this is the change in the flow regime of the stream, which directly affects the riverine and other water dependent ecosystems. One of the main purposes of this study is to estimate the impact of farm dam development on the flow regime.

The analysis presented here provides a good indication of the level of farm dam development within the Upper River Torrens catchment. However, the actual impact from this development on the surface water resources and natural flow regime will be determined through catchment modelling (Section 5). The spatial location of farm dams within the catchment directly influences the volume of flow captured and hence the level of impact. For example, a 50 ML off-stream dam in the upper reaches of a catchment is likely to capture less runoff and hence have a lower impact than a sequence of five 10 ML on-stream dams nearer to the catchment outlet. These on-stream dams would have a larger catchment area and are likely to capture more runoff. Additionally, they would need to fill and then overflow before any upstream runoff can move downstream.

2.3.1 Number and Storage Capacity of Dams

Spatial information on farm dams in the Upper Torrens catchment was obtained from digitised 1:20,000 ortho-rectified aerial photographs taken during 1999. Using the digitised surface areas, estimates of the farm dam storage capacities were obtained from the following relationship (Pikusa, 1999):

$$V = 0.0002\,A^{1.2604} \qquad (1)$$

where:

V = volume/capacity (ML); and

A = surface area (m^2).

This formula was developed using surveyed dam information from the Marne River catchment and is one of a number of relationships between farm dam surface area and volume that has been developed within DWLBC and other South Australian Government Departments over the last ten years. Other relationships include those of McMurray (1996; 2001) and Billington and Kotz (1999). There are large variations in volume estimates produced by these formulae. Because very little data on farm dam volumes within the Upper River Torrens catchment have been used in the development of any of the available formulae, the relationship in Equation 1 was chosen because it generally produced a median value of all equation estimates. A summary of methods can be found in McMurray (2003b).

Due to a lack of surveyed farm dam data from the Upper River Torrens catchment and uncertainty associated with the use of surface area to volume relationships, a physical survey of as many dams over 15 ML, as permitted by land owners, was undertaken in parallel to this study. For the larger dams, these physical surveys identified shortcomings (both over- and under-estimating capacity by as much as 100%) with the farm dam storage relationships currently used. Dam volumes used for modelling and the statistics contained in this report use the results from the survey where available, and estimate capacities using Equation 1 for all other dams.

The 1999 level of farm dam development in the Upper River Torrens catchment was estimated at 1,354 dams with a storage capacity of 5,750 ML. Table 2 shows the distribution of these dams based on size classes. These numbers show that although dams less than 5 ML constitute 85% of the total number of dams, they contribute only 34% of the total dam capacity within the catchment. Therefore, 66% of the total storage capacity is contained in only 15% of the dams. This is highlighted in Figure 4. Because of the large proportion of storage capacity contained in the larger dams and the generally higher uncertainty in the volume estimates from surface areas of these dams, the physical survey provided a much more accurate estimate of total storage.

The extent of farm dam development at a major sub-catchment level is shown in Figure 5, with Mount Pleasant, Birdwood and Kersbrook Creek having the largest catchment storage, followed by Angas Creek and Millers Creek. Birdwood, Kersbrook Creek and Angas Creek have the highest number of dams followed by Millers Creek, Sixth Creek and then Mount Pleasant. Therefore, although Mount Pleasant has the second highest catchment storage, it has only the sixth highest number of dams. The distribution of farm dams by size within each sub-catchment is presented in Appendix A.

Table 2 Classification of Farm Dams by Capacity.

Dam Size Category	Number of Dams	Total Storage Capacity (ML)
< 0.5 ML	75 (6)[1]	26 (1)[2]
0.5 – 2 ML	811 (60)	1099 (19)
2 – 5 ML	257 (19)	807 (14)
5 – 10 ML	122 (9)	859 (15)
10 – 20 ML	40 (3)	603 (10)
20 – 50 ML	36 (2)	1100 (19)
> 50 ML	13 (1)	1256 (22)
Totals	1354 (100)	5750 (100)

[1] Number of dams in size category as a percentage of total number of dams.
[2] Total storage capacity of size class as a percentage of total storage capacity.

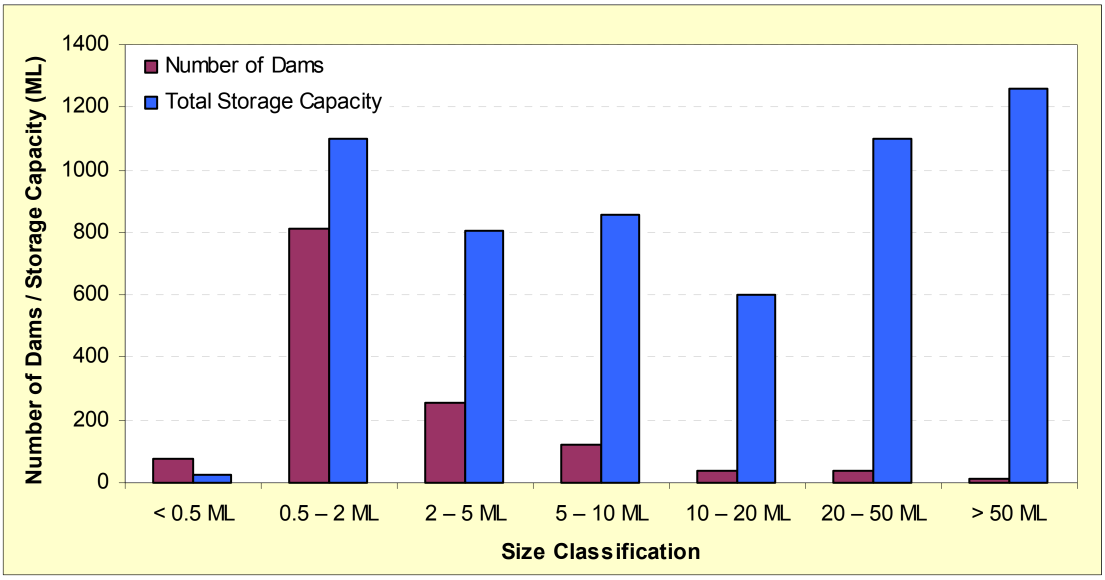


Figure 4 Comparison of the Number and Storage Capacity of Farm Dams by Size Class.

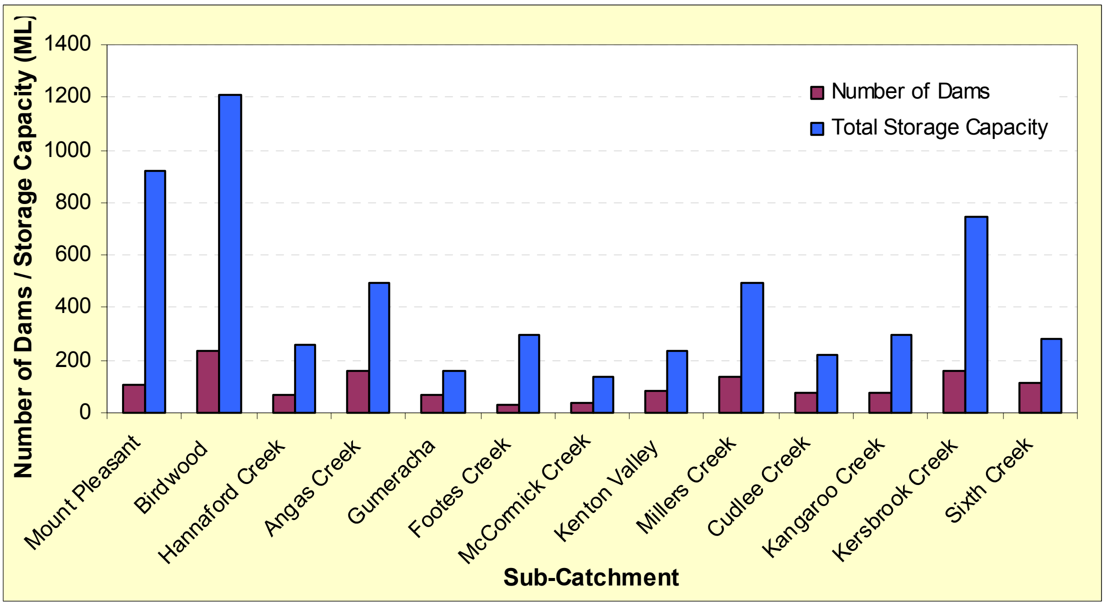


Figure 5 Comparison of the Number and Storage Capacity of Farm Dams between Major Sub-Catchments.

It must be noted that the estimates of farm dam storage capacity for the Upper River Torrens catchment and for individual sub-catchments presented here differ significantly with the values stated in the Torrens Catchment Water Management Plan (TCWMB, 2002; Tonkin Consulting, 2000b; 2000c). The values in the Catchment Plan over-estimate the total catchment storage capacity by almost 40% (9,400 ML as compared with 5,750 ML) and at a sub-catchment level by 20% to 70%. The main reason for the differences is unclear since the same aerial photography has been used and the surface area to volume relationship used here (Pikusa, 1999) produces higher storage capacities than that used for the Catchment Plan (McMurray, 1996). Such large over-estimations will adversely affect the effective estimation of surface water resources.

2.3.2 Dam Density

Considering just the total number of farm dams and storage capacity within a sub-catchment may result in misleading conclusions as to the level of development. Therefore, farm dam density (ML/km^2) should also be evaluated, as this incorporates the sub-catchment area and provides a better indication of the intensity of development. The higher the farm dam density is, the higher the impact of farm dams on the natural flow regime is likely to be.

The farm dam density of the entire Upper River Torrens catchment is 17 ML/km^2 but is quite variable across sub-catchments. Figure 6 compares the farm dam storage capacity and density within each sub-catchment, showing that the Mount Pleasant sub-catchment has the highest density of farm dam development. Footes Creek has the next highest density, even though the total storage capacity is lower than many of the other sub-catchments. The spatial distribution of farm dam development based on density at a major sub-catchment level is shown in Figure 7.

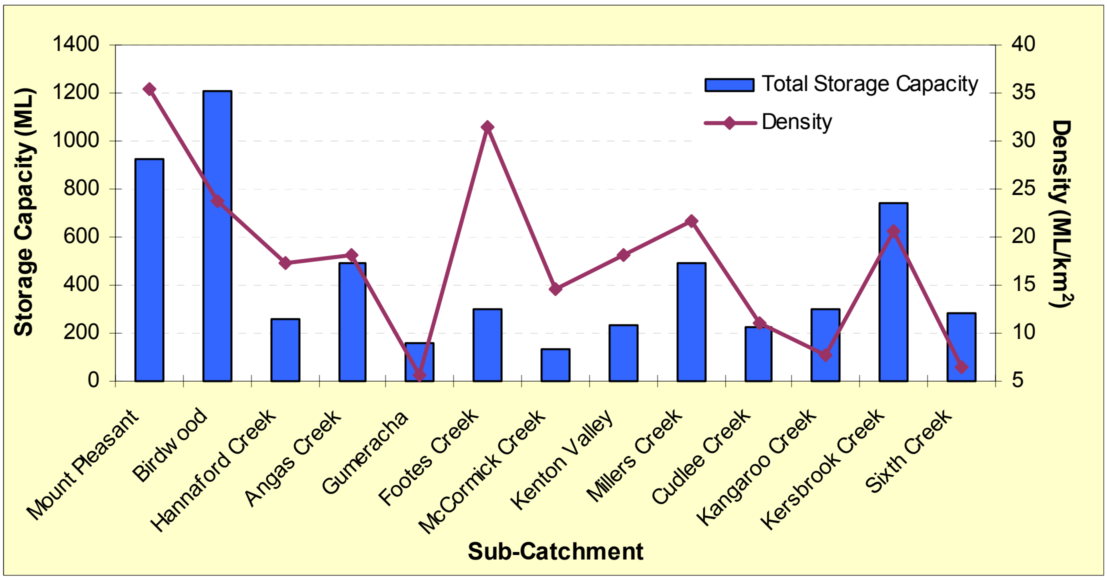


Figure 6 Comparison of Storage Capacity and Density of Farm Dams between Major Sub-Catchments.

Farm dam densities at a sub-catchment level provide information about the overall impact of dams in the sub-catchment. However, density alone does not take into account the spatial position of dams and the effect that they may have on individual stream reaches. Figure 8 presents the dam density for individual stream reaches with a stream order of three and above. This highlights areas within each sub-catchment that are likely to be under higher pressures from farm dams and conversely, areas where there is currently little farm dam development.

Figure 7 Farm Dam Density in Major Sub-Catchments.

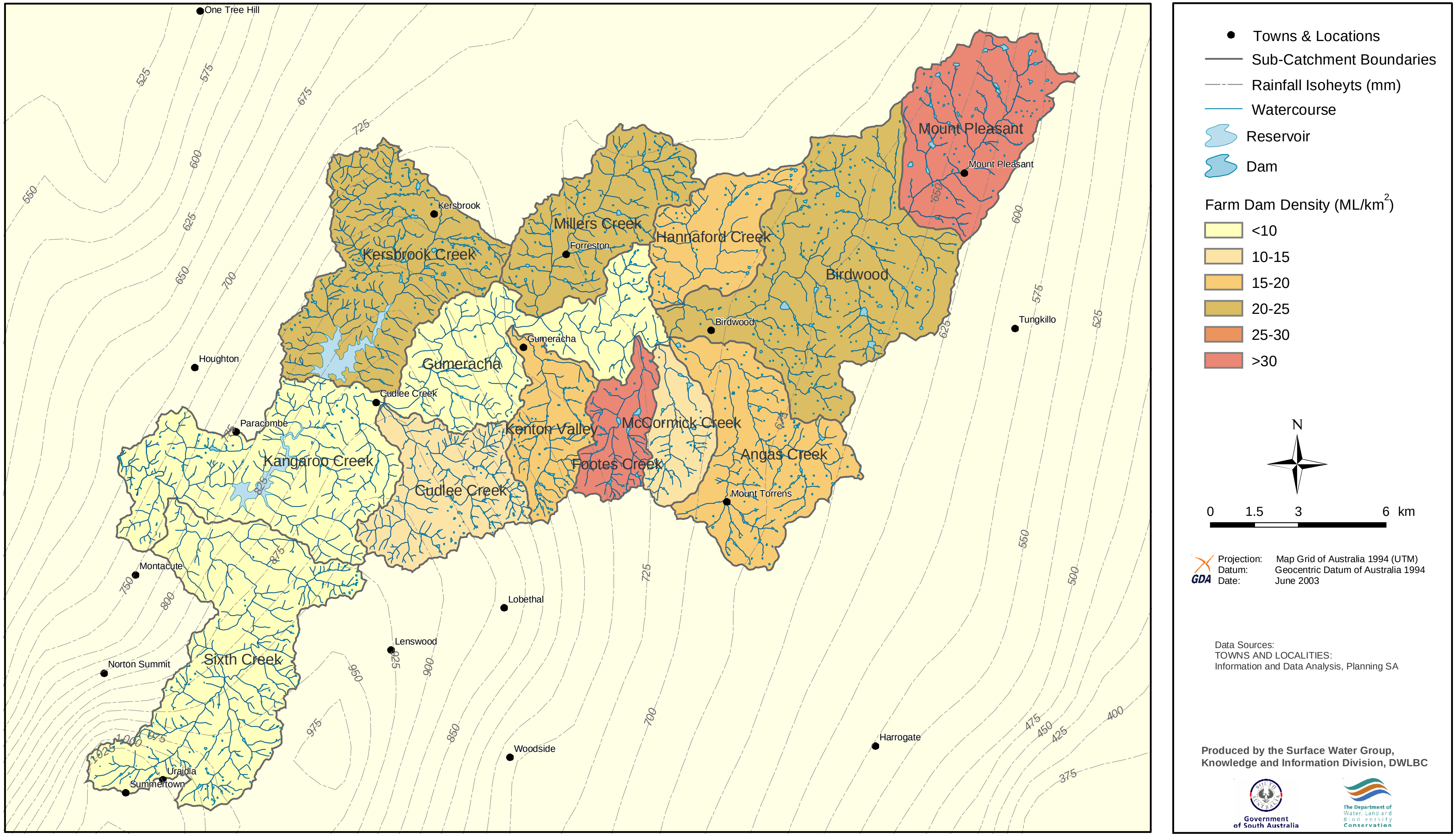
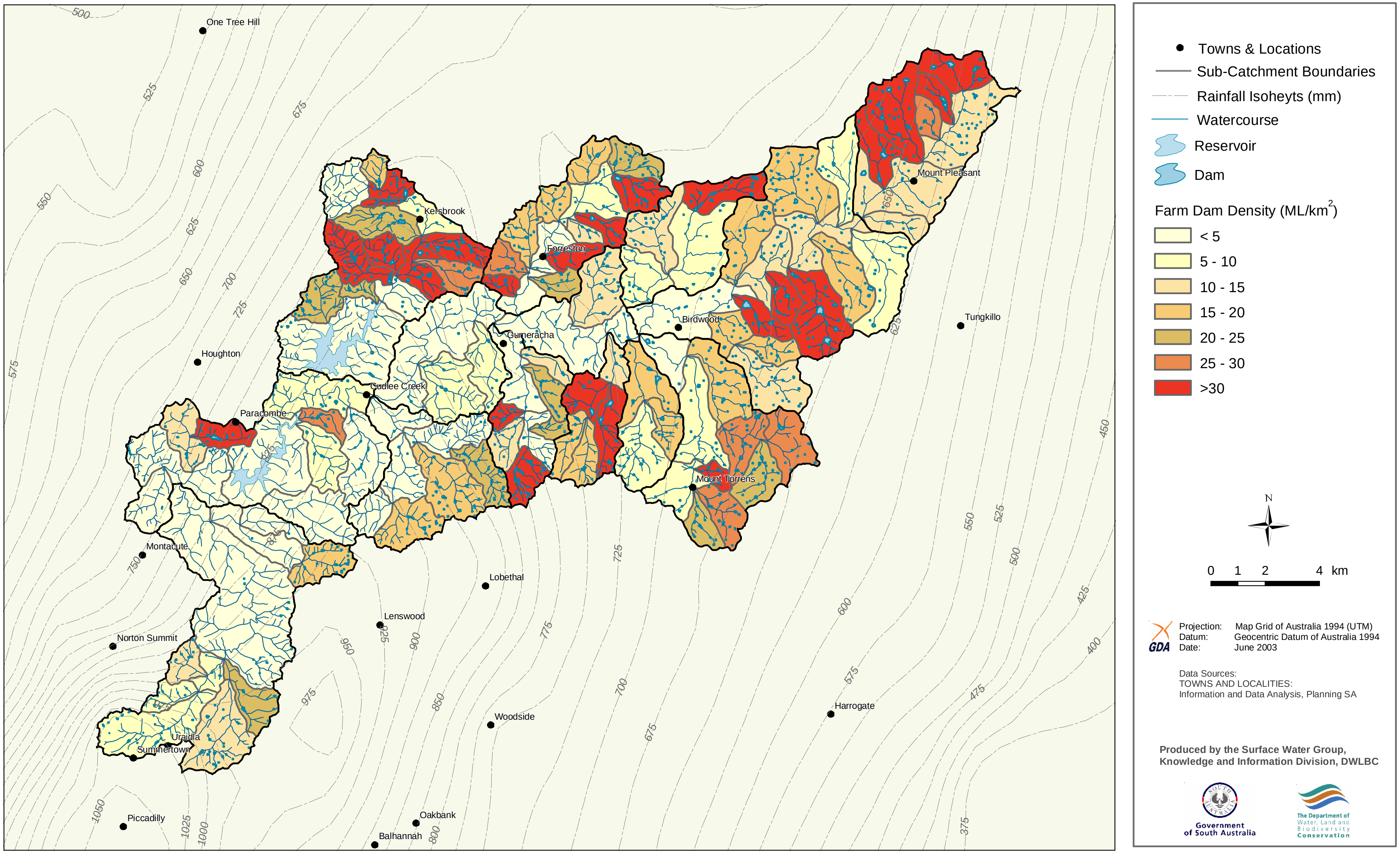


Figure 8 Farm Dam Density in Stream Reaches.



2.3.3 Dam Development Limits

The Upper River Torrens catchment is contained within the Mount Lofty Ranges Watershed, which is defined under the *Water Resources Act 1997*. As a result, the 50:50 rule applies to farm dam development. This restricts the allowable size of a farm dam for a given property to 50 percent of the median annual adjusted runoff from that property. The adjusted runoff is defined (State Water Plan, 2000) as "the annual catchment discharge with the impact of farm dams removed".

Although the 50:50 rule is defined on a property basis, an indication of whether a catchment is approaching or has exceeded current development limits can be obtained by determining the remaining available dam volume at a sub-catchment level. Table 3 shows this information for each major sub-catchment in the Upper River Torrens catchment. While no individual sub-catchment has exceeded the 50:50 development rule, Mount Pleasant is highly developed and the rule may actually have been exceeded on a property basis, although this has not been investigated.

Table 3 Development Limits at a Major Sub-Catchment Scale.

	Catchment Area (km^2)	Average Annual Rainfall[1] (mm)	Median Annual Adjusted Runoff[2] (mm)	Allowable Farm Dam Volume[3] (ML)	Current Farm Dam Volume (ML)	Current Development Levels[4] (%)
Mount Pleasant	26.1	668	2365	1183	922	78
Birdwood	50.9	707	6288	3144	1211	39
Hannaford Creek	15.1	686	1832	916	260	28
Angas Creek	27.2	727	2731	1366	493	36
Gumeracha	28.4	799	3808	1904	160	8
Footes Creek	9.5	809	1400	700	297	42
McCormick Creek	9.3	772	1133	567	136	24
Millers Creek	22.8	772	2777	1388	493	36
Kenton Valley	12.8	794	1634	817	223	27
Cudlee Creek	20.1	883	2482	1241	223	18
Kangaroo Creek	38.6	844	3824	1912	297	16
Kersbrook Creek	36.1	811	4811	2406	742	31
Sixth Creek	44.2	929	7843	3921	283	7
Totals	341.1	756	41024	20512	5750	28

[1] Average annual rainfall calculated for each sub-catchment using rainfall gauge data and isohyets (refer Section 4.2.3).
[2] Median annual adjusted runoff determined from catchment modelling in Section 5.
[3] Allowable farm dam volume calculated by the 50:50 rule (0.5 x median annual adjusted runoff x catchment area).
[4] Current development level calculated as current farm dam volume as a percentage of allowable farm dam volume.

The median annual adjusted runoff was determined by catchment modelling (Section 5). Because streamflow records are generally limited and there is uncertainty associated with the modelling of adjusted runoff in many areas, an alternative method to calculate the median adjusted runoff is to assume the median runoff is equal to 10% of the mean annual rainfall. This "rainfall-based" method is often used for the estimation of development limits and is useful for the initial establishment of water use policies on a regional basis. However, assuming a runoff coefficient of 0.1 will generally overestimate the amount of runoff and hence allows larger farm dams in lower rainfall catchments while underestimating runoff in higher rainfall catchments. It is therefore preferable to model the adjusted runoff when possible.

2.4 Land Use and Irrigation Requirements

2.4.1 Land Use

Land use data provides information on the principal manner in which specific areas of land are managed, for example, horticulture, forestry and livestock. Land management affects the amount of rainfall that will become runoff, for example, areas of native bushland and forest generally produce less runoff than grassed areas used for grazing livestock (Zhang, 1999).

For this study, land use data was obtained from the *Land status data mapping for the Mount Lofty Ranges Watershed* project (Bradley and Billington, 2002) conducted by the Department of Environment and Heritage. This data was obtained from 1:20,000 ortho-rectified aerial photographs taken during September 2001.

The classification of land use within the land status data-set, contained descriptions to a level not required for this study, for example, the species of citrus (such as grapefruit, lemons, limes etc) was given under an orchard category as part of the horticulture land use. As such, the land use data was aggregated to form ten general categories as follows:

1. *Livestock - Broadscale grazing*: includes grazing land for sheep, beef cattle, horses and goats (generally unirrigated);
2. *Livestock - Intensive grazing*: includes grazing land for dairy cattle, horses, deer, alpacas, free-range hens, ostriches and emus (generally irrigated);
3. *Forestry - Exotic vegetation*: non-native vegetation such as pines, willows, ash and paulownia;
4. *Forestry - Native vegetation and protected areas*: native vegetation including forestry, revegetation areas and areas of remnant vegetation;
5. *Protected and recreation areas*: includes conservation and national parks, reserves and parklands, some wetlands, road/water reserves, golf courses and ovals;
6. *Horticulture and Floriculture*: includes all orchards such as citrus and stonefruit, row crops such as berries and vegetables and flowers (native, exotic and herbs), but excluding vines as these generally have different water requirements than other crops;
7. *Horticulture - Vines*: includes grapes, hop, kiwifruit and passionfruit;
8. *Residential and Industrial*: includes residential accommodation, commercial properties, cultural areas such as schools and community buildings, manufacturing/industrial operations and transport/storage facilities;
9. *Mining*: includes mining and extractive industries such as open cut, alluvial and sand mining and restored lands; and
10. *Water Bodies*: includes farm dams, reservoirs, sewage ponds, lakes and some wetlands.

Table 4 shows the relative areas of each aggregated land use category and Figure 9 the spatial distribution of each category over the catchment. At a catchment scale it can be seen that broadscale grazing is the highest land use, followed by forestry (native vegetation) and protected/recreation areas.

Table 4 Land Use Classification for the Upper River Torrens Catchment

Land Use Category	Area (km^2)	Percent of Total Area (%)
Livestock - Broadscale grazing	216.6	65.3
Livestock - Intensive grazing	8.4	2.5
Forestry - Exotic vegetation	11.7	3.5
Forestry - Native vegetation/protected areas	40.8	12.3
Protected and Recreation areas	24.8	7.5
Horticulture and Floriculture	9.2	2.8
Horticulture - Vines	10.2	3.1
Residential and Industrial	3.5	1.1
Mining	0.9	0.3
Water Bodies	5.7	1.7

At a sub-catchment scale, broadscale grazing is the primary land use. The exceptions are in the Sixth Creek, Kersbrook Creek and Kangaroo Creek sub-catchments where the majority of the forestry (native vegetation) and protected/recreation areas are located. These land uses cover large proportions of each of these sub-catchments.

Forestry (exotic vegetation), vines, horticulture and floriculture and intensive grazing are also significant land uses, particularly at a sub-catchment scale. The Kersbrook Creek, Gumeracha and Cudlee Creek sub-catchments have the largest areas of forestry (exotic and native vegetation) while intensive grazing is found primarily in the Angas Creek, Hannaford Creek and Birdwood sub-catchments. Areas of vines are located mainly in the central portion of the catchment (Millers Creek, Gumeracha and Footes Creek sub-catchments) although in recent years viticulture development has expanded to include the upper portions of the Mount Pleasant and Sixth Creek sub-catchments. The Sixth Creek sub-catchment also has a large proportion of horticulture and floriculture. There are only small areas of mining in the entire catchment, the largest of these being CSR Montacute Quarry in the Kangaroo Creek sub-catchment. Appendix B.1 presents a full description of the areas of each land use in each sub-catchment and the distribution of a number of the land use categories over the catchment.

2.4.2 Irrigation Requirements

Irrigation water is generally obtained from two sources, namely from runoff captured in farm dams or from groundwater extracted through bores. Water usage for irrigation is not monitored in the Upper River Torrens catchment and as such estimates have to be made. Land use data provides information on the potential irrigation requirements for areas of land within the catchment. However, it should be noted that on-farm irrigation practices for a particular crop can vary significantly between properties in a given region in any given year. This was apparent from an irrigation evaluation study conducted in the Mount Lofty Ranges (PIRSA Rural Solutions, 2002) and Australian Bureau of Statistics Data (Thomson, 2002). Therefore, estimates of irrigation requirements for various crops only provide an indication of the levels of water that are used or needed.

Areas of land assumed to be irrigated were those containing land uses of intensive grazing, viticulture, horticulture and floriculture as identified in Section 2.4.1. This gives an irrigated area of 27.8 km^2 (2780 Ha) for the catchment as shown in Table 5. Also shown are estimates of irrigation required for the individual land uses (Thomson, 2002) obtained from Australian Bureau of Statistics data. The total irrigation requirements for the catchment are estimated at 10340 ML. Appendix B.2 presents the irrigation requirements for each sub-catchment.

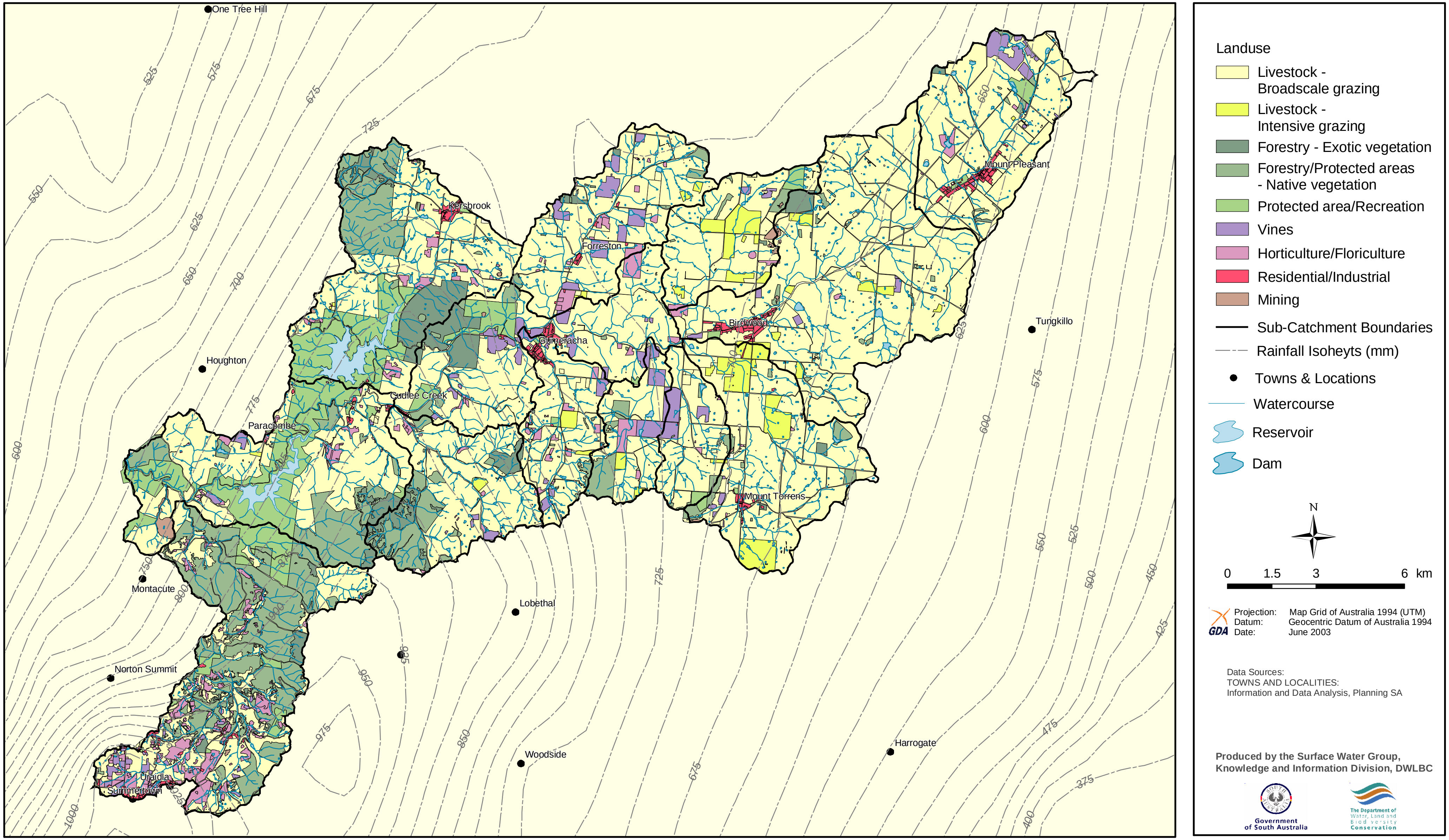
Table 5 Irrigation Requirements for the Upper River Torrens Catchment

Land Use Category	Area (Ha)	Irrigation Rate (ML/km^2)	Irrigation Volume (ML)
Livestock - Intensive grazing	840	5.5	4620
Horticulture and Floriculture	920	4.0	3680
Horticulture - Vines	1020	2.0	2040
		Total	10340

Previous information and data on land use areas often classified an entire property area as a particular land use, even though not all of that area may be devoted to that particular land use. As such, previous studies (Billington, 1999; Tonkin Consulting, 2000b; 2000d; Teoh, 2003) applied a "proportion irrigated" factor to the assumed application volumes to account for this discrepancy. The land use areas and information used in this study were not property based but described the actual areas of each land use. Therefore, "proportion irrigated" factors were not required. It was also difficult to compare successive land use data sets to determine rates of development and as such this has not been reported here.

The estimates shown in Table 5 differ significantly with the values stated in Billington (1999) and the Torrens Catchment Water Management Plan (TCWMB, 2002; Tonkin Consulting, 2000b; 2000d). The main reason for the differences is the adoption of higher application volumes, although it is not clear how these were derived. Because of the large differences and high degree of uncertainty in estimated irrigation volumes, their use during catchment modelling is not recommended. In this study, irrigation requirements and volumes are used only to describe the level of impact that it may have on the surface water resources in the catchment. The actual volumes are not used during the catchment modelling process and a farm dam usage factor is applied to simulate irrigation (refer Section 4.2.2). However, for the Catchment Plan (TCWMB, 2002; Tonkin Consulting, 2000d) estimates of irrigation volumes were used to determine the approximate extraction of water from farm dams and groundwater aquifers. This data is based on optimum irrigation use and not water availability. However, these irrigation values were subsequently incorporated into the catchment model (Tonkin Consulting, 2000b) to determine the water resource availability at a sub-catchment level and may have adversely affected the results presented in the Catchment Plan (TCWMB, 2002), particularly for low yielding sub-catchments.

Figure 9 Land Use in the Upper River Torrens Catchment.



2.5 Water Supply Operations and Bulk Transfers

The Upper River Torrens catchment is an important component of the water supply system for metropolitan Adelaide. However, the associated water management operations have resulted in a highly modified flow regime, which may have had negative impacts on the aquatic environment.

Figure 10 shows the significant water supply infrastructure, operations and flow paths and The following describes the major infrastructure and operations.

- Millbrook Reservoir was completed in 1914 with a storage capacity of 16,000 ML. This is essentially an off-stream storage as it derives very little of its water supply from its local catchment area of 36.1 km^2 (Kersbrook Creek). The reservoir has spilled four times in the last ten years, generally after intense rainfall in its catchment when the reservoir had already filled to capacity. From here, water may be pumped to the Anstey Hill Treatment Plant (since 1980) or released down the main River Torrens channel into Kangaroo Creek Reservoir.
- Kangaroo Creek Reservoir was completed in 1969 and upgraded in 1982-83 for flood protection purposes. It has a storage capacity of 19,000 ML but despite being an on-stream storage, the reservoir has very little catchment area (53 km^2), instead relying heavily on releases and spill from Millbrook Reservoir and spill over Gumeracha Weir. It has spilled four times in the last ten years.
- Gumeracha Weir (storage capacity 200 ML) and the diversion channel to Millbrook Reservoir were completed in 1918, after which time the majority of upstream surface runoff was diverted to Millbrook.
- Gorge Weir was constructed in 1860 to allow the diversion of flow to the Thordon Park Reservoir and subsequently to the Hope Valley Reservoir (completed 1872, diversion from 1884). It was modified in the 1970s to allow diversion to the Hope Valley Filtration Plant (completed 1977). It has a storage capacity of 24 ML with the majority of runoff reaching the weir originating from the Sixth Creek sub-catchment and releases from Kangaroo Creek Reservoir. Releases and spill from the weir flow into the Torrens Lake.
- The Mannum-Adelaide (M-A) pipeline began operation in 1954 to transfer water from the River Murray to Adelaide as a means of ensuring security of supply. The primary operations are as follows:
    - ⇨ Three pump stations are used to pump water to a summit storage.
    - ⇨ From the summit storage the pipeline is a gravity main from which water can be discharged through scour points at Angas Creek or directly into Millbrook Reservoir.
    - ⇨ After a number of low rainfall years, because sufficient water could not be pumped directly to the reservoir, the Mount Pleasant scour point was completed in 1968.
    - ⇨ Water discharged at the Mount Pleasant and Angas Creek scours moves down the main River Torrens channel to Gumeracha Weir, from which it is diverted to the reservoir via the diversion channel.
    - ⇨ There are minor transfer pipelines to the Warren Reservoir and the Onkaparinga River.
    - ⇨ Water that is not discharged through one of the three scour points or secondary pipelines flows into the Millbrook Tanks.
    - ⇨ Water from both the Millbrook Tanks may be pumped to the Anstey Hill Treatment Plant.

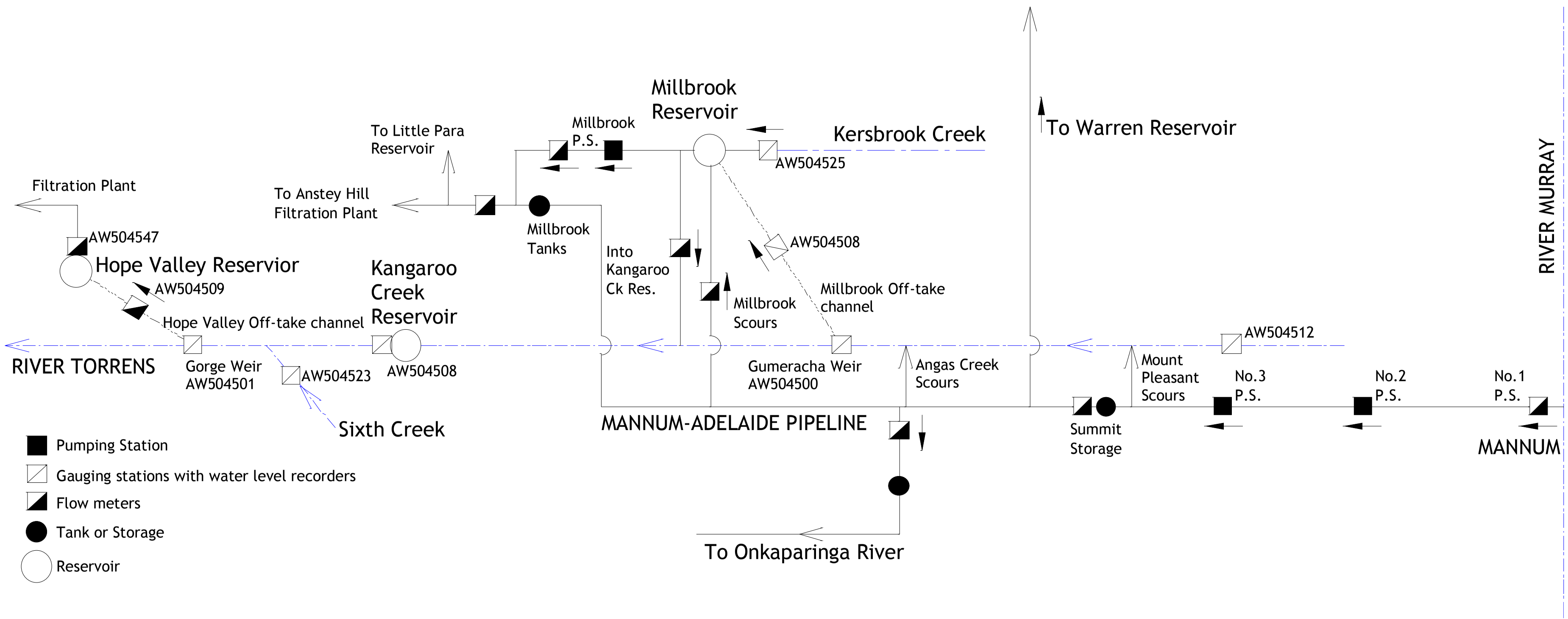


Figure 10 Bulk transfer and reservoir network.

In order to use the water supply infrastructure for hydrological modelling, a closed catchment and hence complete water balance for each system must be established. However, for such an important water supply system it is surprising that there is limited and often questionable data available. Table 6 shows the weir, reservoir and diversion channel water level gauging stations currently in operation and Table 7 the availability of M-A pipeline and reservoir data.

Table 6 Weir, Reservoir and Diversion Channel Gauging Stations

Station Number	Location	Custodian	Period of Record	% of Missing (Doubtful) Data
AW504500	River Torrens @ Gumeracha Weir	DWLBC	1974-2002	0.2 (0.0)
AW504501	River Torrens @ Gorge Weir	DWLBC	1974-2002	1.4 (1.8)
AW504508	Millbrook Reservoir Offtake Channel	DWLBC	1974-2002	1.5 (1.0)
AW504509	Hope Valley Offtake Channel	DWLBC	1993-2002	0.5 (3.4)
AW504520	Millbrook Reservoir @ Dam Embankment	DWLBC	1994-2002	n/a*
AW504531	River Torrens @ Kangaroo Creek Reservoir	DWLBC	1980-2002	n/a*

* n/a - no rating curve available (AW504520), no new rating curve determined since reservoir upgrade (AW504531).

Table 7 Availability of M-A Pipeline and Reservoir Data

Data Type	Daily Record	Source	Monthly Record	Source
Mount Pleasant Scours	2000-2002	SA Water	-	-
Angas Creek Scours	2000-2002	SA Water	-	-
Millbrook Scours	1974-1981	DWLBC	-	-
	2000-2002	SA Water	-	-
Mount Pleasant/Angas Creek Scours (Combined)	1974-1981	DWLBC	-	-
Total Scour Discharge (Three Scours)	-	-	1982-1994	DWLBC
	-	-	1995-1999	SA Water
Millbrook Reservoir Volumes	1994-2002	SA Water	-	-
Millbrook Reservoir Release	1994-2002	SA Water	-	-
Kangaroo Creek Reservoir Volumes	1994-2002	SA Water	-	-

2.5.1 Gumeracha Weir

Gumeracha Weir is the first location downstream from the Mount Pleasant gauging station (refer Section 3.3.1) where water level is recorded and is the only point where the natural runoff from almost half the catchment can be determined and modelled. However, being a 34.4 metre by 2.44 metre broad rectangular weir, it is not sensitive to low volume inflows (refer Appendix E.1). The natural runoff into the weir pool and hence the water balance at the weir is defined as:

$$Natural\ Inflow = \Delta Volume + Diversion + Spill + Releases + Transfers + Evaporation \qquad (2)$$

The scour valves at the base of the weir are rarely opened and daily evaporation from the weir pool is negligible. The change in weir pool volume, the spill and the diversions to Millbrook Reservoir are all measured, however, there is limited useful information surrounding releases from the Mount Pleasant and Angas Creek scours, which are both upstream. The majority of available data is a combined record from the two scours in addition to the Millbrook Reservoir discharge point downstream. Without definite information about when the various scours were open it is not possible to disaggregate the record into the water discharged upstream and downstream of the weir at a daily time scale.

The effect of M-A pipeline transfers on the inflow to the weir pool is significant as shown in Figure 11. The observed flow is defined as the total of the natural inflow and the discharge from the M-A pipeline at the Mount Pleasant and Angas Creek scours. The total annual discharge from the two scours was estimated from a combination of modelled natural flow results (Section 4.3.2) and monthly scour discharge data for the three scour points. Under current farm dam development, the mean and median natural annual inflows into the weir are approximately 21,000 ML/year and 19,500 ML/year respectively. This is much less than the 33,800 ML/year and 30,600 ML/year under the current conditions that is inclusive of transferred water.

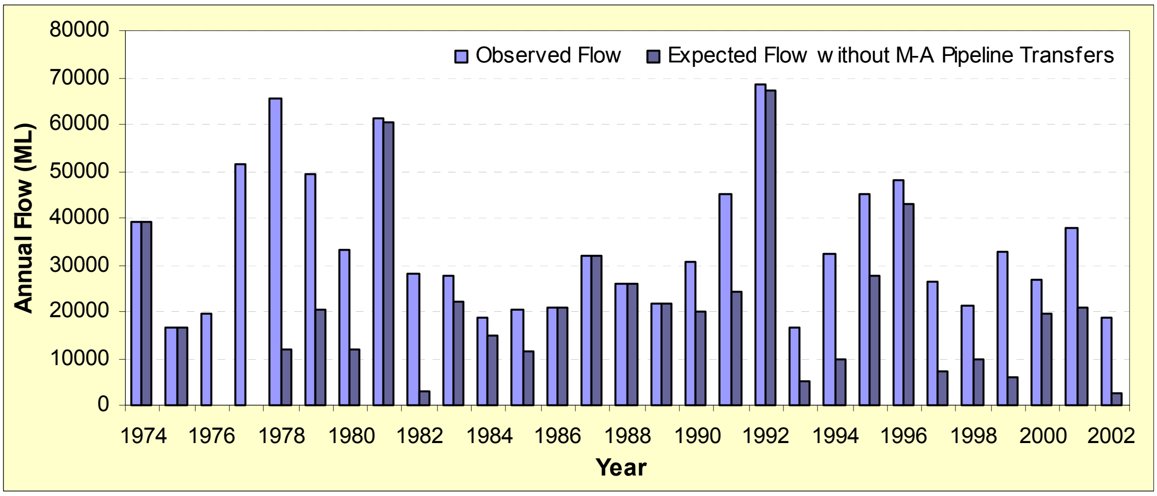


Figure 11 Effect of M-A Pipeline Transfers on Flow into Gumeracha Weir.

The mean monthly values for the natural inflow and the inflow under current conditions are shown in Figure 12. Aside from an overall increase in volume across the year, the largest difference occurs between January and April. There would naturally only be low flows during this period but the effect of the M-A pipeline discharges has created a flow regime with mean monthly flows between 500 and 1000 times higher.

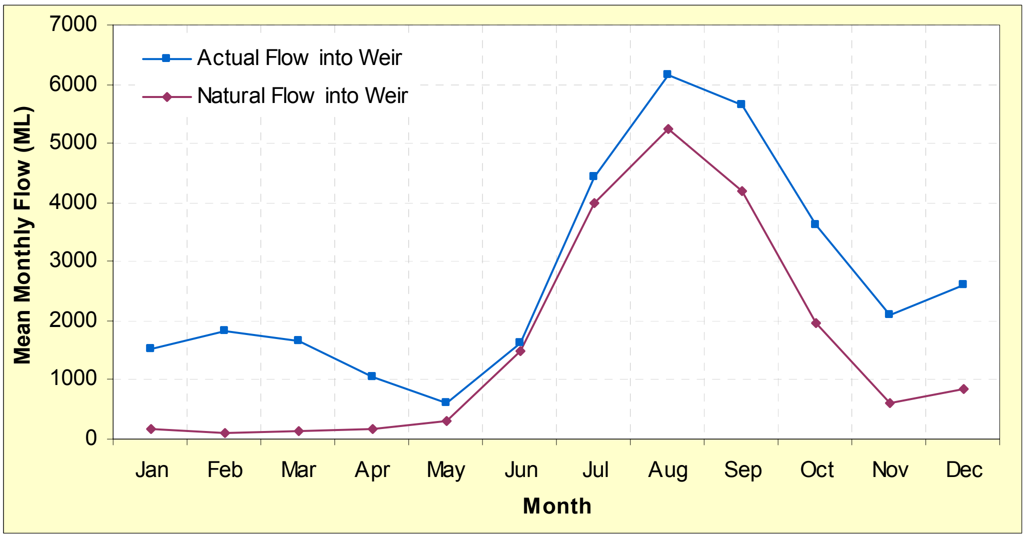


Figure 12 Mean Monthly Recorded and Natural Inflow into Gumeracha Weir.

Figure 13 shows the estimated volumes of water discharged from the Mount Pleasant and Angas Creek scours each year between 1974 and 2002, and the total discharge from the M-A pipeline. Based on this data, the average discharge from the three scours is estimated at 19,000 ML/year, 5,000 ML of which is discharged directly into Millbrook Reservoir.

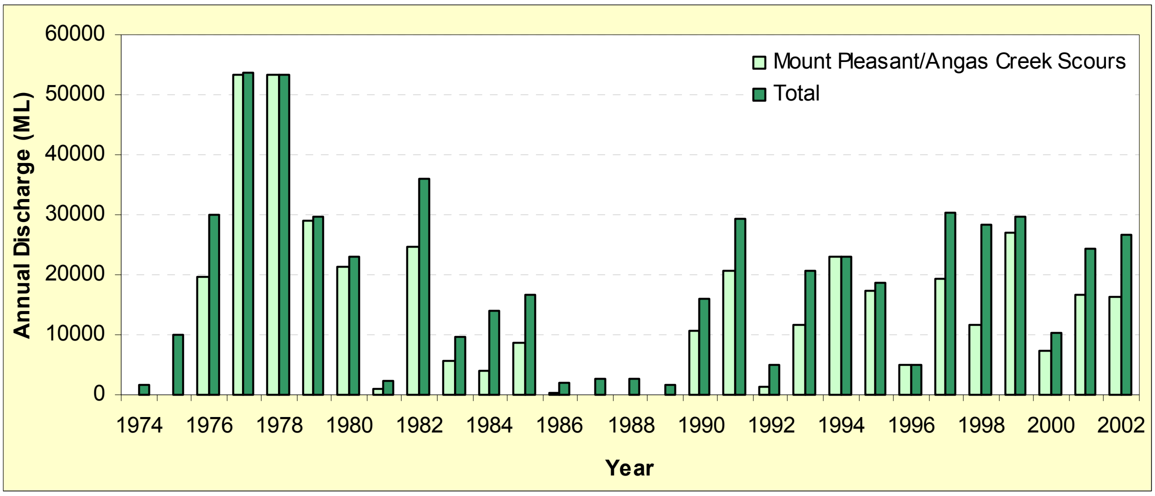


Figure 13 M-A Pipeline Discharge through Mount Pleasant/Angas Creek Scours.

The annual inflow into Gumeracha weir under current conditions and the relative volume of diversion to Millbrook Reservoir and spill is presented in Figure 14. The mean and median annual diversion is 21,000 ML/year and 18,200 ML/year respectively, while the mean and median annual spill is 11,800 ML/year and 9,500 ML/year. In lower rainfall years such as 1976, 1993 and 2002, the majority of water entering the weir pool was diverted and very little spill occurred. This deprived the downstream of most, if not all flow, and is likely to have produced a negative impact on the aquatic ecosystem. The timing of rainfall and hence flow from upstream also affect the quantities of spill over the weir. Once Millbrook Reservoir reaches capacity, no further diversion occurs. Therefore, when large rainfall volumes occur during the latter half of the year as occurred in 1992 and the reservoir is full, much larger volumes of spill over the weir will occur.

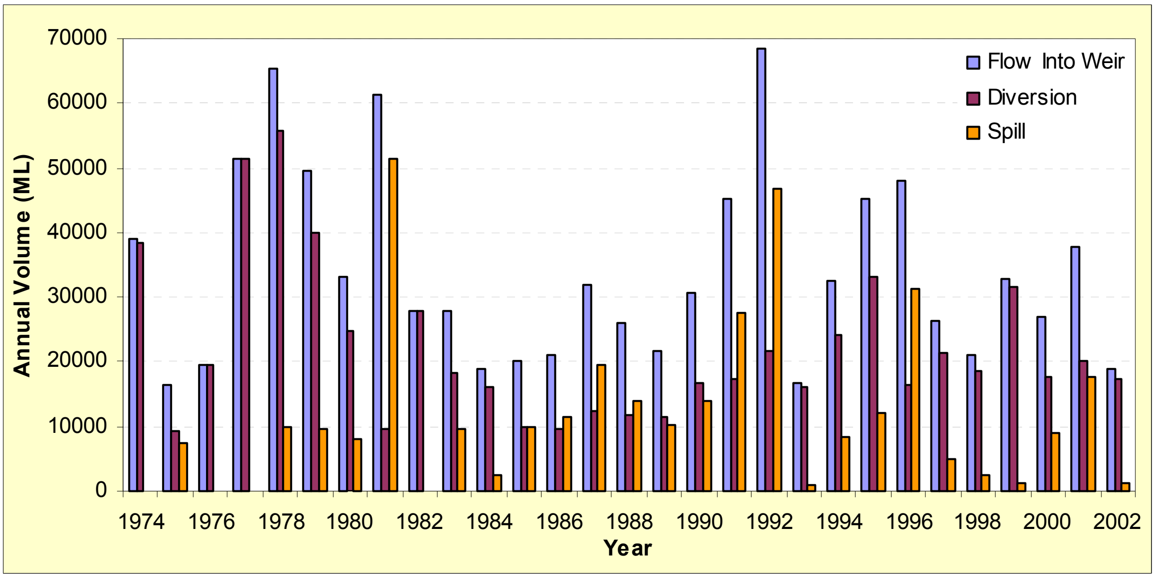


Figure 14 Gumeracha Weir: Inflow, Diversion and Spill.

Figure 15 now shows the mean monthly inflow, diversion, spill and scour discharge values. This highlights the limited spill over the weir that occurs until the winter months and that the majority of flow during the first half of the year is diverted to Millbrook Reservoir, most of which consists of M-A transfer flow.

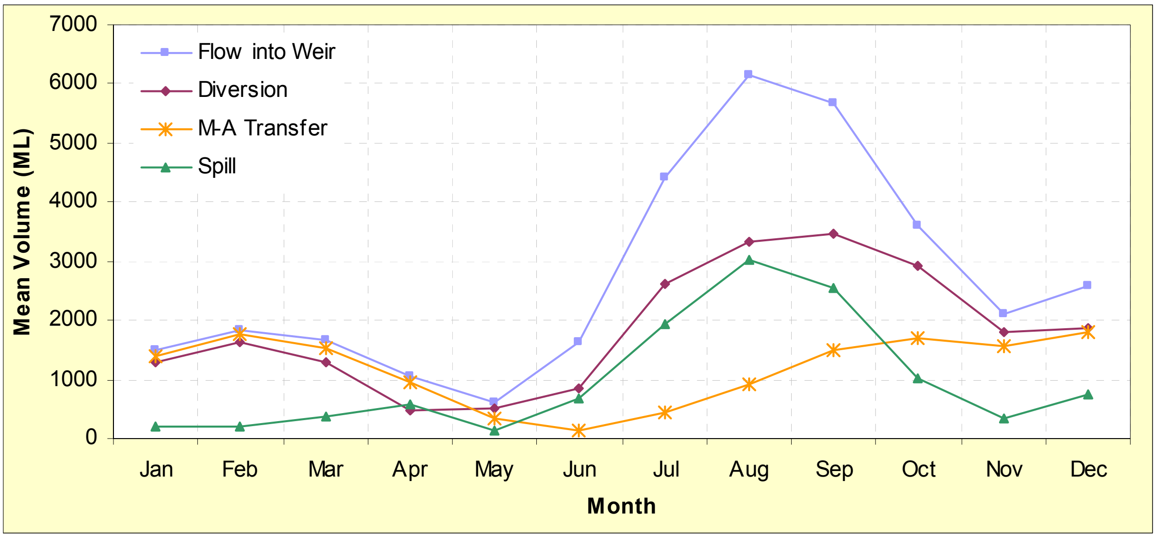


Figure 15 Monthly Variation of Inflow, Diversion and Spill at Gumeracha Weir and Upstream Scour Discharge.

For hydrological model development and calibration, it was only possible to obtain model parameters using data from the periods 1975 to 1981 and 2000 to 2002. Daily volumes of pipeline releases were estimated from information on valve operations sheets currently held by DWLBC for 1975 to 1981. Between 1981 and 2000 records of daily scour valve operations and hence pipeline discharges from each location have not been recorded as part of water operations and hence no data was available. Between 2000 and 2002 the daily pipeline releases from individual scours have been recorded, however, the accuracy of this data is unknown (some periods had negative discharge).

While it would be preferable to consistently pump water from the M-A pipeline directly into Millbrook Reservoir rather than have it flow down the main channel to Gumeracha Weir, it is understood that this flow path provides in-stream water treatment (aeration) benefits to the transferred water, particularly when the River Murray water is of a lower quality. In addition, the current hydraulic capacity of the gravity section of pipeline imposes significant constraints on pumping water from the River Murray directly to Millbrook Reservoir and supply of water to the Anstey Hill Water Treatment Plant, particularly during summer months (Murphy, 2003; TCWMB, 2002). These current physical constraints and a pumping regime based upon economics alone, require the utilisation of the River Torrens in order to maintain unrestricted water supply to metropolitan Adelaide. However, in view of the possibly detrimental effect to the aquatic environment of both the discharges and the operation of Gumeracha Weir, upgrades to the pipeline, changes to the pumping regime and/or low flow bypass mechanisms should be considered and incorporated in the future.

2.5.2 Kangaroo Creek Reservoir

The Kangaroo Creek Reservoir catchment is approximately 53 km^2, bounded downstream by Kangaroo Creek Reservoir and upstream by Millbrook Reservoir and Gumeracha Weir. Hence, it relies on spill from Gumeracha Weir and releases and spill from Millbrook Reservoir. As well as being a second water supply reservoir, the Kangaroo Creek Reservoir is part of the River Torrens flood mitigation scheme. The natural runoff into the reservoir and hence the water balance is defined as:

$$Natural\ Inflow = \Delta Volume + Spill + Releases - GWspill - MR(spill, releases) + Evaporation \qquad (3)$$

where $GWspill$ is the spill over Gumeracha Weir and $MR(spill, releases)$ is the sum of the releases and spill from Millbrook Reservoir.

The volume and timing of water released from Kangaroo Creek Reservoir down to Gorge Weir is not currently recorded and no operational rating curve has been established for Millbrook Reservoir and hence the volumes of spill are unknown.

The spillway control at Millbrook Reservoir consists of a concrete broad crested weir, 52 metres by 0.46 metres. Attempts to estimate spill from daily reservoir water levels using a theoretical rating curve failed during high rainfall and runoff events, particularly during 1992. This may be in part because of the poor physical condition of the spillway control.

Daily reservoir gauging records from 1990 to 1995 provide details on the percentage of opening for the scour valves at the base of the reservoir. A rating curve for the valves was obtained and the discharge estimated. However, this data is only recorded each morning and it is not known whether the valves were open for all or part of the previous 24 hours.

Due to data deficiencies, closure of the water balance and hence calibration of a hydrological model at Kangaroo Creek Reservoir is not currently possible. It is important that the deficiencies in the monitoring network be addressed, particularly given the importance of the Reservoir to the water supply system for Adelaide.

2.5.3 Gorge Weir

The Gorge Weir catchment is approximately 58 km^2, bounded downstream by Gorge Weir and upstream by Kangaroo Creek Reservoir and including the gauged catchment of Sixth Creek (44 km^2). The majority of flow reaching the weir is diverted to Hope Valley via a diversion channel. Model calibration at this location would provide parameter estimates for the area upstream, excluding Sixth Creek from which the runoff is known. The natural runoff into the weir and hence the water balance is defined as:

$$Natural\ Inflow = \Delta Volume + Diversion + Spill + Releases - SCflow - KC(spill, releases) + Evaporation \qquad (4)$$

where $SCflow$ is the flow from the Sixth Creek gauged catchment and $KC(spill, releases)$ is the sum of the releases and spill from Kangaroo Creek Reservoir. As indicated above, the discharge volumes between 1990 and 1995 from Kangaroo Creek Reservoir are doubtful and are not currently being recorded by the reservoir operators. Data on downstream releases from the scour valves at the base of the weir is not available and does not appear to be recorded. Hence, Gorge Weir can not currently be used for model calibration.

2.5.4 Environmental Impact from Water Supply Operations

The operation of water supply infrastructure within the Upper River Torrens catchment (reservoirs, diversion weirs and pipelines) may be adversely affecting the local aquatic environment.

There are numerous potential impacts associated with pipeline transfers between river systems. The treatment of water prior to transfer and discharge introduces chlorine to the natural river water, which may be detrimental to the survival of many fish species. There is also the potential to transfer fish eggs and viruses, invertebrates such as snails or parasites that are not native to the local river system. These species may then displace native species (Scholz, 2003). Because the M-A pipeline discharges water near the headwaters of the catchment, it is likely that anything transferred through the pipeline has the opportunity to move through the main channel for the entire catchment, as well as into the reservoir system.

Releases from Gumeracha and Gorge Weirs and particularly from Millbrook and Kangaroo Creek Reservoirs may have a significant impact on the ecology of the River Torrens downstream. Most reservoirs undergo stratification during spring and summer with the formation of layers with varying water temperatures. When releases occur, they are generally from the colder, bottom layers and if the temperature of the water released is outside of the 20th to 80th percentile of the natural stream temperature, it is regarded as cold water pollution (ANZEC & ARMCANZ, 2000). Releases may reduce the thermal amplitude in streams and rapid rises in temperature that naturally occurs during spring may be reduced or removed. With the release of large volumes of water, temperatures may drop suddenly with peak summer temperatures delayed by weeks or months.

The biological impacts of reservoir releases may be quite severe. Temperatures may exceed the tolerances or reproduction requirements of riverine biota or exclude species based on thermal preference or reduced metabolic and physiological abilities (Ryan *et al*., 2001). Most native fish species breed over the warmer months where the temperature induces spawning. As such, a reduction in temperature or a delay in the natural stream temperature increase can severely impact on fish recruitment and reduced summer temperatures may result in an overall lower biotic production. The colder waters from the lower reservoir layers may have reduced oxygen levels due to the breakdown of organic matter, may have higher nutrient levels and may also release toxicant loads absorbed within bottom sediments (Ryan *et al*., 2001).

It is important that a monitoring network be installed to accurately describe and record the operations of the reservoir systems, which includes both hydrological data as well as information on environmental parameters.

2.6 Environment

The Torrens Catchment Water Management Board (TCWMB) was established in 1995 and since this time has implemented planning measures, catchment rehabilitation works and community education and awareness programs primarily to improve catchment water quality and watercourse health. It has also begun investigations related to water resources and associated ecosystems, which supports the goal, "ensuring sufficient water is maintained in creeks, rivers and aquifers to be available for equitable and economic community use and to maintain ecosystems" (TCWMP, 2002).

Any changes to natural flow patterns and volumes have direct consequences for aquatic ecosystems. Aquatic species, from in-stream, riparian and flood plain vegetation, to macro-invertebrates, frogs and fish, are dependent on the flow regimes that maintain the habitats in which they exist. While some have wide environmental tolerances, others are more sensitive to environmental conditions and occupy more specific habitats. Changes to these environmental conditions, such as the timing and duration of flows, affect the important ecological responses to flow including the recruitment of seedlings or larvae, fertilisation or spawning cues, and the maintenance and growth of animal and plant populations.

Historically, the Upper River Torrens catchment contained significant terrestrial, semi-aquatic and aquatic native vegetation in addition to numerous species of fish, amphibians, reptiles, birds and mammals, and invertebrates such as mussels, shrimps and yabbies. Although detailed survey data is not currently available for watercourses in the catchment (TCWMB, 2002) land clearance, water supply infrastructure and diversions and on-stream farm dams have impacted on the number and abundance of these species. A number of native freshwater fish are currently extinct or present at very low abundances and the more the aquatic and riparian habitat has been modified, the greater the dominance of non-native fish (Tonkin Consulting, 2002e).

This study does not directly assess the status of or impacts on the habitats of water dependent ecosystems. However, the main outcomes of the study, that is, the impact of farm dams and water supply infrastructure on the flow regime, will be useful to further assess the status and effect on water dependent ecosystems within the catchment. Improving altered flow patterns could aid in catchment rehabilitation and facilitate the re-establishment of vegetation and fish.

3. CATCHMENT HYDROLOGY

3.1 Rainfall

The hydrological computer model developed in this study is used to transform the rainfall falling on the catchment into runoff. The volume of rainfall directly affects the volume of runoff; the higher the rainfall, the higher the potential runoff. Rainfall patterns can also vary significantly over a catchment. For example, locations at higher elevations generally have higher rainfall levels than those at lower elevations. Therefore, a good understanding of both the volume and variability of rainfall over a catchment is important if a realistic transformation to runoff is to be obtained.

3.1.1 Data Availability and Processing

Daily rainfall data in South Australia is collected by the Bureau of Meteorology (BoM) and DWLBC. Figure 16 shows the location of stations within or near to the Upper River Torrens catchment. Although there appears a good distribution of stations across the catchment, many of these have as little as 10 years of data, particularly those at higher elevations.

Table 8 shows the stations that were used as input for hydrological modelling. These were chosen because of long term recorded data that could be used to represent the spatial variability over the catchment. The data from these stations were used to determine rainfall at catchment, major sub-catchment and minor sub-catchment scales.

During the model scenario testing stage, 100 years of observed rainfall data was used as input to generate 100 years of streamflow data. Therefore, the data from these sites were evaluated for the period 1902-2002 (where available). Information for other stations that were used during the data processing stage (discussed below) are presented in Appendix C.1.

Table 8 Rainfall Stations used for Hydrological Modelling

Station Number	Location	Period of Record	Percentage of Missing (Accumulated) Data
023705	Birdwood Department of Transport	1902-2002	3.8 (0.5)
023719	Gumeracha District Council	1902-2002	1.4 (8.2)
023731	Cudlee Creek (Millbrook)	1914-2002	0.6 (1.4)
023737	Mount Pleasant	1902-2002	2.1 (6.6)
023750	Uraidla	1902-2002	0.7 (7.8)
023803	Ashton Co-op	1933-2002	30.8 (2.8)

Missing Data

The majority of data sources contain missing segments. Missing data in daily rainfall records may occur in two forms: when a value has not been recorded on a particular day(s) but the cumulative total has been recorded on a subsequent day; or where the data is missing due to a recording error.

The first type are referred to as accumulated records and may be disaggregated over the total number of missing days. SKM (2000) disaggregated the rainfall data at these stations for the period up to 1998 using the method described in Porter and Ladson (1993). This assumes that the influence of the rainfall at nearby stations to the station where accumulated data is to be disaggregated is inversely proportional to the distance between the stations. Using a number of nearby stations reduces the uncertainty from using data from a single station. This method was also used to disaggregate data within the period 1999-2002. The full procedure is given in Appendix C.1.

Stations with missing data due to recording errors were infilled by using data from a nearby station. The nearby station was chosen as the one with the highest correlation between daily values that had data concurrent with the missing period. To infill the missing period, the daily rainfall value at the nearby station was then adjusted by the ratio of the concurrent mean annual rainfalls of the two stations. The full procedure and correlations between the rainfall stations are presented in Appendix C.1.

Data Consistency

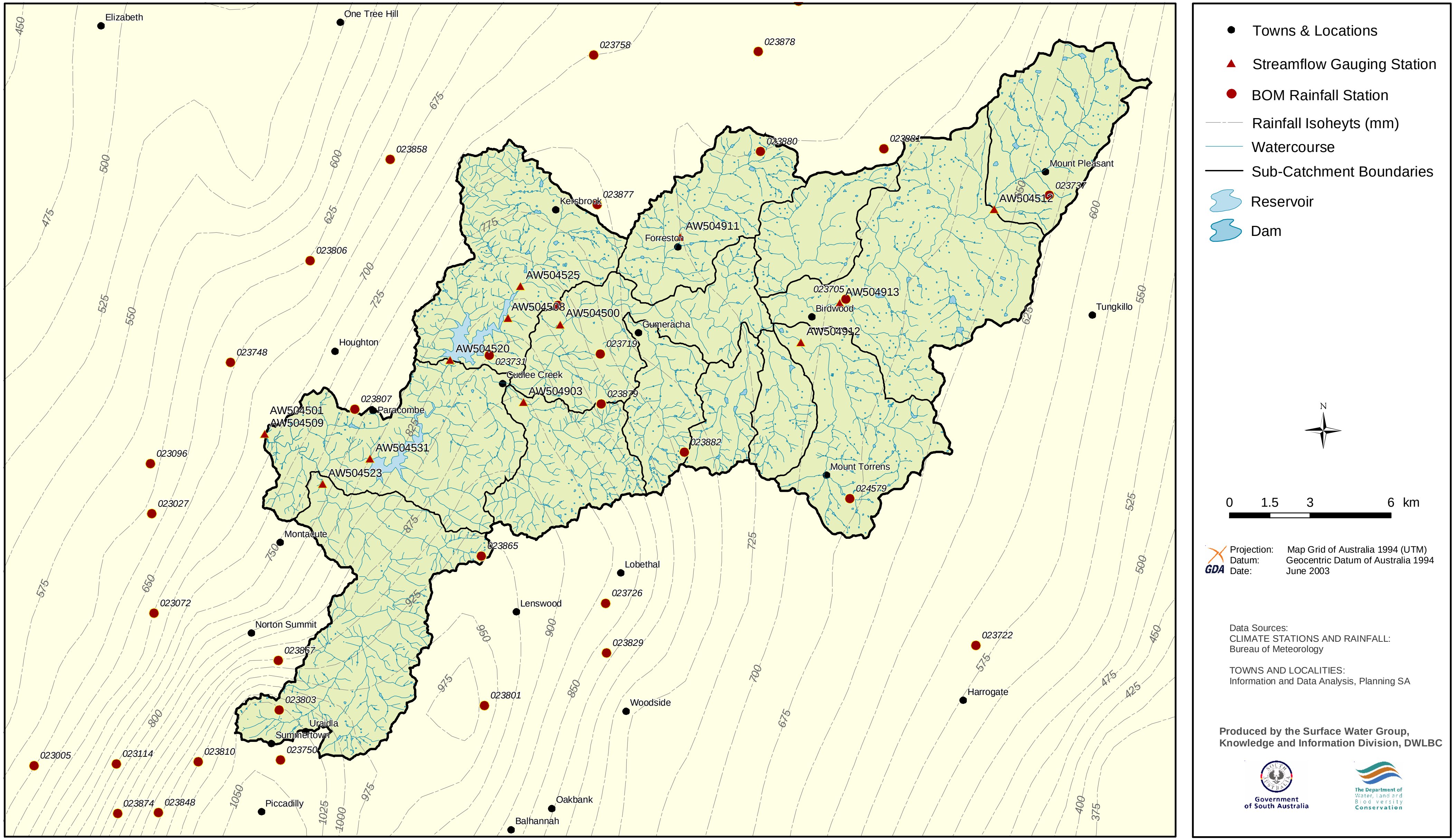
To identify the occurrence, magnitude and nature of trends within long time series records the double mass curve technique (Grayson *et al*.; 1996) is often used. It is constructed by plotting the accumulated values of two time series against each other. A break in slope or a gradual change in curvature will reveal a change in the constant proportionality between the two sets of data. This indicates the presence of a trend such as in measured rainfall due to localised station conditions. For example, changes in instrument exposure at a station resulting from the growth of obstructive vegetation. The method is often used to establish the presence of such changes within rainfall records and adjustments can subsequently be made to affected data sets to ensure consistency of record.

In this study the consistency of each rainfall record was confirmed by constructing a double mass curve using an average of the monthly rainfall from eight to ten neighbouring stations. Using an average of a number of records reduces inconsistencies that may be present in any one record. Each of the rainfall records used for hydrological modelling required some adjustment and the full procedure and analysis are presented in Appendix C.1.

Extension of Data Records

The daily rainfall records at Cudlee Creek (023731) and Ashton (023803) were extrapolated back to 1902 to create a long term record of 100 years. This allows for the examination of extended wet and dry rainfall periods and the subsequent effect on streamflow. The record extension was done by using a proportional relationship with a nearby site. Data from Gumeracha (023719) was used to extend Cudlee Creek (proportion 0.9669; daily rainfall correlation 0.931) and from Uraidla (023750) to extend Ashton (proportion 0.9659; daily rainfall correlation 0.879).

Figure 16 Hydrological Stations within the Upper River Torrens Catchment.



3.1.2 Data Analysis

Analysis of the rainfall data at each of the stations to be used for hydrological modelling was undertaken at monthly, annual and decadal time scales. In addition, an analysis of the average catchment rainfall calculated from these stations is also provided. The rainfall regime and its variability at each of these time scales affects runoff and hence surface water availability differently. For example, the volume and distribution of rainfall at a monthly time scale influences the timing and volume of runoff that will occur at varying times throughout the year. Rainfall changes at a yearly time scale affect the total volume of runoff that a catchment will produce.

Annual Rainfall

The annual rainfall was found to vary significantly across the catchment. Table 9 shows the mean and median annual rainfall and the standard deviation of the mean annual rainfall for each station and the total catchment. The standard deviation provides an indication as to the variability of the annual rainfall; the lower the standard deviation, the less the variability of annual totals around the mean. Along the main river channel, the upper reaches around Mount Pleasant are the driest, with the rainfall increasing down the catchment to the Cudlee Creek area before decreasing again towards Gorge Weir. Rainfall increases through each sub-catchment from the main River Torrens channel to the upper reaches at higher elevations.

Rainfall isohyets over the catchment are shown in Figure 16. Although the values of these isohyets are currently under review and were not specifically used during hydrological modelling, they do provide an indication of the spatial variability of rainfall not only across the catchment but also within each sub-catchment. For example, the change in mean annual rainfall within the Mount Pleasant sub-catchment is less than that within the Sixth Creek sub-catchment.

Table 9 Annual Statistics

Station	Mean (mm)	Median (mm)	Standard Deviation (mm)
Birdwood (023705)	734	739	169
Gumeracha (023719)	823	814	184
Cudlee Creek (023731)	859	863	196
Mount Pleasant 023737)	668	657	160
Uraidla (023750)	1082	1067	237
Ashton (023803)	1064	1054	229
Catchment Rainfall*	756	754	169

* catchment rainfall calculated using relative position and values of isohyets – refer Section 4.2.3

Another measure of the variability of annual rainfall is to examine the 10th and 90th percentiles. These are shown in Figure 17 together with the 50th percentile (median). The 10th percentile represents the threshold of the lowest 10 percent of the recorded values and there is a 10 percent probability that the annual rainfall in any given year will be lower than this value. Conversely, the 90th percentile is the value that exceeds all but 10 percent of the recorded value such that there is also a 10 percent probability that the annual rainfall in a given year will be greater than this value. The closer the values at these two percentiles, the lower the variability. From the values shown in Figure 17 it can be seen that as the median rainfall increases so too does the variability, for example, the variability of annual rainfall values at Uraidla is greater than those at Mount Pleasant.

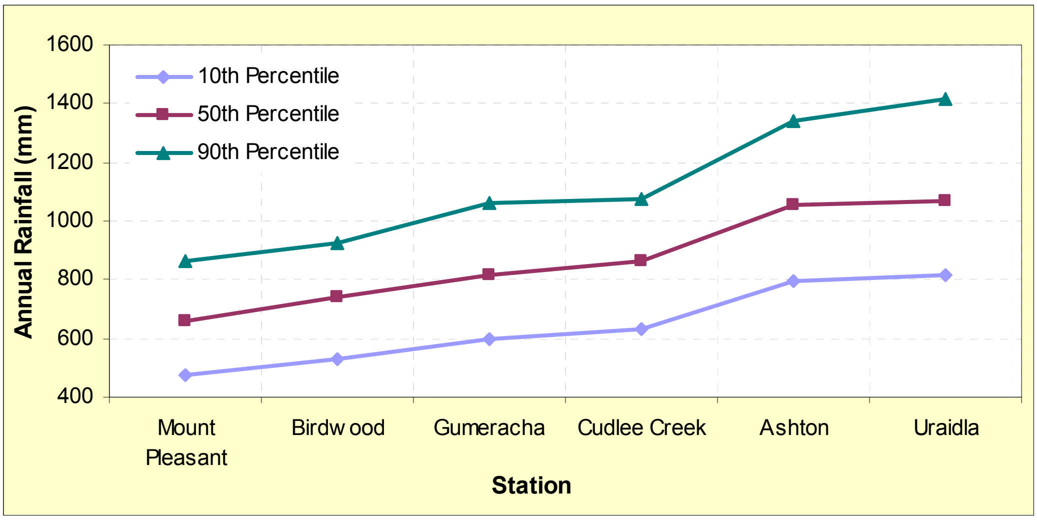


Figure 17 Variability in Mean Annual Rainfall Totals at Stations used for Modelling.

Long term changes in annual rainfall values can be observed using trendlines and residual mass curves. A trendline is a linear function that indicates whether the long term annual rainfall is increasing, decreasing or stable. A residual mass curve is the cumulative deviation of a set of data from the mean value of that data. A positive (upward) sloping curve indicates years of higher than average rainfall while a negative (downward) sloping curve indicates years with lower than average rainfall.

Figure 18 shows the annual totals for average catchment rainfall and the variability of these values around the long term mean value. The trendline indicates that although the mean of the data over the last 100 years is shown as 756 mm, there is a decreasing trend. This also indicates that over the period prior to when the lines cross (approximately 1950) the mean rainfall would be greater than for the period afterwards. The residual mass curve indicates significantly increasing annual rainfall from 1902 to 1925 (including a sharp three year decrease), then alternating smaller increases and decreases until 1975 then significantly decreasing annual rainfall to 2002.

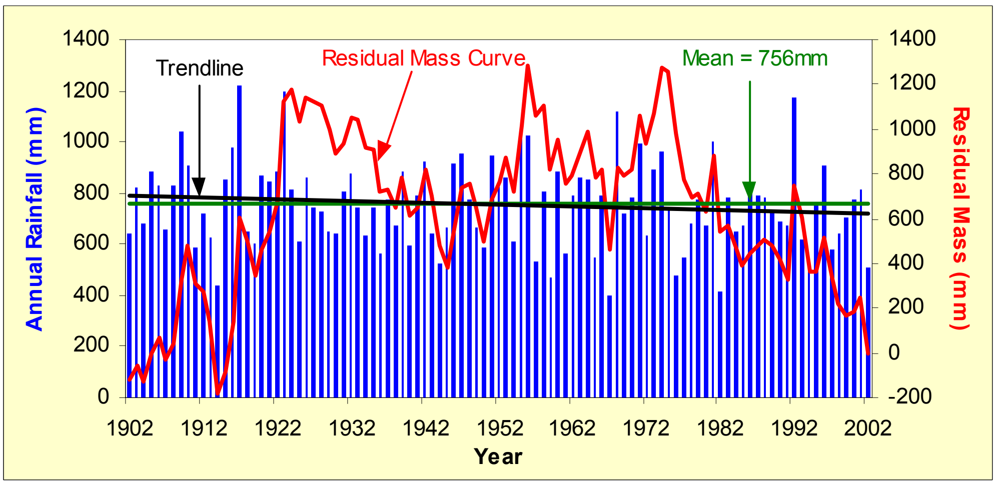


Figure 18 Annual Rainfall Totals and Variability for the Upper River Torrens Catchment.

Appendix C.2 presents the trendlines and residual mass curves for the annual rainfall from each of the sites used for catchment modelling and similar results were found to those shown for the average catchment rainfall.

Monthly Rainfall

The mean monthly data for average catchment rainfall is shown in Figure 19 and for each site used for catchment modelling in Figure 20. At each location and for the total catchment, 80 percent of the rainfall occurs between April and October. In comparing the magnitudes of the mean monthly rainfall in the months of November to March between sites, it is interesting to note that the differences are not as great as during the remainder of the year, even though the annual rainfall totals are significantly different. This indicates that the higher rainfall months (April to November) are primarily responsible for the majority of the rainfall difference between sites.

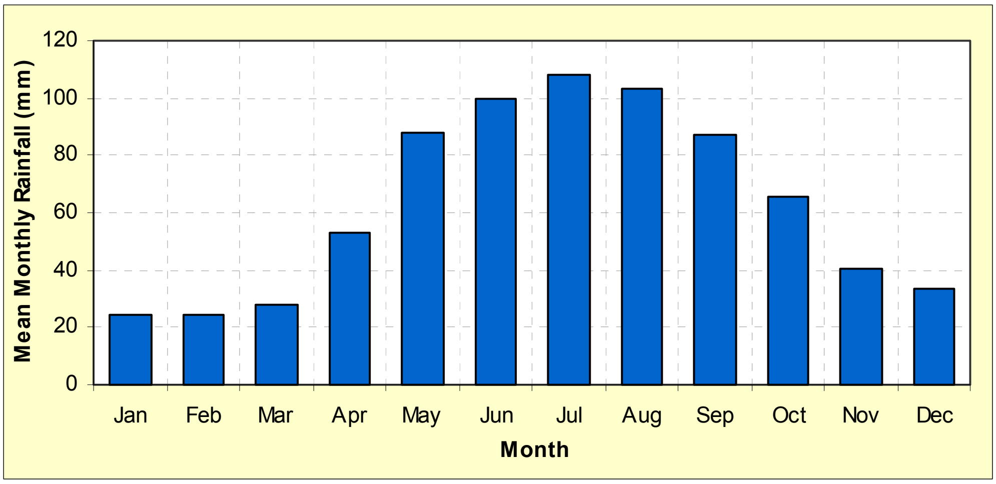


Figure 19 Mean Monthly Rainfall Totals for the Upper River Torrens Catchment.

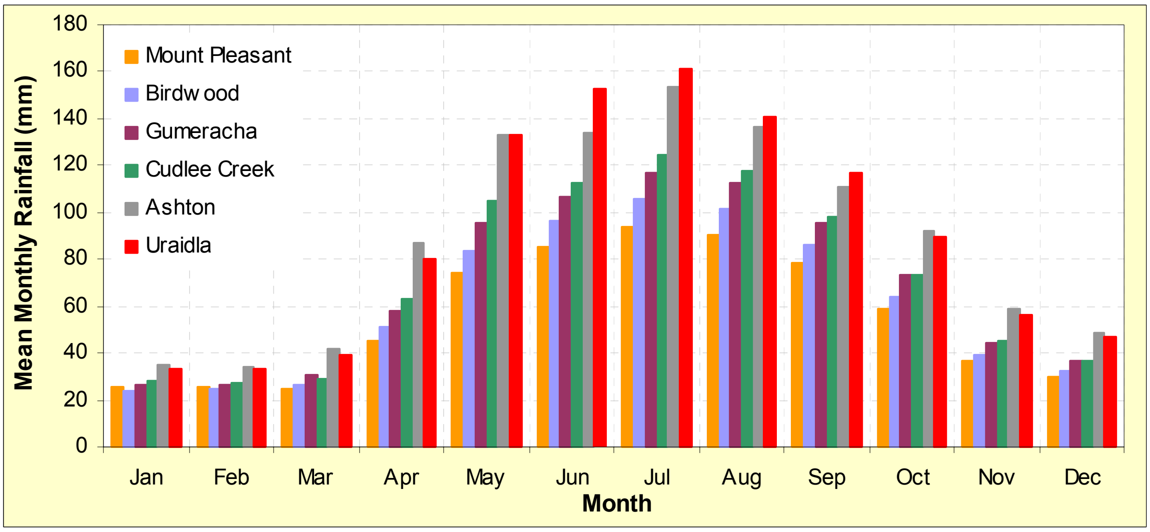


Figure 20 Mean Monthly Rainfall Totals at Stations used for Modelling.

An analysis of the monthly rainfall was also undertaken to detect any trends or long term changes in the data. Residual mass curves were plotted for each month, together with the annual curves. Figure 21 shows a number of these curves for the average catchment rainfall. The curve for June generally follows the annual curve, suggesting decreases in June rainfall may form part of the reason behind the decreasing annual trend. A reduction in June rainfall may have a large impact on the annual runoff from a catchment. The majority of runoff in the Upper River Torrens catchment occurs later in the year (refer Section 3.3.2). Much of the autumn and early winter rainfall infiltrates into the soil and saturates the catchment. This early season saturation is an important requirement for producing runoff later in the year. Therefore, reductions in June rainfall delay the major runoff events and can reduce the overall annual runoff.

The curves for most other months do not show significant trends, with the exception of May and September. These months also show increasing rainfall through to around 1935. Although September rainfall then decreases until around 1955 before remaining relatively constant, the May rainfall decreases until around 1945 and then increases. A plot with all monthly curves for each individual stations are presented in Appendix C.2 where similar results were found. Trends in May, June and September rainfall were particularly significant.

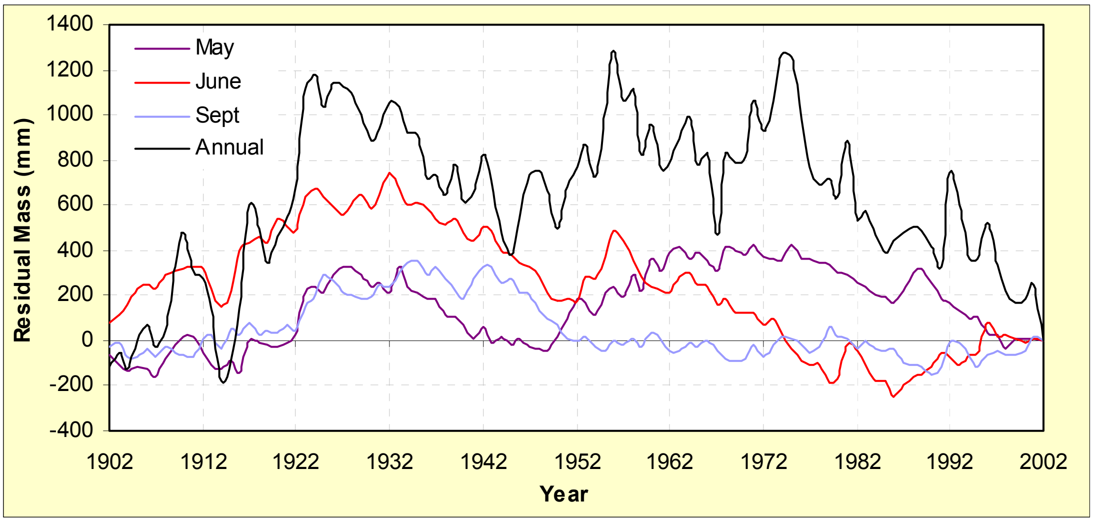


Figure 21 Monthly Residual Mass Curve for Upper River Torrens Catchment.

The significant increases in both annual and June rainfall at the beginning of the 1900s and then the significant decreases toward the end of the century have also been observed in other catchment studies, in particular, the Barossa Valley (Cresswell; 1991), Marne River catchment (Savadamuthu; 2002), Onkaparinga River catchment (Teoh; 2003) and Finniss River catchment (Savadamuthu; 2003).

In addition to the monthly residual mass curve, a trendline was applied to the monthly totals over the period 1902 to 2002. For each station, the trendlines for most months indicated no long term increases or decreases. However, for June monthly totals there were clear long term decreasing trends at most stations. May and September monthly totals also showed some long term decreasing trends but these were usually less significant. July showed a slight increasing trend at some stations. Figure 22 clearly shows this decreasing trend for May and June in the average catchment rainfall data with the results for each station shown in Appendix C.2.

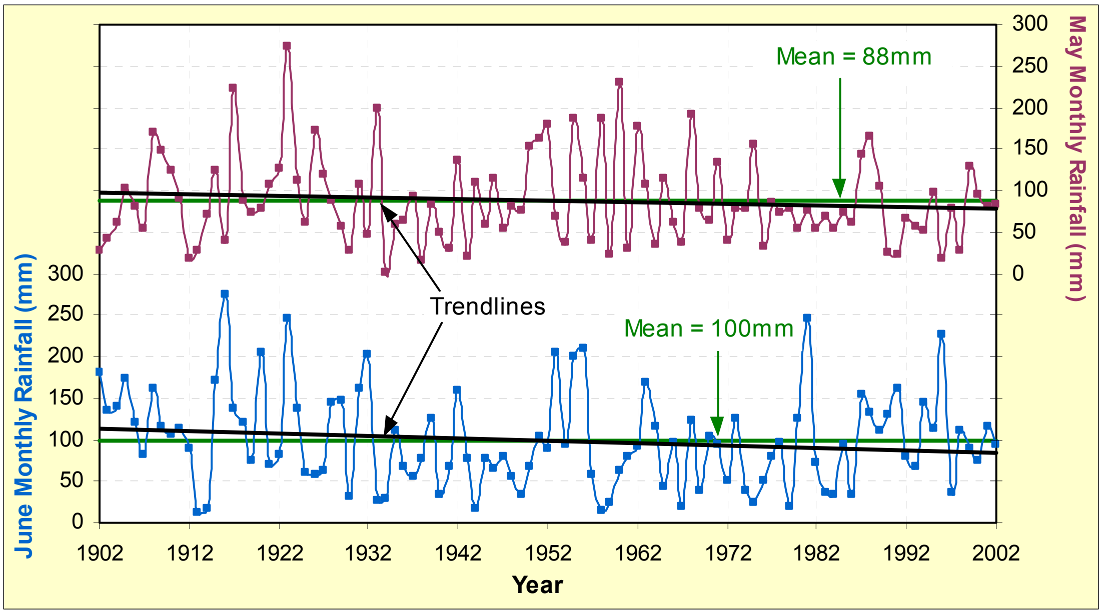


Figure 22 May and June Monthly Rainfall Totals and Trends for the Upper River Torrens Catchment.

Decadal Rainfall Analysis

The study of climate variability and climate change has increased over the last twenty years and has included the analysis of variables such as rainfall at a decadal time scale. This is in part because natural climate variability at decadal time scales has the potential to interact with and interfere in an unambiguous detection of climate change (Latif *et al*., 1999).

A decadal rainfall analysis of the data at each site used for catchment modelling revealed significant statistical trends. Figure 23 shows this analysis for average catchment rainfall. The "mean decade rainfall" is the average rainfall over non-overlapping ten year periods. Average rainfall significantly above the long term mean can be seen in the ten year periods 1916 to 1925, 1946 to 1955, 1966 to 1975 and below the long term mean in the periods 1936 to 1945, 1956 to 1965 and 1976 to 1985.

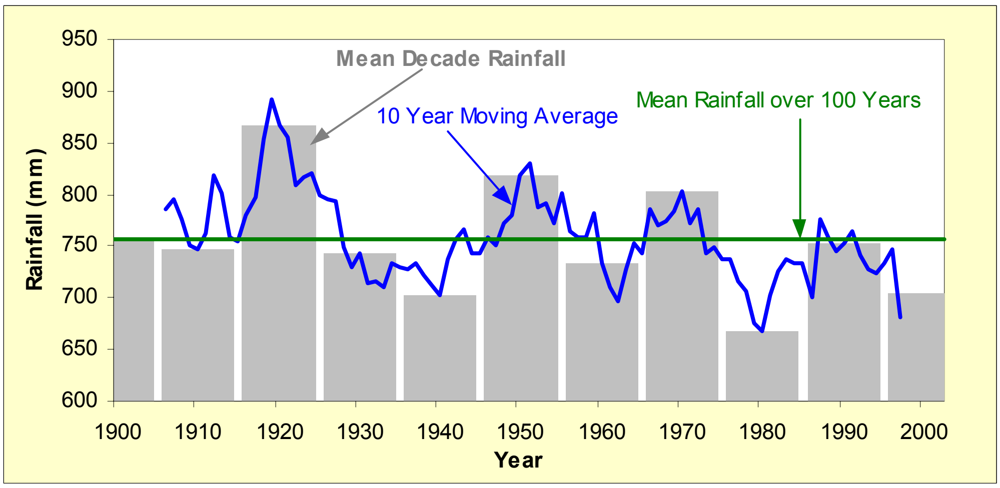


Figure 23 Decadal Rainfall Pattern for the Upper River Torrens Catchment.

Average rainfall over “standard” decades (for example, 1900 to 1909, 1910 to 1919) was initially examined but the ten year moving average clearly highlights the high (peaks) and low (troughs) rainfall periods as not being consistent with standard decades.

It is worth noting that the height of successive above average rainfall peaks in both the ten year moving average and the mean decade rainfall have decreased, resulting in the above average peak from 1986 to 1995 being close to the long term mean. Similar results are not seen with the below average periods. Although conclusions could be drawn with regards to long term changes in the rainfall regime or even climate change, without longer rainfall series it cannot be ascertained whether this may just be an example of long term rainfall variability. However, it does highlight the need to prepare and ensure security of supply of water resources for extended periods of below average rainfall.

Appendix C.2 presents the decadal analysis for data from each station and similar results were found at each. A decadal analysis of annual rainfall data from locations in the Eastern Mount Lofty Ranges (Savadamuthu, 2003) have also shown similar patterns, indicating a regional trend.

3.2 Evaporation

Evaporation is the transfer of moisture into the atmosphere, whether from a free water surface such as a dam or reservoir, a soil surface or by the process of transpiration from plants. Accurate estimates are essential for hydrologic water-balance calculations because evaporation influences the amount of rainfall that is intercepted by vegetation and absorbed by the soil before surface runoff will occur. It also significantly reduces the volume of water stored in dams and reservoirs, particularly during summer.

3.2.1 Data Availability and Processing

The availability of daily evaporation data is limited, particularly in comparison to rainfall data. In previous investigations (for example, Savadamuthu, 2002; Teoh, 2003) a value of daily evaporation for each month has been obtained from the mean monthly rainfall for that month. However, it has been suggested (Lindsey and Farnsworth, 1997) that a limitation of the use of mean monthly values for evaporation is the large day-to-day variance in evaporation that often occurs during spring and autumn. Seasons may also begin early in some years and late in others or significant variations from mean monthly values may occur at any time during the year, for example, evaporation may be suppressed by lower temperatures and high humidity during a rainy period in the middle of summer, or extremely hot and dry periods may cause the evaporation to be very high during some years. Such factors may cause serious errors in the estimates of evaporation and hence the resulting water balance. During calibration of the catchment model (Section 4.3), significant improvements were found in the representation of the observed streamflow data by using daily data, which justified using this approach.

There are two sources of evaporation data that may be used for catchment modelling, namely measured pan evaporation or evaporation calculated using empirical equations. The method chosen usually depends on the type of surface from which evaporation is occurring because the factors affecting evaporation differ between a dam or reservoir surface compared to a soil or plant surface. It has been shown that data from both sources can be used interchangeably (Heneker, 2002) with the use of an evaporation adjustment coefficient. The catchments modelled include both open water and soil/vegetative surfaces but one method was chosen and an adjustment coefficient applied to the data set to represent average evaporation from all surfaces.

Pan evaporation is based on evaporation from an open water surface and provides an index of the integrated effects on evaporation from solar radiation, air temperature, air humidity and wind. It is collected at a number of locations across the Mount Lofty Ranges, although not within the Upper River Torrens Catchment. The closest sites with recorded pan evaporation are located at the South Para Reservoir and at the Lenswood Research Centre. However, the length of record and missing periods of data made it difficult to obtain a good quality, long term set of daily data.

Empirical equations used to calculate evaporation incorporate estimates of the main factors that affect evaporation (solar radiation, air temperature, air humidity and wind). Data sets of solar radiation and temperature in particular are often more readily available, have longer data records and have less missing data than pan evaporation records. Although there are many such empirical equations available, the Priestley-Taylor method (Priestley and Taylor, 1972) was used. This has been used for numerous catchment modelling studies in Australia (for example Sumner *et al.*, 1997; Heneker, 2002). A description of the method is presented in Appendix D.1.

The Priestley-Taylor method uses solar radiation data but because solar radiation is not widely monitored in Australia, it often has to be estimated, spatially interpolated or extrapolated using relationships between solar radiation and sunshine hours and temperature. In this case, a method using sunshine hours and maximum and minimum temperature was used.

Table 10 lists the sunshine hours and temperature stations that were used to calculate evaporation. These stations are at very similar locations with one ceasing operation in early 1999 after the other began operation in late 1996, although only the temperature records overlap. Information for other stations used during the data processing stage (discussed below) are presented in Appendix D.2.

Table 10 Climate Stations used to Calculate Evaporation for Hydrological Modelling

Station Number	Location	Data Type	Period of Record	Percentage of Missing Data
023321	Nuriootpa Comparison	Sunshine Hours	01/1959-02/1999	0.3
		Temperature	01/1957-02/1999	0.3
023373	Nuriootpa Viticultural	Sunshine Hours	03/1999-12/2002	0.5
		Temperature	09/1996-12/2002	2.0

These stations were chosen because of their long term recorded data and because they have been used to generate potential evaporation data for other studies (Sumner *et al.*, 1997). Variation between evaporation sites in the same region is generally considered lower than for rainfall and an evaporation adjustment factor can usually compensate for the distance between the station and the catchment. Few stations have longer term records with the exception of some stations in Adelaide. However, the stations used here are located at 275 metres, which is within the elevation range over the catchment (refer Figure 2) and are more suited than stations at lower elevations.

Missing Data

To infill missing temperature records a linear relationship was formed with a nearby site, while missing sunshine hours records were estimated from a fitted third order polynomial (Chiew and McMahon, 1991) between sunshine hours data and cloud cover data at the same location (where possible). Examples of the regression relationships and correlations are presented in Appendix D.2.

3.2.2 Data Analysis

Analysis of the calculated evaporation data for Nuriootpa (023321/023373) was undertaken at annual and monthly time scales. In addition, the statistics and trends of the sunshine and temperature data used to calculate the evaporation were also examined.

Annual Evaporation

The annual evaporation totals over the period 1959 to 2002 are shown in Figure 24 for which the mean annual evaporation is 1112 mm. The median annual evaporation and the standard deviation of the mean annual evaporation are 1113 mm and 37 mm respectively, suggesting that there is generally low variability of annual totals from the mean. However, the trendline for the annual data shown in Figure 24 indicates an increasing trend in annual evaporation over the period of record. An examination of the component data (sunshine hours and temperature) is presented in Appendix D.3, together with pan evaporation data from the same site. This analysis showed an increasing trend was also present in the annual pan evaporation data at this location and also in annual sunshine data.

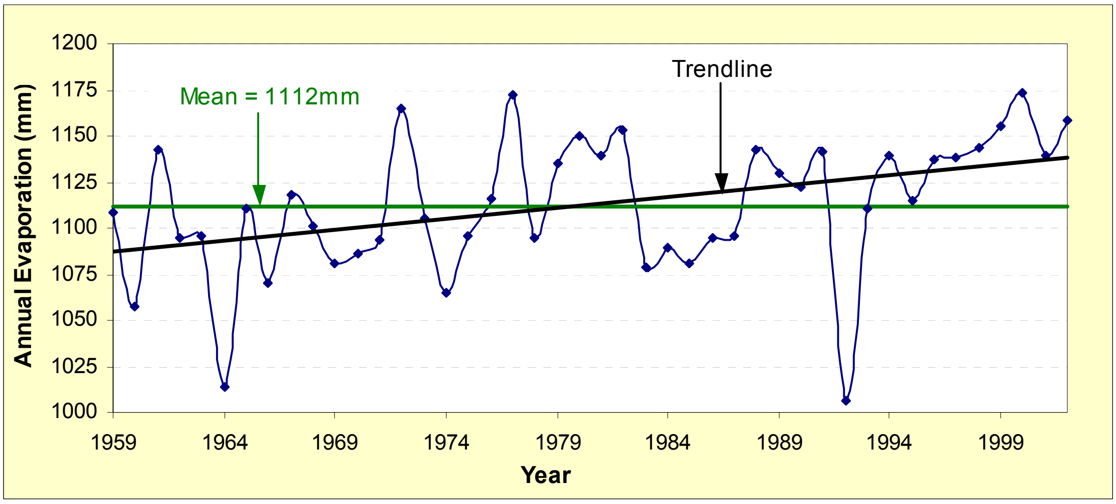


Figure 24 Annual Evaporation and Long Term Trends at Nuriootpa (023321/023373).

There is a high correlation between rainfall and evaporation, the higher the rainfall, the lower the evaporation. Therefore, higher rainfall during months of normally higher evaporation will have a large impact on the evaporation total as can be seen in Figure 24 for 1992. This year produced higher than average rainfall, particularly between August and December, which reduced the annual evaporation total considerably.

Monthly Evaporation

The mean monthly evaporation data is shown in Figure 25. As indicated above, rainfall and evaporation are highly correlated. Therefore, the distribution of mean values over the year is the reverse of that for mean monthly rainfall data, with the lowest evaporation occurring in June and the highest in January.

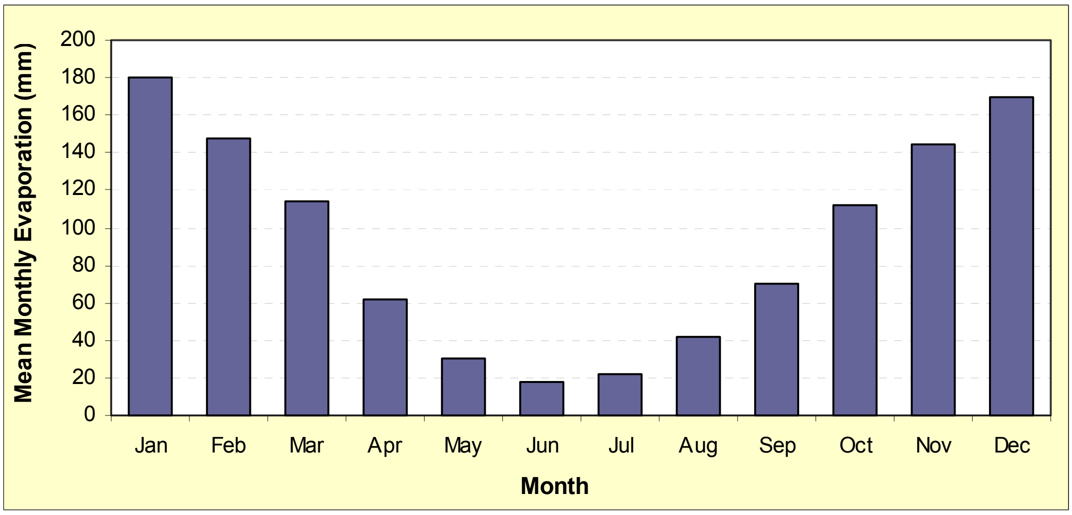


Figure 25 Mean Monthly Evaporation at Nuriootpa (023321/023373).

The evaporation data was examined for any evidence of a trend over the period of record. Almost every month showed an increasing trend, the most significant of these being in February and September as shown in Figure 26. May and December also showed significant increases in evaporation over time. An analysis of the temperature and sunshine hours data in Appendix D.3 shows trends in these months to be particularly significant.

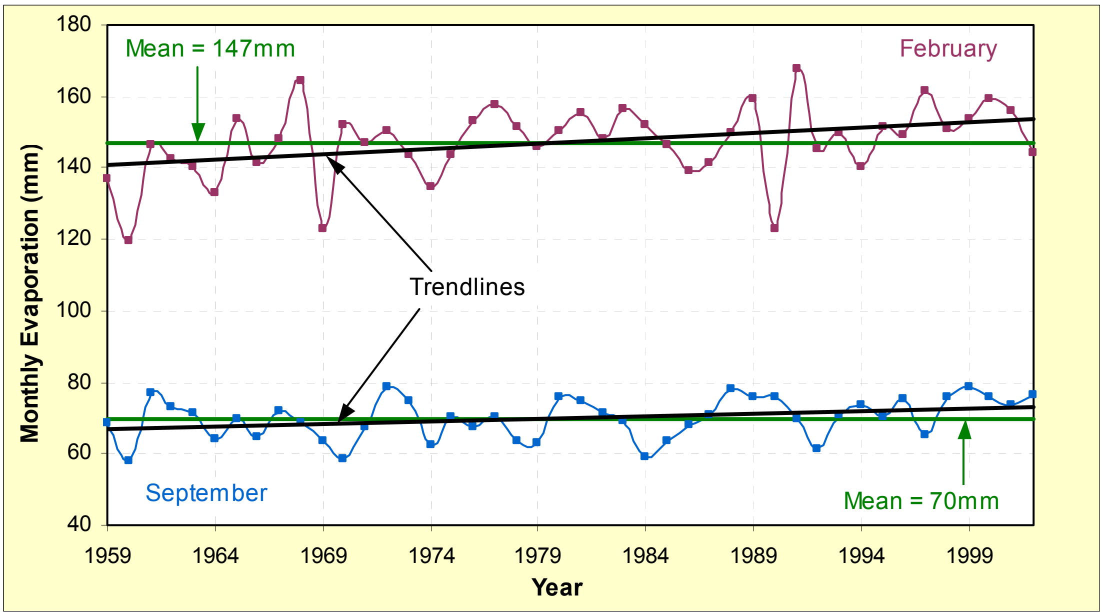


Figure 26 Long Term Trends in February and September Monthly Evaporation Totals at Nuriootpa (023321/023373).

3.3 *Streamflow*

The hydrological computer model developed in this study uses a set of model parameters to transform rainfall and evaporation into runoff. To ensure that the most appropriate set of parameters is selected, good quality streamflow information is required and it is desirable to have records that encompass high, low and average rainfall and runoff years. Without long term, good quality streamflow records, it is more difficult to calibrate a model that will predict accurate levels of runoff over a range of large and small rainfall events and for varying annual rainfall totals.

3.3.1 Data Availability and Processing

Daily streamflow data in South Australia is collected by DWLBC and the Bureau of Meteorology (BoM). Figure 16 shows the location of stations where water level is recorded, which can be transformed into streamflow by way of a rating table. Unless there is water released into the watercourse, for example from the M-A pipeline, this streamflow represents the runoff from the upstream catchment.

Table 11 Streamflow Gauging Stations.

Station Number	Location	Custodian	Period of Record	% of Missing Data
AW504500	River Torrens @ Gumeracha Weir	DWLBC	1974-2002	0.2
AW504501	River Torrens @ Gorge Weir	DWLBC	1974-2002	3.2
AW504512	River Torrens @ Mount Pleasant	DWLBC	1974-2002	-
AW504523	Sixth Creek @ Castambul	DWLBC	1978-2002	6.9
AW504525	Kersbrook Creek @ u/s Millbrook Reservoir	DWLBC	1990-2002	11.4
AW504903	Cudlee Creek @ d/s Road Bridge Lobethal Road	BoM	1996-2002	3.7
AW504911	Millers Creek @ Forreston	BoM	1997-2002	-
AW504912	Angas Creek @ Muellers Road	BoM	1997-2002	6.1
AW504913	River Torrens @ Birdwood	SA Water	1995-2002	29.7*

* The data from AW504913 is five-minute telemetry data and if a number of five-minute intervals were missing on a given day, all data for that day is discarded and the day recorded as missing. Hence, this may overestimate the total missing data.

Of these stations listed above, only the gauges at Mount Pleasant (AW504512), Sixth Creek (AW504523) and Kersbrook Creek (AW504525) provide reasonable quality streamflow data that is not affected by reservoir releases or bulk water transfers.

The Cudlee Creek (AW504903), Millers Creek (AW504911), Angas Creek (AW504912) and Birdwood (AW504913) stations are all maintained as flood warning sites and field-based water level to streamflow relationships are not available. Analysis of the data at these sites showed numerous problems including apparent instrument stutter where the recorded water level oscillates between two heights. This was particularly apparent in the low flow months between December and May. Although the streamflow recorder responded to rainfall and hence runoff events during June to November, the total runoff often far exceeded the total catchment rainfall and hence was considered in error. None of the data from these sites are suitable for any form of hydrological analysis or modelling until physical measurements of water level and streamflow are taken to develop rating curves.

The Gumeracha Weir (AW504500) and Gorge Weir (AW504501) sites contain reasonable records but must be used in conjunction with other diversion and transfer data (refer Section

2.5) if they are to provide a useful record of runoff. The streamflow reaching Gumeracha Weir consists of a combination of natural surface runoff in addition to M-A pipeline transfers from the scours at Mount Pleasant and Angas Creek. As indicated in Section 2.5 records available for these scours are limited. Much of the water reaching the weir is then diverted to Millbrook Reservoir via the Millbrook Reservoir offtake channel (AW504508). Only in periods of extremely high rainfall will more water overflow the weir than can be diverted to the reservoir and in years of low rainfall very little streamflow moves downstream. The streamflow reaching Gorge Weir consists of natural runoff from the Kangaroo Creek sub-catchment (downstream of the reservoir) and the Sixth Creek sub-catchment, in addition to releases and spill from Kangaroo Creek Reservoir. A large portion of the streamflow reaching the weir is diverted to Hope Valley Reservoir via the Hope Valley offtake channel (AW504509).

Although there were some sections of missing data within the available records these were not infilled due to lack of good correlated reference stations. It is more difficult to correct streamflow data for trend and homogeneity than it is for rainfall data because runoff is influenced by many factors and the transformation of rainfall to runoff is highly non-linear.

The primary data processing undertaken was to identify sections of the data for which the quality may be doubtful. The majority of streamflow gauges have inlet pipes that connect the pool behind the measuring weir to a well such that the height of water in the well is equal to the height of water in the weir pool. Therefore, this pipe may become blocked due to silt or debris and requires regular maintenance and back flushing. This will cause periods of the data to be doubtful. Other errors may be due to inoperative recorders, station reconstruction, debris interference on control or one off events such as a major release of water to flush Torrens lake in Adelaide due to algae. During model calibration, periods of data that may be doubtful can be excluded or a lower weight given to the accuracy of the predicted values.

3.3.2 Data Analysis

An analysis of the data from the gauging stations at Mount Pleasant (AW504512), Sixth Creek (AW504523) and Kersbrook Creek (AW504525) was undertaken at annual, monthly and daily time scales. The data from Gumeracha Weir (AW504500) was used in conjunction with data from the Millbrook diversion channel (AW504508) and scour releases to estimate catchment runoff upstream of the weir. Statistics for streamflow at Gorge Weir (AW504501) are unavailable because the quantities of water released from Kangaroo Creek and Millbrook Reservoirs in addition to the reservoir spills are not known (refer Section 2.5). In addition, because very little runoff from the total catchment area reaches the weir, it does not provide a good indication of total catchment yield. Total catchment yield was instead determined by hydrological modelling and values are presented in Section 5.1.3.

Data from the four stations above will be used for hydrological modelling. The sensitivity of the control section at various flow ranges must also be taken into consideration during model calibration. Appendix E.2 details the control sections for each of these streamflow gauging stations.

Annual Streamflow

The annual statistics of the data from the available streamflow gauging stations and hence for the gauged catchments are shown in Table 12. The values for each station given here differ from those given in the Torrens Catchment Plan (TCWMB, 2002; Tonkin Consulting, 2000b) where they appear to have been overestimated.

Table 12 Annual Statistics from Streamflow Gauges.

Gauged Catchment	Mean (ML)	Median (ML)	Standard Deviation (ML)
Mount Pleasant (AW504512)	2073	1851	2215
Sixth Creek (AW504523)	8367	7667	4588
Kersbrook Creek (AW504525)	2187	1730	1647
Gumeracha Weir (AW504500)*	21000	19500	16300

* Values for natural inflow into Gumeracha Weir are indicative only due to the required separation of scour data between scour points (refer Section 2.5).

Figure 27 shows the annual streamflow totals for the Mount Pleasant gauged catchment, highlighting the large inter-annual streamflow variability, from a maximum flow of 8,807 ML in 1992 to a minimum of 28 ML in 1982. This streamflow variability corresponds to the observed variability in annual rainfall totals, where for this case 1992 was a significantly above average rainfall year and 1982 significantly below average.

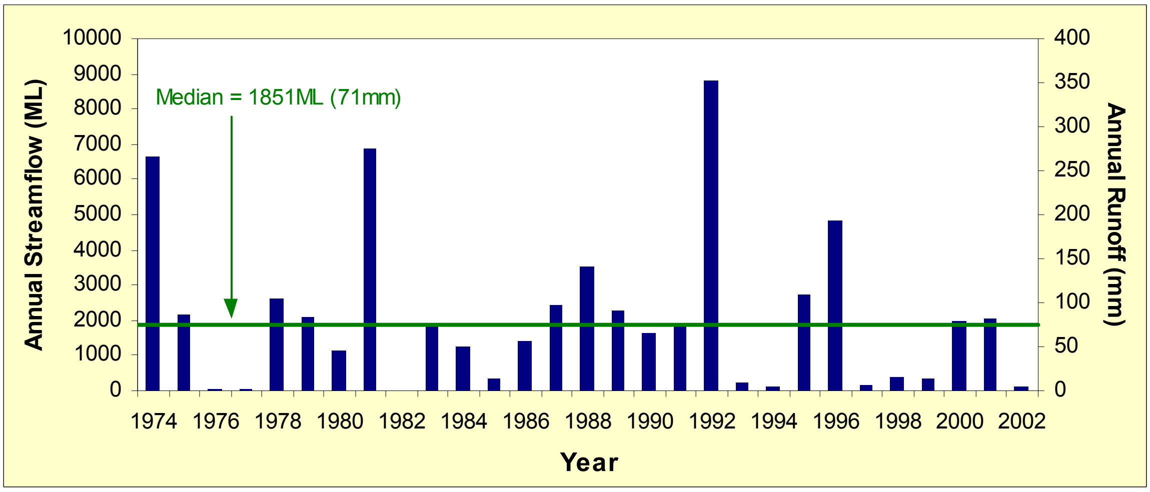


Figure 27 Annual Streamflow from Mount Pleasant Gauged Catchment.

Figure 28 shows the observed annual totals from the Gumeracha Weir gauged catchment, which include the M-A pipeline transfers and the estimated “natural” flow with these transfers removed. The variability of the natural flow is similar to that seen in data from the other stations with a maximum flow of 67,135 ML in 1992 and a minimum of 1,903 ML in 1976. However, the effect of the M-A pipeline transfers removes many of the low flows because these “drier” years are when large volumes of water are transferred through the M-A pipeline. This creates a regime where the annual flow in most years is greater than the median flow that would naturally occur. While the maximum recorded flow of 68,582 ML in 1992 is comparable to the natural maximum flow, the minimum recorded flow is 26,476 ML, much greater than the minimum natural flow and in a year when no M-A pipeline transfers occurred upstream of the weir.

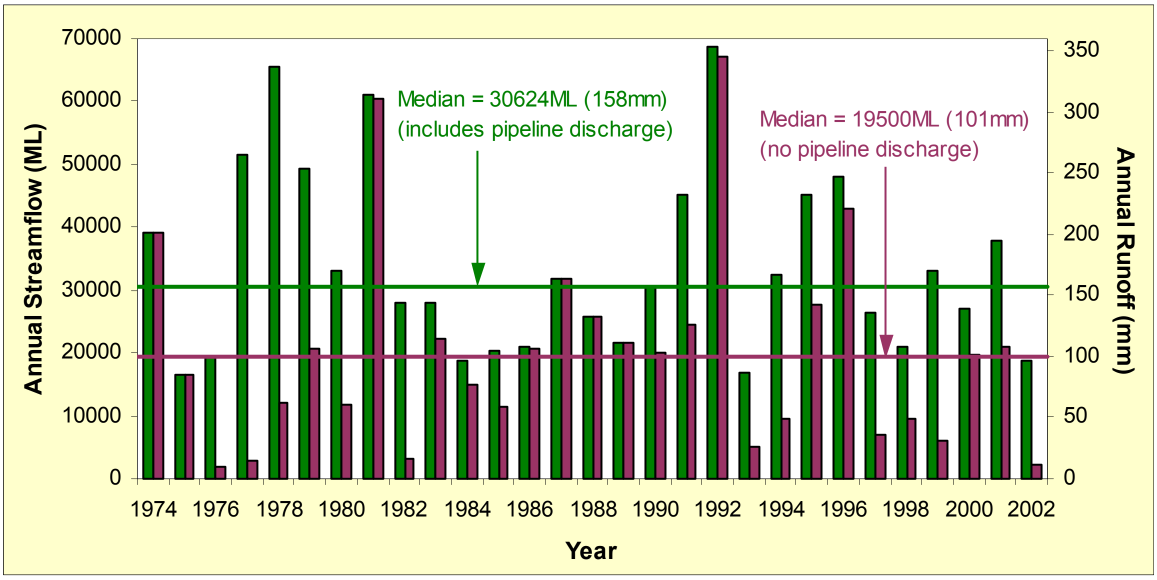


Figure 28 Annual Observed and "Natural" Streamflow from Gumeracha Weir Gauged Catchment.

Annual streamflow totals for the remaining stations from Table 12 are presented in Appendix E.2 with similar trends in rainfall totals and annual variability to those above.

Monthly Streamflow

The rainfall data presented in Section 3.1.2 showed that 80 percent of the annual rainfall occurs between April and November. For annual streamflow, this ranges from 95 percent between June and October for lower rainfall catchments such as Mount Pleasant as shown in Figure 29 and Kersbrook Creek (refer Appendix E), down to 85 percent between May and November in the higher rainfall catchments such as Sixth Creek (refer Appendix E). The highest streamflow months are generally July and August. Despite significant rainfall during April and May in most catchments, the delay in runoff results from much of the rainfall in the first half of the year infiltrating into the soil. As the soil becomes more saturated the more runoff occurs. This is particularly apparent for the lower rainfall catchments, which take longer to become saturated. Appendix E.2 presents the mean monthly streamflow values for the remaining gauged catchments.

Figure 30 shows the effect that the M-A Pipeline transfers have on the mean monthly streamflow into Gumeracha Weir. Because of these transfers, the relationship between the recorded streamflow to rainfall does not provide any insight into the runoff characteristics of the catchment and highlights the unnatural flow conditions that they have created. The mean monthly natural inflow into Gumeracha Weir, also shown in Figure 30, indicates that without the pipeline transfers there would be a period of lower flow between January and May with 95 percent of the catchment runoff occurring between June and December.

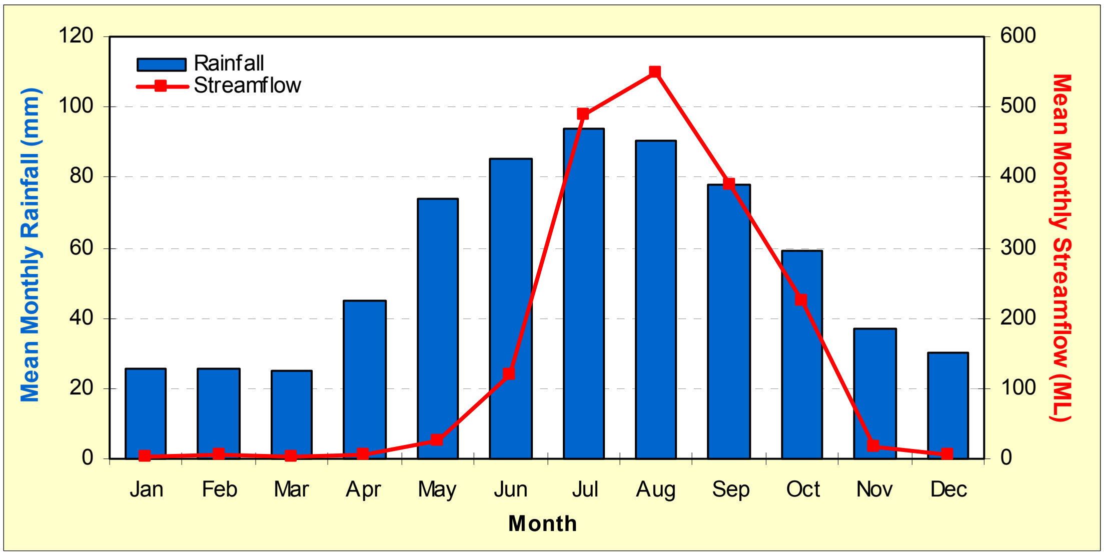


Figure 29 Mean Monthly Streamflow and Rainfall from the Mount Pleasant Gauged Catchment.

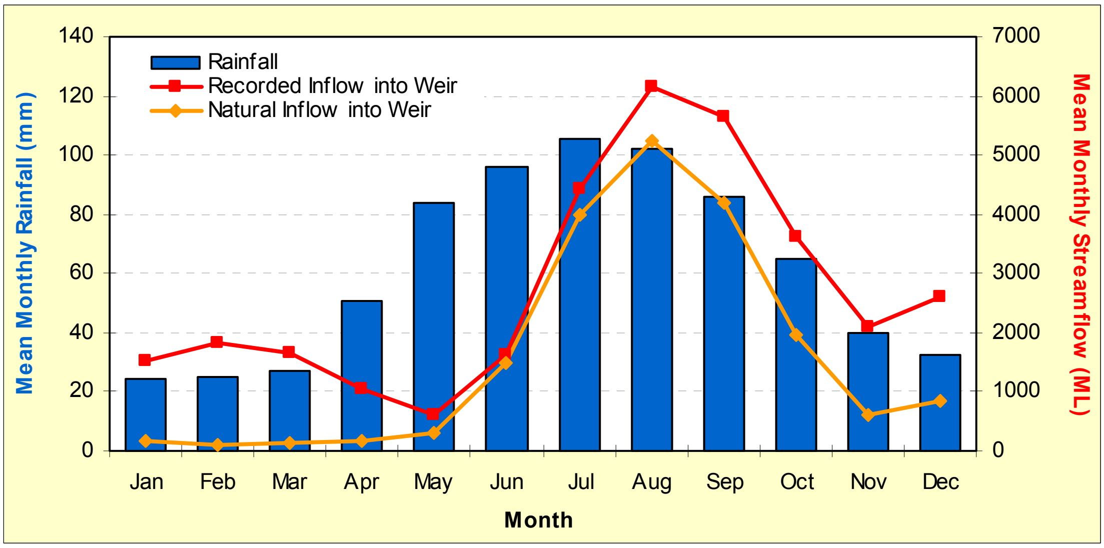


Figure 30 Mean Monthly Streamflow and Rainfall from the Gumeracha Weir Gauged Catchment.

Daily Streamflow

The daily statistics of the available streamflow data are shown in Table 13. The mean value of a dataset can be adversely affected by small numbers of large values. Therefore, in data sets that contain large variability and large numbers of small or zero values, the median is often a better measure of the expected flow. For example, a mean flow of 5.7 ML/day is observed at the Mount Pleasant gauging station but for over half the year the flow is less than 0.1 ML/day. The large variability in daily flow is also seen by the high values for the standard deviation.

Table 13 Daily Statistics from Streamflow Gauges.

Streamflow Gauge	Mean (ML)	Median (ML)	Standard Deviation (ML)
Mount Pleasant (AW504512)	5.7	0.11	36.6
Sixth Creek (AW504523)	23.2	7.46	64.0
Kersbrook Creek (AW504525)	6.0	0.24	33.8
Gumeracha Weir (AW504500)*	92.4	34.55	251.7

* Values for recorded inflow into Gumeracha Weir and which includes M-A pipeline transfer.

One of the simplest and more informative means of showing the daily flow characteristics of a stream is the flow frequency curve. This shows the percentage of time the specified flows were equalled or exceeded during the period of record and provides insight into the volume of flow that may occur during an average year. Figure 31 shows the flow frequency curve at the Mount Pleasant gauging station from which the characteristics presented in Table 14 can be interpreted. A similar analysis was undertaken for the daily streamflow data from each of the other stations and is presented in Appendix E.2.

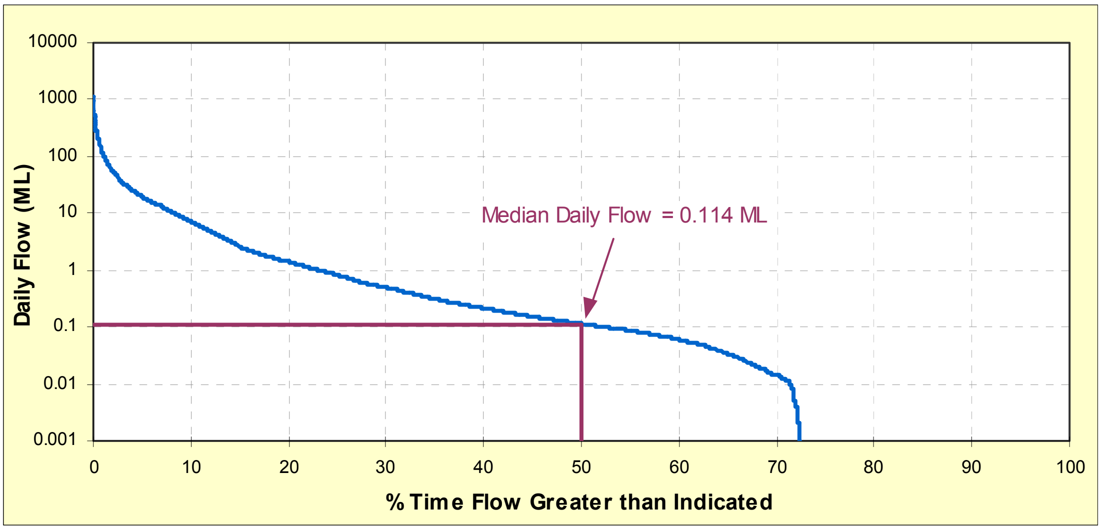


Figure 31 Flow Frequency Curve at Mount Pleasant Gauging Station.

Table 14 Characteristics of Flow Frequency Curve at Mount Pleasant Gauging Station.

Flow Criteria	% Year	No. Days
Ceases to Flow*	27	99
Flow ≥ 1 ML/day	23	84
Flow ≥ 10 ML/day	8	30
Flow ≥ 20 ML/day	5	18
Flow ≥ 50 ML/day	2	8
Flow ≥ 100 ML/day	1	4

* Flows below this are difficult to measure and model accurately.

One of the main objectives of this study is to evaluate if the duration of any of the flow ranges have been impacted by farm dam development or water supply operations in the upstream catchment, and determine the extent of the impact on the flow ranges. This will be explored further in Section 5.

3.3.3 Rainfall-Runoff Relationships

Annual rainfall-runoff relationships provide a straightforward means of determining how much runoff can be expected from a catchment given a specific level of rainfall. They are often used for comparing the characteristics of different catchments and can also be used for initial runoff estimates from ungauged catchments. The average annual runoff coefficient and the TanH function are two commonly used tools.

An annual runoff coefficient is the annual rainfall divided by the annual runoff, indicating the proportion of runoff that occurred for a given annual rainfall in a given year. The average annual runoff coefficient is the average of the annual runoff coefficients for all years in the available record (refer Appendix E.3 for more details). Table 13 shows the average annual runoff coefficient for each sub-catchment.

Table 15 Runoff Coefficients for Gauged Catchments.

Gauged Catchment	Average Annual Runoff Coefficient
Mount Pleasant (AW504512)	0.105
Sixth Creek (AW504523)	0.198
Kersbrook Creek (AW504525)	0.121
Gumeracha Weir (AW504500)*	0.132

* Values for natural inflow into Gumeracha Weir.

The TanH function is a simple rainfall-runoff function that also provides an effective site-based relationship that can be used to infill annual or monthly runoff values. The function and its parameters are described in detail in Appendix E.3. Figure 32 shows this relationship for the Mount Pleasant gauged catchment. It can be seen that little or no runoff occurs for annual rainfall below 350 mm. An annual rainfall of 600 mm is needed before significant volumes of runoff occur. In terms of estimating annual runoff data for a given annual rainfall, if the catchment had an annual rainfall of 800 mm, then the curve would predict a catchment runoff of 148 mm, which is equivalent to 3,856 ML, for that year. Rainfall-runoff curves for the remaining gauged catchments are presented in Appendix E.3.

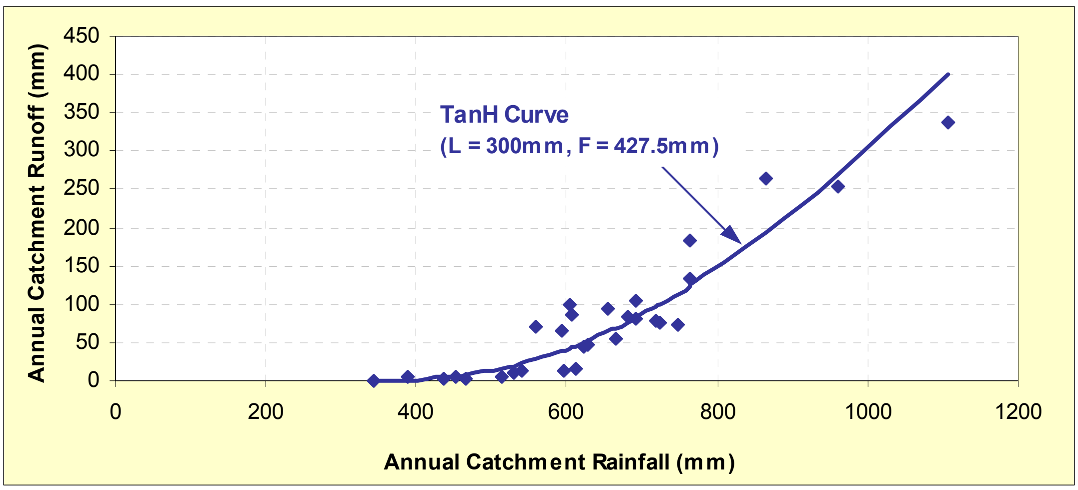


Figure 32 Rainfall-Runoff Curve for Mount Pleasant Gauged Catchment.

4. SURFACE WATER MODELLING

4.1 Overview

Hydrological computer models that can adequately describe catchment rainfall-runoff processes and incorporate current development levels provide a flexible means of determining the availability of surface water resources, predicting long term catchment behaviour and estimating the impact that development has on the natural flow regime. At the same time, such models provide scope to conduct environmental flows assessment, analyse the impact of potential future development levels and facilitate the assessment of various water management options.

The type of surface water model used for a given study depends on many factors. A model must be complex enough to capture and replicate the physical processes without being overly complex, which can result in parameter estimation difficulties. Conceptual models provide one the simplest approaches to surface water modelling and generally use a water balance approach. These involve the catchment being conceptualised by a number of interconnected storages with mathematical functions describing the movement of water into, between and out of them. Parameter estimates for the model must be obtained by fitting computed hydrographs to observed hydrographs as direct physical measurements of the parameters are usually difficult or impossible.

For this study, long-term rainfall and evaporation data was used to calibrate a conceptual surface water model to simulate long-term runoff data for the Upper River Torrens catchment. This involved the following stages:

1. *Model Construction*: The spatial distribution of those physical features that control or influence the volume of runoff and its movement through a catchment were represented as a series of interconnected nodes, each corresponding to a different feature such as a rural area, urban area, reservoir, farm dam, flow diversion structure or pipeline discharge point. Each node was characterised by a series of mathematical equations that describe how water (rainfall, evaporation or runoff) moves into, is stored in and moves out of that node.

   The majority of nodes for a given catchment represent either rural or urban areas in which the transformation of rainfall into runoff occurs. This was carried out using a rainfall-runoff or conceptual water balance model that simulated the physical processes interception, evaporation, transpiration, infiltration, percolation, recharge and baseflow using a set of mathematical transfer functions linking a number of interconnected water stores.

2. *Model Calibration*: The conceptual water balance model parameters (which are required for the mathematical transfer functions) are estimated by an iterative process. Input rainfall and evaporation data is transformed into computed runoff hydrographs that are then compared to observed hydrographs from recorded streamflow records. The parameter set that produced computed hydrographs that best represent the observed hydrographs were chosen as the optimal parameter set.

   An iterative process is the only method available to solve the transfer equations as direct physical measurements of the parameters are difficult. This process was undertaken using a combination of an optimisation algorithm and by manual manipulation of parameter values with the criteria defining the optimal parameter set and overall model suitability based on a combination of the correlation between daily, monthly and annual computed and observed hydrographs and the representation of daily flow frequency curves.

The suitability of a particular water balance model and the efficiency of the calibration process is highly dependent on data availability. The less data that is available the less complicated the water balance model should be if reasonable calibration is to be obtained.

3. *Scenario Evaluation*: The calibrated model was used to generate synthetic runoff data under current catchment conditions and also for a number of modified catchment conditions (such as pre-development and potential farm dam development). This allowed an evaluation of the effect that current development levels have had on the natural flow regime and to predict future impacts (both natural and human induced). It also provided a flexible means to facilitate the assessment of various water management options.

4.2 Model Construction Methodology

The WaterCress (Water - Community Resource Evaluation and Simulation System) modelling platform (Clark *et al.*, 2002; Cresswell, 2002) was used to construct a catchment model for the Upper River Torrens catchment. In recent times, WaterCress has been used for a number of other catchment studies (Savadamuthu, 2002; Teoh, 2002) because it allows flexibility in the description of catchment attributes such as rural and urban areas, diversion weirs, water supply infrastructure, farm dams and reservoirs, aquifers, wetlands and sewage treatment works. It also contains a number of conceptual water balance models for rainfall-runoff transformation in rural and urban areas.

The methodology for constructing the model in this study involved the following:

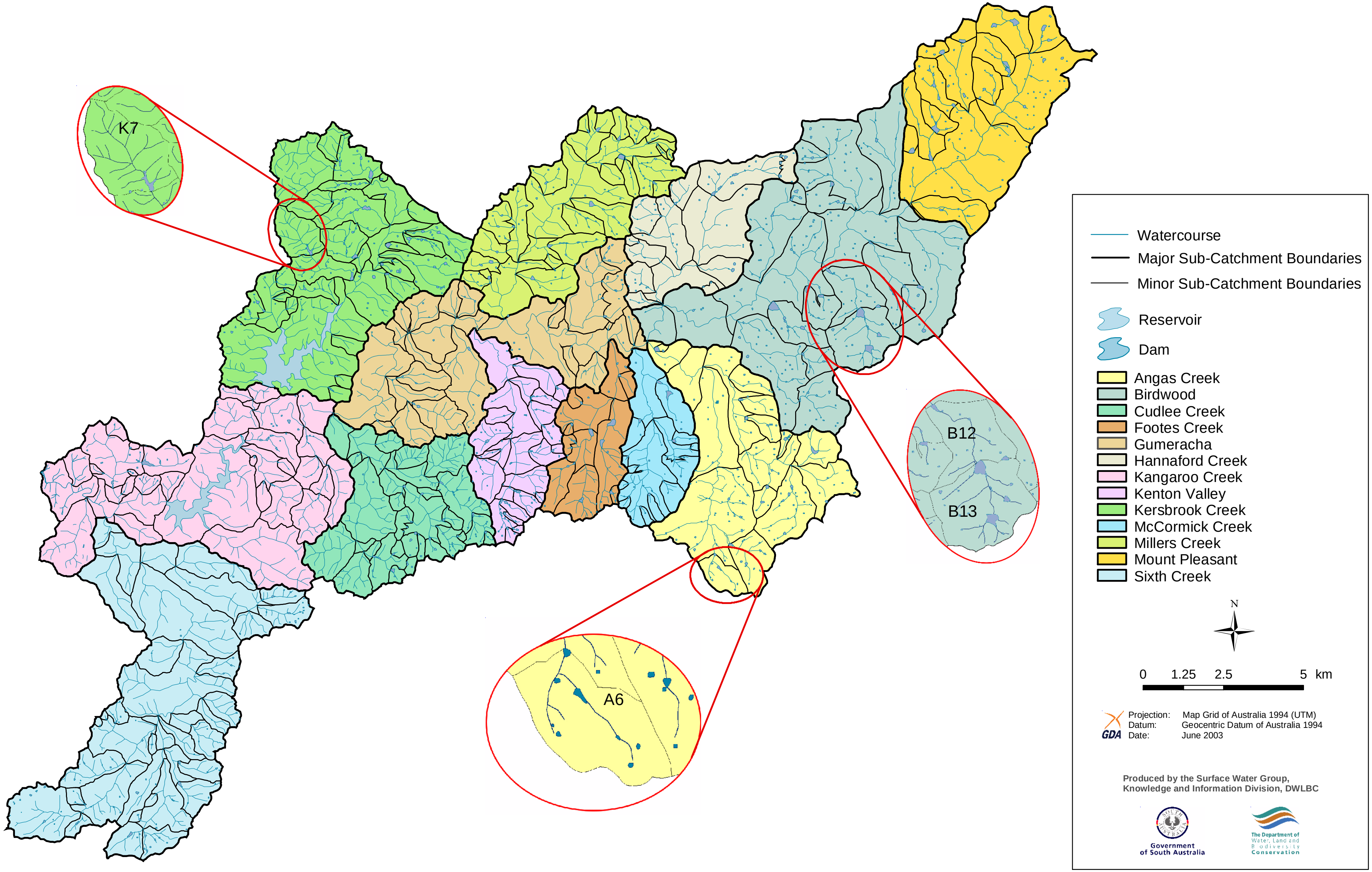
- Sub-division of major sub-catchments into minor sub-catchments (refer Section 4.2.1);
- Calculation of dam storage, surface area, diversions and irrigation demand/water usage within each minor sub-catchment (refer Section 4.2.2);
- Identification of major water supply infrastructure including diversion weirs and pipe transfer discharge points;
- Representation of the spatial relationship of minor sub-catchments, farm dam storage and water supply infrastructure as a series of interconnecting nodes;
- Preparation of daily rainfall and evaporation data files and quantification of rainfall spatial variability (refer Section 4.2.3);
- Preparation of daily streamflow data files for model calibration; and
- Selection of water balance models for rainfall-runoff transformation (refer Section 4.2.4).

Once the model has been constructed, the calibration of water balance model parameters is undertaken.

4.2.1 Minor Sub-Catchments

The major sub-catchments defined in Section 2.2 were further sub-divided into minor sub-catchments for modelling as shown in Figure 33. These minor sub-catchments were based on significant on-stream or *controlling* dams as these delay all upstream catchment runoff from moving downstream until the dam is full and overflows. Four minor sub-catchments are also identified in Figure 33, where the on-stream dams have been identified as controlling the runoff from upstream. Appendix F.1 presents further information on model construction.

Figure 33 Minor Sub-Catchments in the Upper River Torrens Catchment.



Other factors considered were secondary streams, groups of off-stream farm dams from which runoff will overflow into areas without dams, rainfall patterns and land use information such as large areas of forestry. It was preferable to have major stream reaches defined as minor sub-catchments as this allowed a straightforward evaluation of localised streamflow volumes and development impacts. Major rural towns were also defined separately.

Table 16 shows the number of minor sub-catchments defined within each major sub-catchment. The area of minor sub-catchments not draining into farm dams, which is free to flow directly into the stream network provides an indication of the "free to flow" area. It is an upper estimate of this area as runoff may flow into an on-stream dam in a downstream minor sub-catchment. The sizes of rural towns are also presented.

Table 16 Minor Sub-Catchments in the Upper River Torrens Catchment.

Sub-Catchment	Number of Minor Sub-Catchments	Area Without Farm Dams (km^2)	Rural Town Area (km^2)
Mount Pleasant	16	11.7 (45)*	0.695
Birdwood	23	21.4 (42)	0.652
Hannaford Creek	14	8.0 (53)	-
Angas Creek	21	15.6 (57)	0.202
Gumeracha	10	18.5 (65)	0.252
Footes Creek	10	3.4 (36)	-
McCormick Creek	8	5.4 (58)	-
Kenton Valley	23	6.0 (47)	0.275
Millers Creek	25	9.1 (40)	0.052
Cudlee Creek	24	9.8 (49)	-
Kangaroo Creek	30	28.4 (74)	-
Kersbrook Creek	26	20.9 (57)	0.345
Sixth Creek	34	36.2 (82)	0.199

* Area without farm dams as a percentage of total sub-catchment area.

Each minor sub-catchment is represented by a rural catchment node in the model. For those containing farm dams, a proportion of the runoff was diverted into an off-stream dam node (refer Section 4.2.2).

4.2.2 Farm Dam Attributes and Irrigation Demand

The streamflow data used to calibrate the catchment model is influenced by farm dams. This influence changes over the period of observed record as new dams are constructed. However, because the actual rate of dam development is unknown, this study assumes that the numbers and capacities of dams within each minor sub-catchment remained constant over the period of available data.

The farm dams within each minor sub-catchment are represented in the model by off-stream dam nodes. This representation has a number of important characteristics.

1. For each dam node, the capacities of all farm dams within the represented minor sub-catchment were aggregated to form a single storage. A proportion of the runoff occurring from the rural catchment node (rural area within the minor sub-catchment) was then diverted into the dam. This proportion is dependent on the location of the dams(s) and hence the catchment area draining into the dam(s). For example, an on-stream controlling dam will capture 100% of runoff from the upstream catchment and therefore

the diversion to this dam would be 1.0 if this dam lies on the downstream catchment boundary. However, if the dam is located partway up a stream branch, then a smaller proportion of runoff from the total minor sub-catchment will enter the dam. Similarly, when the total storage comprised numerous truly off-stream dams spread throughout the minor sub-catchment less than 100% of the total runoff will be captured and the diversion will be less than 1.0. The maximum daily diversion to a dam is assumed to equal the capacity of the dam.

2. The total surface area for the aggregated dam storage is the sum of the surface areas for each individual dam. The surface area and dam capacity were then used to determine an approximate surface area to capacity relationship using the following relationship:

$$V = F_1 \, A^{F_2} \tag{5}$$

   where:

   V = volume/capacity (ML);

   A = surface area (m^2); and

   F_1, F_2 = parameters.

   An examination of the relationship between dam capacity and surface area for a number of minor sub-catchments showed that F_2 could remain constant at a value of 0.7934. A value of F_1 was then calculated for each dam node. Calculating values of F_1 for each dam node ensured that when the aggregated dam was full, the surface area calculated by this equation was equal to the surface area of the aggregated dam.

3. The amount of water used for annual irrigation was estimated at 30% of the total dam capacity and this use was assumed to occur between October and March. A value of 30% provides annual storage carry-over and it is reasonable to expect that irrigators would not allow their dams to dry out completely. There is very little recorded information on water use from farm dams and because it was not known which dams in the catchment are used for irrigation, stock or domestic purposes, a value of 30% and assumed summer usage provides an average value. It does however correspond with preliminary estimates of water use from farm dams by McMurray (2003a). The monthly usage factor, as a percentage of the annual usage volume is as follows:

   January = 24%, February = 19.5%, March = 12.6%;
   April to September = assume no irrigation;
   October = 6.6%, November = 16.6%, December = 20.7%.

Appendix F.1 provides more details about model construction, the representation of farm dams and the characteristics for each dam node.

4.2.3 Rainfall Spatial Variability

The WaterCress modelling platform allows a rainfall record to be linked with each rural, urban and dam node and a rainfall factor applied. By applying a different rainfall factor to each node and hence each minor sub-catchment, it allows the data from the rainfall stations presented in Section 3.1 to be adjusted and therefore incorporate rainfall spatial variability.

The relative position and values of the rainfall isohyets shown in Figure 16 were used to determine the appropriate rainfall factor. The factor was defined as the ratio of the isohyet passing through the minor sub-catchment to the isohyet passing through the rainfall station.

For example, if the isohyets passing through the minor sub-catchment and rainfall station were equal to 800 mm and 750 mm respectively, then a rainfall factor of 1.07 would be applied to the data from the rainfall station.

Table 17 shows the average rainfall for each sub-catchment and Appendix F.1 provides details of the rainfall stations and factors used for each minor sub-catchment.

Table 17 Sub-Catchment Average Rainfall.

Sub-Catchment	Average Rainfall
Mount Pleasant	669
Birdwood	707
Hannaford Creek	686
Angas Creek	727
Gumeracha	799
Footes Creek	809
McCormick Creek	772
Kenton Valley	794
Millers Creek	772
Cudlee Creek	883
Kangaroo Creek	844
Kersbrook Creek	811
Sixth Creek	929

4.2.4 Water Balance Model

The water balance model chosen to transform rainfall into runoff for rural sub-catchments was a modified Australian Water Balance Model (AWBM) (Heneker, 2002). The model schematic and parameter descriptions are provided in Appendix F.2. This model differs from the original AWBM (Boughton, 1993; 2000) as it incorporates daily evaporation data and a linear surface routing store derived from first principles. The linear store formulation used allows for the delay between the occurrence of surface runoff and its appearance as streamflow while at the same time allowing for fast runoff from small or efficient catchments.

4.3 Model Calibration

The WaterCress model with modified AWBM rainfall-runoff model was calibrated using the daily rainfall and evaporation data (Sections 3.1 and 3.2) to streamflow data (Section 3.3) available for the Mount Pleasant (AW504512), Sixth Creek (AW504523), Kersbrook Creek (AW504525) and Gumeracha Weir (AW504500) gauged catchments.

4.3.1 Calibration Method

Calibration of the WaterCress model with modified AWBM rainfall-runoff model was carried out by using a combination of the SCE search method (Duan *et al*., 1992; Kuczera, 1997) in the NLFIT program (Kuczera, 1994) and the manual manipulation of parameter values. NLFIT is a Bayesian non-linear regression program to which specific model algorithms or executable programs can be added and subsequently calibrated. The WaterCress program was linked to NLFIT, with the option to calibrate daily, monthly and yearly flow values, as well as the daily flow frequency curve.

The appropriateness of the calibrated parameters was assessed by comparing the values predicted by the model with observed data at annual, monthly and daily timescales in addition to correlation statistics. These statistics are used to determine how well a model is able to reproduce the observed data. Two common statistics for this assessment are the coefficient of determination (R^2) and the coefficient of efficiency (E).

Although the SCE search method has the ability to locate the statistically optimal parameter set for a given model and flow data, it was sometimes necessary to slightly adjust model parameters to specifically improve an aspect of the modelled data. For example, slight adjustments were sometimes made to alter the cease to flow point on the flow frequency curve. Such adjustments made very little difference to the correlation statistics but improved the reproduction of an important model feature (flow frequency curve) at the small expense of another (for example, monthly runoff totals).

Appendix F.3 contains further details on the SCE search method, NLFIT program and correlation statistics.

4.3.2 Calibration Results

The appropriateness of the calibrated parameters was assessed by comparing the values predicted by the model with observed data at annual, monthly and daily time-scales. Statistics of the modelled and observed data were compared and correlation statistics examined (refer Section 4.3.1). The parameter values are detailed in Appendix F.4.

The R^2 and E correlation statistics shown in Table 18 indicate that at each location and for each time-scale the model performs satisfactorily. In particular, the good correlation between daily values at Gumeracha Weir shows that the delay in M-A pipeline transfers reaching the weir and transmission losses from these transfers were well modelled, particularly given the large uncertainties with the available data. The importance of using daily evaporation to reproduce flows at all time scales was also established during calibration. Using average values of monthly evaporation tended to overestimate higher flows and underestimate lower flows because the evaporation input does not include the observed variability of evaporation with rainfall at a daily time scale.

Table 18 Statistical Results from Model Calibration.

Gauged Catchment	Calibration Period	Time-Scale	R^2	E	Mean Flow (ML)	
					Observed	Modelled
Mount Pleasant	1974-2002	Daily	0.85	0.72	5.7	5.5
(AW504512)		Monthly	0.95	0.89	167	173
		Annual	0.97	0.93	2013	2071
Sixth Creek	1978-2002	Daily	0.87	0.75	21.1	21.6
(AW504523)		Monthly	0.95	0.90	642	658
		Annual	0.96	0.92	8278	8367
Kersbrook Creek	1993-2002	Daily	0.84	0.71	6.2	6.0
(AW504525)		Monthly	0.95	0.91	188	182
		Annual	0.96	0.90	2252	2187
Gumeracha Weir*	1975-1981	Daily	0.93	0.87	122.8	116.0
(AW504500)		Monthly	0.99	0.97	3737	3532
		Annual	0.99	0.95	44846	42383

* Annual observed flow is for the calibration period only and differs from the long term (1974-2002) mean observed value of 30624ML.

Correlation between daily values are determined by how well the response of a catchment to rainfall is modelled, that is, how the model reproduces the peaks and recessions of the observed data. The correlation between monthly and annual values are determined more by the representation of total flow over each month and year, meaning that the timing and height of the peaks and recessions may not be well represented but the total aggregated volumes may be reasonable. This causes the correlation at daily time-scales to be slightly lower than at the annual and monthly time-scales. The values obtained indicate a generally good representation of catchment response. It is more difficult for the model to replicate every flow peak and recession in the daily flow record than the total monthly and annual flows.

Figure 34 shows the observed and modelled streamflow data for the Mount Pleasant gauged catchment over the calibration period. In addition, the correlation (R^2) between the observed and modelled daily streamflow values are shown for each year. In general, better daily correlations were obtained in average and above average rainfall years and hence flow years (that is, years with a flow around 2,000 ML or more). During calibration, parameters are determined to obtain the best representation of the entire time series, which may sometimes lead to overestimation in low flow years. However, although the correlation between daily values is better in other years, the overall annual streamflow totals and variability are replicated successfully. Appendix F.5 presents the observed and modelled annual streamflow data and daily correlation values for each of the other gauged catchments. Satisfactory results were obtained for each.

Figure 35 shows the observed and modelled mean monthly streamflow values for the Mount Pleasant gauged catchment and the correlation (R^2) between the observed and monthly values for each month. A generally good representation of the mean monthly values was obtained for this sub-catchment and for each of the three other gauged catchments presented in Appendix F.5. A good correlation between monthly values was obtained for most months except for March and April. This pattern was apparent for the Kersbrook Creek and Gumeracha Weir gauged catchments, with the former also producing less satisfactory monthly correlations over the summer months.

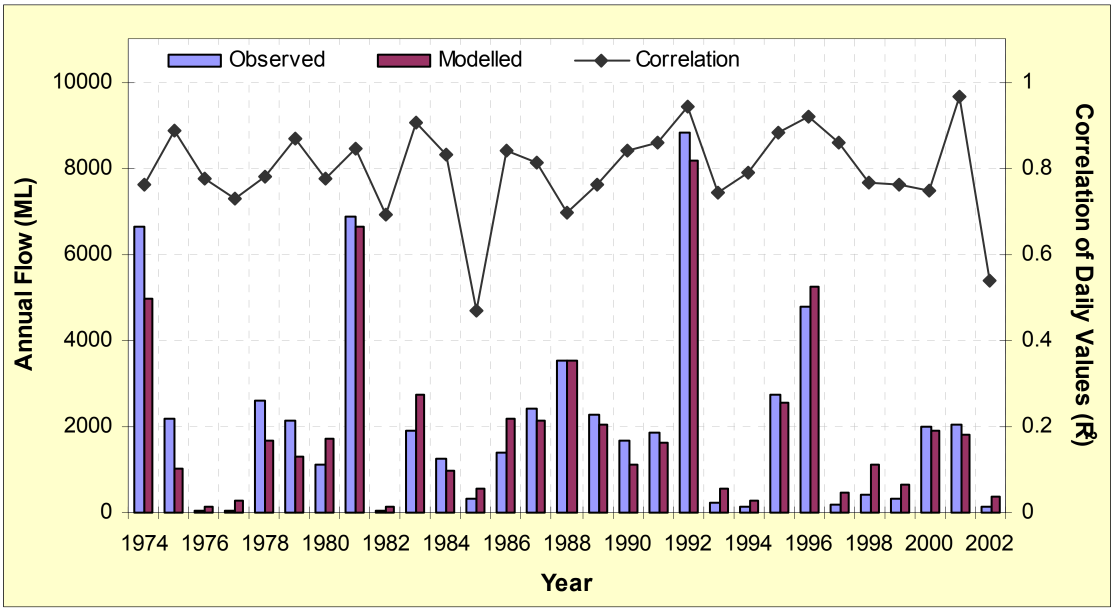


Figure 34 Observed and Modelled Annual Streamflow from Mount Pleasant Gauged Catchment.

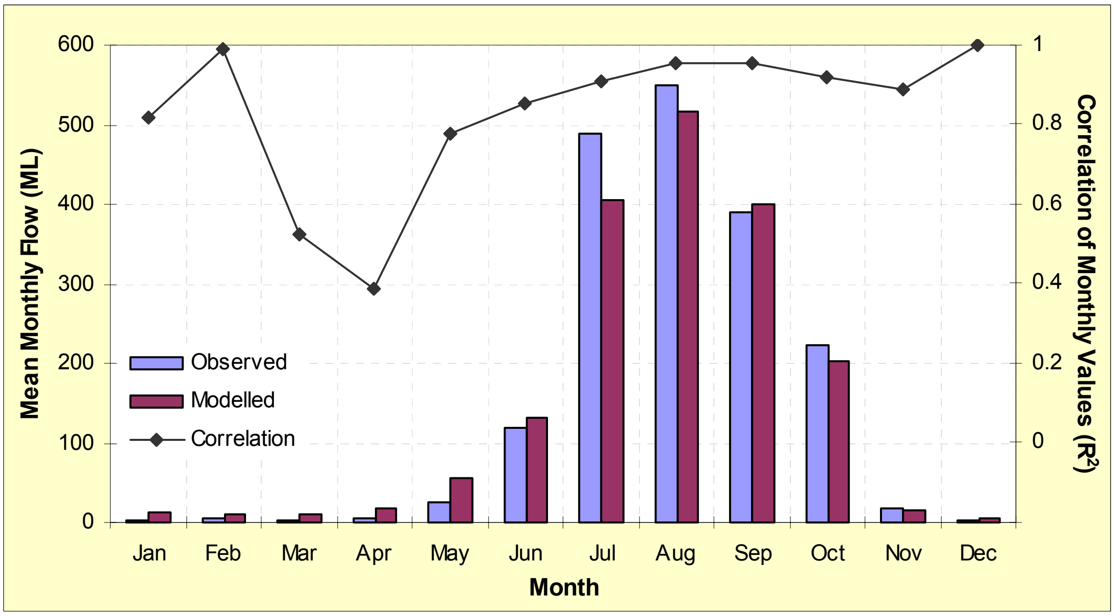


Figure 35 Observed and Modelled Monthly Streamflow from Mount Pleasant Gauged Catchment.

The less satisfactory correlation between monthly totals in some months highlights an inability to successfully reproduce later summer and early spring flow, which is a deficiency in most of the currently available conceptual water balance models. There is also often a tendency to overestimate lower flows in late winter. Much of this can be explained in terms of the saturation overflow mechanism for surface runoff (refer Appendix F.2). The catchment soil store is represented as a “bucket” that must fill and overflow before runoff will occur. This means that in summer and early spring when the soil store is virtually empty, it will absorb most if not all of the event rainfall, producing little runoff. Conversely, in late winter, the soil is saturated and hence most of the rainfall runs off. However, runoff events in summer and early spring are often driven by rainfall intensity as opposed to total event volume and if the rainfall intensity is significant enough, not all of this water will be absorbed. Conversely, by late winter there is generally more ground cover and vegetation that will intercept more of the rainfall than in summer, hence reducing the potential runoff. Despite these inadequacies, the model produces satisfactory results for monthly flows for the purpose intended in this study.

Figure 36 shows the observed and modelled daily runoff from the Mount Pleasant gauged catchment in 1983, indicating that the catchment runoff response to rainfall events is successfully modelled. Figure 37 shows that the flow frequency curve at the Mount Pleasant gauging station is reproduced well by the model. The calibration of flows less than 0.1 ML/day were less accurate but further examination showed these to occur mainly during the late summer and early spring months, which as indicated above, the model is able to less satisfactorily reproduce. In addition, the streamflow gauge at Mount Pleasant is a natural rock bar and is therefore less sensitive to recording low flows than, for example, a concrete V-notch weir.

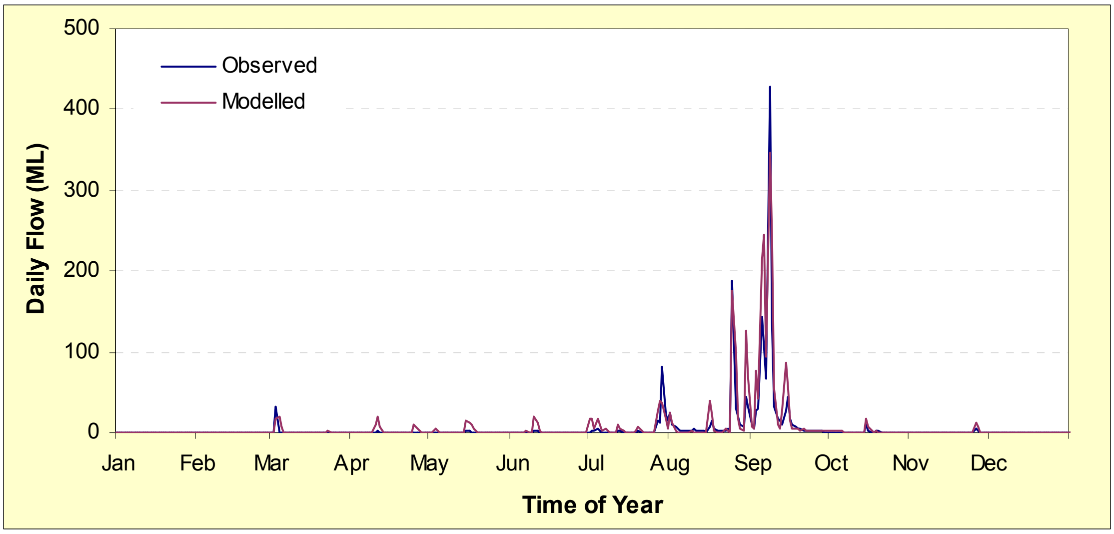


Figure 36 Observed and Modelled Daily Flow from the Mount Pleasant Gauged Catchment (1983).

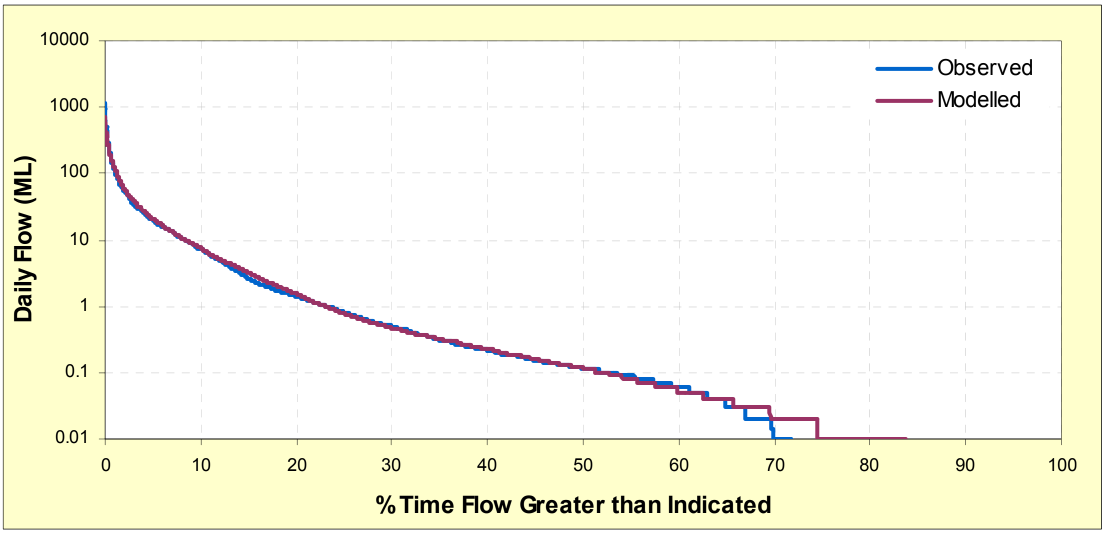


Figure 37 Observed and Modelled Flow Frequency Curve at Mount Pleasant Gauging Station.

Figure 38 shows the observed and modelled daily streamflow from the Gumeracha Weir gauged catchment in 1980, indicating that the flow into the weir from both the M-A pipeline transfers and the natural surface runoff have been modelled successfully. Of particular note is the effect that the M-A pipeline transfers have on the natural flow regime, particularly between January and April and later November/December. It should be noted that once the parameters for the Gumeracha Weir catchment were calibrated, the model was run from 1982 to 2002. For the period 2000 to 2002 when recorded M-A pipeline transfer data was available, the modelled streamflow replicated the observed flow into the weir successfully. This was also achieved for comparisons of natural inflow during periods between 1982 and 1999 when no M-A pipeline discharge occurred.

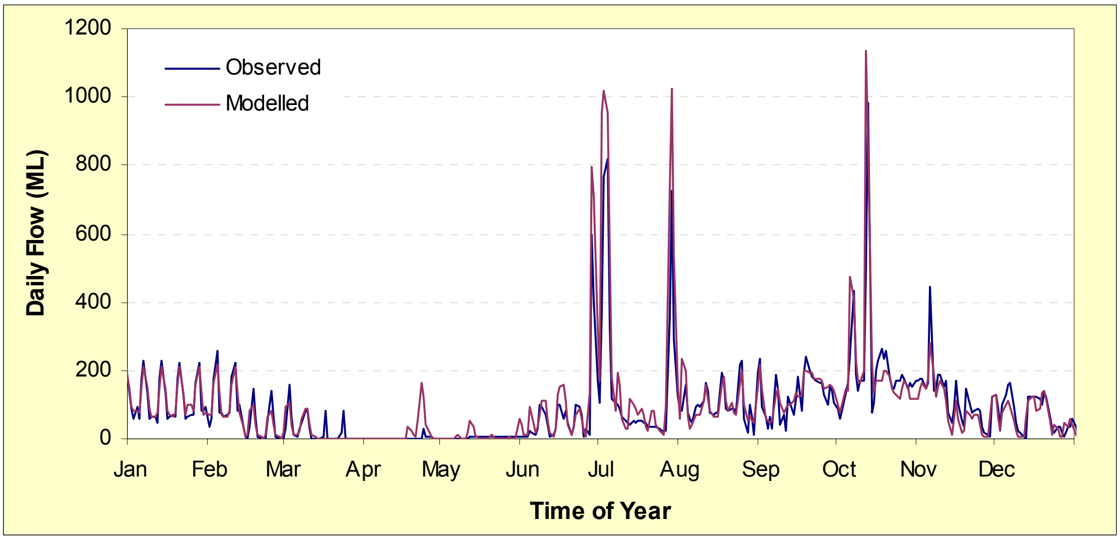


Figure 38 Observed and Modelled Daily Flows into Gumeracha Weir in 1980.

Appendix F.5 presents the daily flow frequency curves and comparisons of observed and modelled daily and monthly flow for each gauged catchment. Generally good results were obtained for each although a less satisfactory calibration was obtained for the flow frequency curve at the Kersbrook Creek gauging station. Examination of the rating curve that converts water level readings into discharge for this station revealed that most of the recorded water level values were outside of the gauged flow values. Therefore, the rating curve had been extrapolated to determine most of daily flow time series. Improvements may be made to the model parameter estimates for this sub-catchment if additional water level and flow gaugings were obtained for this station.

5. MODEL SCENARIO EVALUATION

The calibrated hydrological model of the Upper River Torrens catchment was used to evaluate a number of scenarios, namely:

- quantifying the effect that current levels of farm dam development have had on catchment runoff;
- predicting the impact that increased farm dam development, up to the maximum allowed under the 50:50 rule, would have on pre-farm dam development runoff levels;
- predicting the impact that increased water usage from farm dams would have on current runoff levels, assuming a current usage level of 30% and increased levels of 50% and 70%;
- predicting the impact of three year below average rainfall periods; and
- quantifying the effect that farm dams have had on water supply.

Results for each of these scenarios are presented for each of the calibrated gauged catchments. In addition, modelled results have been generated for the total catchment and for each of the major sub-catchments. General catchment trends and some specific sub-catchment results are included in this section and a complete set of results for each sub-catchment is presented in Appendix G. Results are presented for annual, monthly and daily time-scales.

5.1 Current and Potential Impacts of Farm Dam Development

In this section, the effect that current levels of farm dam development have had on catchment runoff and the potential impact from increased development up to the 50:50 rule is quantified.

5.1.1 Methodology for Calculating Adjusted and Potential Runoff

The methodology for determining the adjusted runoff (without farm dams) involved:

- generating modelled runoff under current farm dam development levels;
- removing all farm dams from the model, then generating modelled runoff without dams;
- determining the effect that current development levels have had on the natural flow regime as the amount of runoff captured by farm dams. This is defined as the difference between the two modelled sets of runoff (current and no dams); and
- calculating the adjusted runoff for the period for which observed data was available for calibration as being equal to the observed runoff plus the difference between the two modelled sets of runoff.

Observed data from gauged catchments are considered “true” flow records. Therefore, in calculating the adjusted runoff by adding the differences in modelled runoff, it is expected that any model errors will cancel each other out and provide a good estimate of pre-farm development runoff.

For each of the major sub-catchments (with the exception of Mount Pleasant, which is also a gauged catchment) it is not possible to determine a “true” adjusted flow. However, the modelled runoff under current conditions and without farm dams provides a good indication of the runoff statistics at varying time scales over the period of model calibration. As for the gauged catchments, the differences between the sets of modelled runoff is the amount of runoff captured by farm dams. Hence, it is possible to quantify the reduction in runoff due to farm dams whether the adjusted runoff is calculated or not.

As stated in Section 2.3.3, the 50:50 rule restricts the allowable size of a farm dam for a given property to 50 percent of the median annual adjusted runoff from that property. However, although the 50:50 rule should technically be applied at a property level, estimating the allowable volume and determining the runoff under such development levels for each major sub-catchment provides an indication of the potential flow reduction.

Section 2.3.3 outlined the potential for development under the 50:50 rule and the farm dam storage available for each major sub-catchment. The increase in dam storage for each minor sub-catchment was then calculated using the following:

- The total farm dam volume was only increased in minor sub-catchments that already contained dams. For example, Table 16 shows that for the Mount Pleasant sub-catchment, 45% of the total area does not contain farm dams and is free to flow area. Therefore, after the total volume of dams is increased, 45% of total area will still be free to flow. Although there is potential for development to occur in such free to flow areas and this methodology may underestimate the total effect of potential development on flow, it is difficult to predict the location of future farm dams. It has been assumed that areas where having a farm dam would be beneficial have already been developed, at least with small dams. In addition, some free to flow areas are unlikely to have potential development, such as native vegetation, forestry and protected areas. This methodology has been applied in previous studies (Savadamuthu, 2002; Teoh, 2002).
- The proportion of available farm dam volume was distributed amongst the minor sub-catchments with dams using the following:

$$V_2 = V_1 + \frac{A_C}{A_T} * D \qquad (6)$$

where:

V_2 = new capacity of farm dams in minor sub-catchment;

V_1 = current capacity of farm dams in minor sub-catchment;

A_C = area of minor sub-catchment;

A_T = total area of major sub-catchment; and

D = farm dam diversion.

5.1.2 Gauged Catchment Results

The effect of current and potential farm dam development was initially assessed for the catchments upstream of the four available gauging stations for which the model was calibrated in Section 4.3, namely Mount Pleasant (AW504512), Sixth Creek (AW504523), Kersbrook Creek (AW504525) and Gumeracha Weir (AW504500).

Changes in the rainfall-runoff relationship and reductions in streamflow resulting from farm dams are presented for each calibration period, with the exception of Gumeracha Weir. At Gumeracha Weir, the period of record for calibration (1975-1981) was considered too short to provide a reasonable estimate of flow reduction for this catchment. Although current annual and monthly natural flows were determined for 1974 to 2002, an adjusted daily flow was not able to be derived for this period. However, the calibrated parameters appeared to provide a reasonable representation of flow events in the absence of M-A pipeline transfers. Therefore, the modelled runoff under current farm dam development conditions was considered a reasonable replacement for the unavailable observed data. The percentage reduction in flows at this location are still accurate estimates as discussed in Section 5.1.1.

Annual Streamflow

The mean and median of the current, adjusted and potential development flows are presented in Table 19. Under current conditions, the difference in mean and median flow values represent the volumes of annual runoff that farm dams are currently capturing. The mean annual flows in these catchments have been reduced by between 2% and 18% and the median annual flows by 2% to 22%. These differing values highlight the varying levels of current development between these catchments, from Mount Pleasant where there is a large number of big dams spread over the catchment, to Sixth Creek where little development has occurred. The runoff capturing affect of dams is also more noticed for the lower rainfall catchment of Mount Pleasant in comparison to the higher rainfall catchment of Sixth Creek.

Table 19 Current and Potential Impact of Farm Dam Development on Annual Flow from Gauged Catchments.

Gauged Catchment	Current Mean Flow (ML)	Adjusted Mean Flow (ML)	Current Reduction (%)	Potential Mean Flow (ML)	Potential Reduction (%)[1]
Mount Pleasant	2073	2527	18	1963	22
Sixth Creek	8367	8510	2	7093	17
Kersbrook Creek	2187	2461	11	1704	31
Gumeracha[2]	23491	25803	9	20597	20
Gauged Catchment	**Current Median Flow (ML)**	**Adjusted Median Flow (ML)**	**Current Reduction (%)**	**Potential Median Flow (ML)**	**Potential Reduction (%)**
Mount Pleasant	1851	2365	22	1687	29
Sixth Creek	7667	7810	2	6331	19
Kersbrook Creek	1647	1927	15	1016	47
Gumeracha[2]	19456	22540	14	15501	31

[1] Potential reduction is from the adjusted flow.

[2] These values are modelled values under current and future development and pre-farm dam development levels rather than true adjusted flow because of lack of observed data.

Future development under the 50:50 rule will potentially reduce the mean annual runoff from these catchments by between 17% and 31% from the adjusted flow, with a decrease in median annual runoff by 19% to 47%. The reduction in potential runoff is influenced by the proportion of catchment runoff that is currently diverted into farm dams and hence the areas where it has been assumed that future development is likely to take place. For a catchment where there is currently less runoff diversion such as in Sixth Creek, the predicted reduction is less. However, if development occurs in other areas within the catchment, the effect is likely to be greater, as the current free to flow area would be reduced.

Figure 39 illustrates the annual variability in runoff reduction due to farm dams under current development levels and potential future development levels in the Mount Pleasant gauged catchment. The higher impacts (greater than 50% reduction in annual runoff) are observed during the significantly below average rainfall years. Under future development conditions, this catchment is unlikely to produce significant levels of annual runoff in such years.

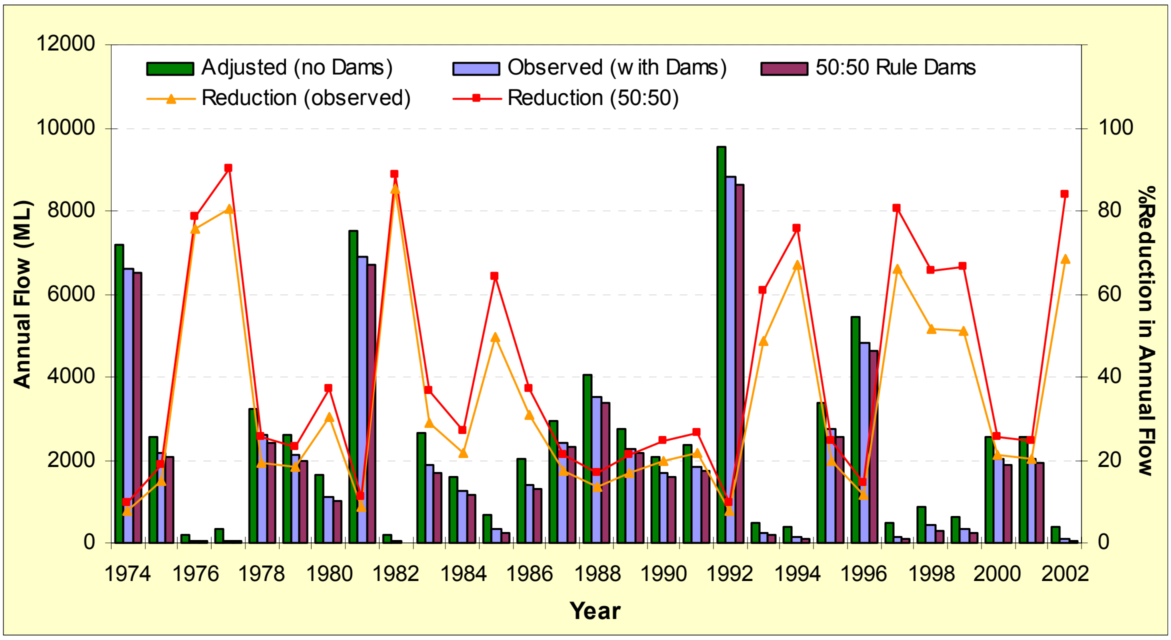


Figure 39 Current and Potential Impact of Farm Dam Development on Annual Runoff from the Mount Pleasant Gauged Catchment.

Results for the other gauged catchments are presented in Appendix G.2 and in particular:

- the Sixth Creek catchment shows the lowest annual reductions under current development conditions (less than 5%), which may increase to 26% under future development conditions;
- the Kersbrook Creek and Gumeracha Weir catchments have much higher annual reductions (up to 51% and 36% respectively) under current conditions, but these have the potential to increase even further (to 96% and 47% respectively); and
- under potential development conditions the Kersbrook Creek catchment is not likely to produce significant flow.

Monthly Streamflow

The impact of farm dams on the mean monthly flows varied over the year. By classing months into groups based on the magnitude of flow reduction, three distinct periods were observed. The general trends and their significance during these periods are described as follows:

1. *July to October*: The impact of dams in terms of the percentage reduction of mean flow is generally lowest during these months. This is the result of the progressively filling dams, many of which may have filled by this time of the year. Once a dam has filled and begun to overflow, the upstream catchment effectively becomes a free to flow area. However, while the percentage flow reduction is generally low, the actual flow reduction volume may be quite high as much of the annual rainfall occurs during these months.
2. *November to March*: During these months, the impact of farm dams on mean flow is at its greatest. Lower rainfall and runoff months, combined with increasing evaporation and dam water use, causes the reduction in flow to often increase rapidly during this period. While these flows may be significantly lower than those during the winter months and contribute only a small percentage of the total annual flow, they are critical for various water dependent ecosystems. Considerable reductions in flow during this period may seriously affect the survival of such ecosystems.
3. *April to June*: The percentage reduction of mean flow decreases over this period but the reduction is still significant. By the end of summer, most dams are likely to be relatively empty and as the catchment becomes saturated, much of the runoff produced during these months will be captured by the dams. This delays the onset of the winter flows downstream and overall, shortens the length of the higher flow season.

Table 20 shows the range of current and potential reductions from farm dam development on mean monthly flows in the calibrated gauged catchments. These values highlight the importance of considering the effects of farm dams at a monthly time scale. For example, the current reduction in mean annual flow for the Mount Pleasant catchment was significant at 18%. However, the percentage flow reductions at a monthly scale under current conditions show that these are even more significant than the annual reduction, reaching over 80% in some months. The potential reductions in monthly flow under the 50:50 rule are even greater.

Table 20 Current and Potential Impact of Farm Dam Development on the Mean Monthly Flows from Gauged Catchments.

Gauged Catchment	Current Reduction (%)			Potential Reduction (%)[1]		
	July to October	November to March	April to June	July to October	November to March	April to June
Mount Pleasant	12-16	41-83	67-79	14-21	45-86	50-82
Sixth Creek	0-2	8-29	0-8	14-16	24-44	17-26
Kersbrook Creek	0-5	30-100	42-95	8-32	50-100	80-100
Gumeracha[2]	3-8	35-52	16-38	9-24	49-63	35-56

[1] Potential reduction is from the adjusted flow.

[2] These values are modelled values under current and future development and pre-farm dam development levels rather than true adjusted flow because of lack of observed data.

Differences between the annual and monthly flow reductions occur because the summer and autumn flows are lower than the winter and spring flows and most of the flow reduction volume occurs during these higher flow seasons. Hence the annual reduction is only slightly higher than the total July to October reduction. In terms of total volume, the flow reductions over the remainder of the year constitute only 2% to 5% of the annual reduction. Similar relationships can be seen for each of the other catchments. Changes to monthly flow patterns and volumes can have potentially larger impacts on aquatic ecosystems than does the reduction of total annual flow. If large flow reductions occur during the drier summer months and the onset of winter flows is significantly delayed, many species may not be able to survive in the changed environment.

Figure 40(a) shows the current and potential reductions in mean monthly flows over the year for the Mount Pleasant gauged catchment and Figure 40(b) the same reductions but with statistical calculations excluding the data from 1992.

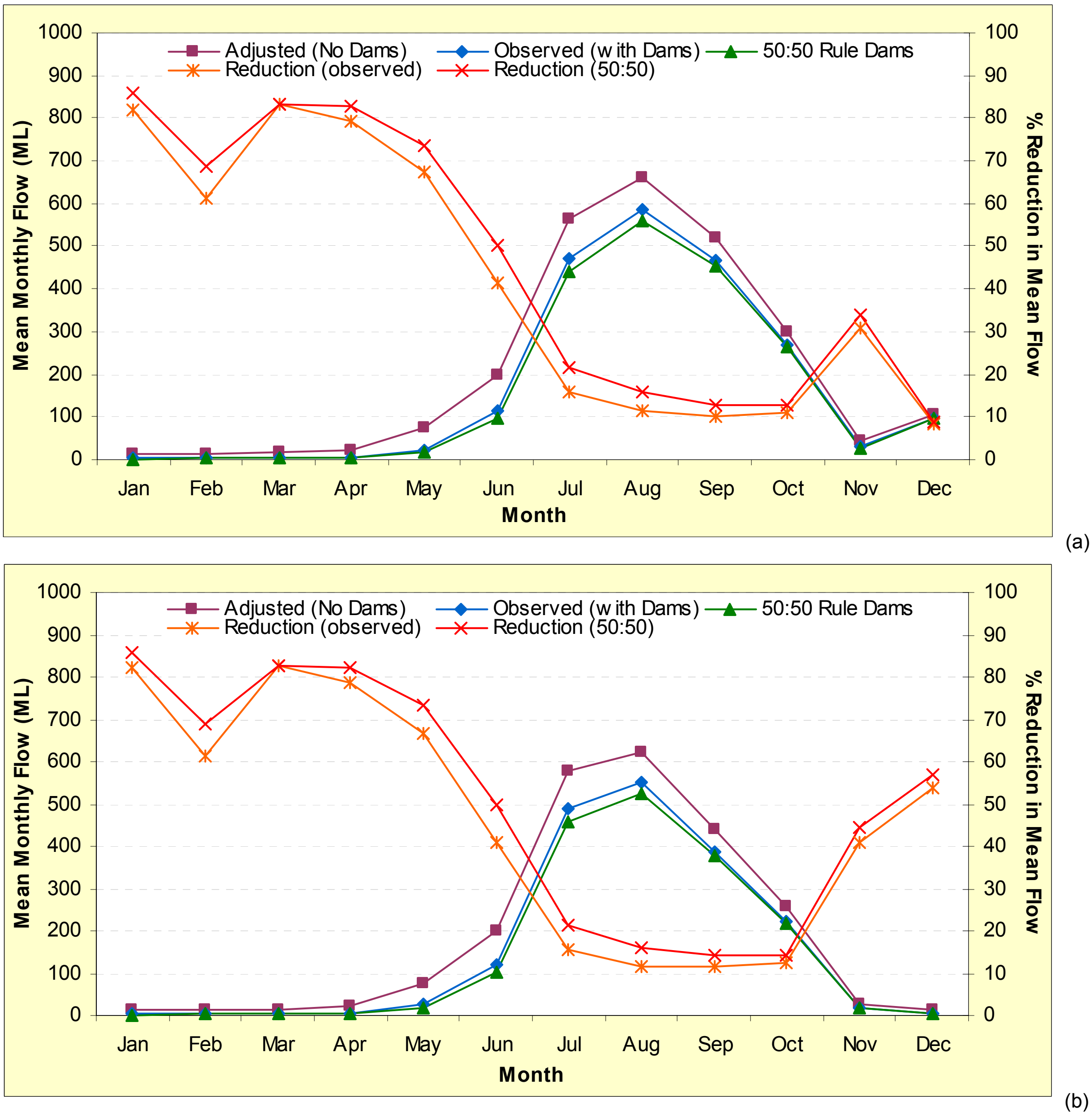


Figure 40 Mean Monthly Flow Variations under Current, Adjusted and Potential Farm Dam Development for Mount Pleasant Gauged Catchment: (a) all data (b) excluding 1992 data.

Rainfall during 1992 was much higher than average with November and December particularly wet months. These values tend to bias the mean monthly flows and decrease the monthly flow reductions to lower values than what would generally be expected in an average year. The effect is greater in catchments where the flow reductions are higher. Both sets of mean monthly flow values have been included here and in Appendix G.2 for each gauged catchment for comparison and completeness.

Both figures highlight the high percentage reductions over the summer and autumn months with an 83% reduction in March, 82% in January and 79% in April. The high reduction in April causes the onset of winter flows to be delayed. As the winter flows increase, the reduction in mean monthly flows decreases to 12% between August and October, before increasing during November as rainfall decreases and less runoff occurs. The flow reduction patterns are similar for each gauged catchment, with the magnitudes of the reductions varying between catchment as indicated in Table 20.

Daily Streamflow

The effect of farm dams on daily flow patterns and volumes have the most direct consequences for aquatic ecosystems. Changes to the environmental conditions, such as the timing and duration of flows, affect important ecological responses to flow including the recruitment of seedlings or larvae, fertilisation or spawning cues, and the maintenance and growth of animal and plant populations.

Figure 41 shows the flow frequency curves for the Mount Pleasant gauged catchment under current (observed), adjusted and potential development (50:50 rule) conditions. These provide an immediate indication of changes to the duration of flows. The current conditions show a significant decrease in the median daily flow of over 50% and an overall decrease in the duration of flows less than 60 ML/day. This decrease becomes more significant as the daily flow falls below 3 ML/day. Under pre-farm dam development conditions the catchment would cease to produce flow for 20% of the year. Under current conditions this has increased to 30%.

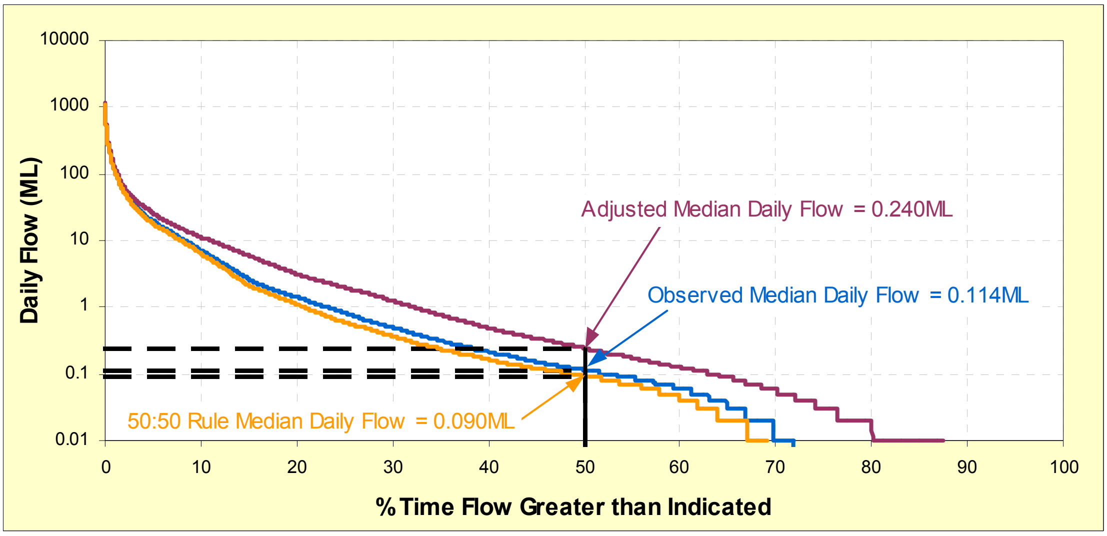


Figure 41 Flow Frequency Curves for the Mount Pleasant Gauged Catchment under Current, Adjusted and Potential Farm Dam Development Conditions.

There is less difference between the flow frequency curves under current and potential development conditions, indicating that the catchment is already highly developed. The primary differences are for flows less than 1 ML/day. These flows often occur during summer, when the impacts of any increased farm dam development will be greatest.

Table 21 shows some flow exceedance characteristics for each of these curves. Caution should be used for flows less than 0.1 ML/day as these were modelled less accurately than the higher flows (refer Section 4.3.2). Most of the higher flows (>20 ML/day) occur during the winter months when the impact of farm dams on flow is lowest.

Table 21 Flow Exceedance Characteristics of Observed, Adjusted and Potential Farm Dam Development Flow Frequency Curves for the Mount Pleasant Gauged Catchment.

Flow Criteria	Current		Adjusted		Potential	
	% Year	No. Days	% Year	No. Days	% Year	No. Days
Flow ≥ 0.1 ML/day*	53	195	64	234	50	181
Flow ≥ 1 ML/day	23	84	32	117	21	76
Flow ≥ 10 ML/day	8	30	11	40	8	29
Flow ≥ 20 ML/day	5	18	6	23	5	17
Flow ≥ 50 ML/day	2	8	3	9	2	8
Flow ≥ 100 ML/day	1	4	1	5	1	4

* Flows below this are difficult to measure and model accurately.

Table 22 presents current, adjusted and potential daily flow percentile values. The 50th percentile refers to the median flow while the 10th and 90th percentiles are a measure of data variability. The closer the flow volumes at these two percentiles, the lower the variability (refer Section 3.1.2). The 10th and 20th percentile flows are in the low flow region. Although the model was unable to represent these flows as accurately as higher ones, the percentage reductions are still good estimates of the impact.

Values at the 50th percentile indicate the median flow has reduced by over 50% and may potentially increase to over 60% under future development. The higher flow percentiles also show significant flow reductions under both current and potential conditions.

Table 22 Flow Percentiles of the Observed, Adjusted and Potential Farm Dam Development Flow Frequency Curves for the Mount Pleasant Gauged Catchment.

Flow Percentile	Current Daily Flow (ML)	Adjusted Daily Flow (ML)	Current Reduction (%)	Potential Daily Flow (ML)	Potential Reduction (%)
10th	0.00	0.00	-	0.00	-
20th	0.00	0.02	100	0.00	100
50th	0.11	0.24	54	0.09	63
80th	1.42	3.15	55	1.11	65
90th	7.23	11.19	35	6.44	42

A similar analysis of daily streamflow is presented for each gauged catchment in Appendix G.2. The results show that:

- current development in the Sixth Creek catchment has primarily impacted on the low flows (less than 7 ML/year) producing a reduction in the mean daily flow of 9%. Future development may further impact the low flows and also the medium flows, possibly resulting in a further 18% reduction in the median daily flow;

- the impact of current dams has been greatest in the Kersbrook Creek catchment where the cease to flow condition has increased from 20% to 40% of the year and the median daily flow has reduced by 60%. Under future development the median daily flow may possibly reduce by a further 30% and the cease to flow condition by 8%; and
- current dams have impacted on both the low and medium flows in the Gumeracha Weir catchment, reducing the median daily flow by 45%. Future development is unlikely to have large additional impacts on the low flows, with an 8% further reduction possible in the median daily flow. However, the impact on the medium flows is significant with an additional reduction to the 80th percentile flow of 15% from the current reduction of 18%.

Rainfall-Runoff Relationships

Section 3.3.3 described annual rainfall-runoff coefficients and their straightforward means of determining how much runoff can be expected from a catchment given a specific level of rainfall. Table 23 shows the adjusted annual runoff coefficients for each of the gauged catchments, indicating that average annual runoff coefficient has decreased by between 0.4% to 4% due to current farm dam development. It should be noted that this does not imply that the catchment is actually producing less runoff, but that between 0.4% and 4% of runoff is captured by farm dams.

Table 23 Annual Runoff Coefficients for Gauged Catchments.

Gauged Catchment	Adjusted Runoff Coefficient	Current Runoff Coefficient	Reduction (%)
Mount Pleasant	0.131	0.105	2.6
Sixth Creek	0.202	0.198	0.4
Kersbrook Creek	0.137	0.121	1.7
Gumeracha Weir*	0.173	0.132	4.0

* Values for natural inflow into Gumeracha Weir.

The TanH rainfall-runoff function (refer Appendix E) under current farm dam development (observed) and adjusted flow conditions is shown in Figure 42 for the Mount Pleasant gauged catchment. This shows the effective reductions in annual runoff for varying annual rainfall. Appendix G.2 presents a comparison of TanH functions for each of the remaining gauged catchments.

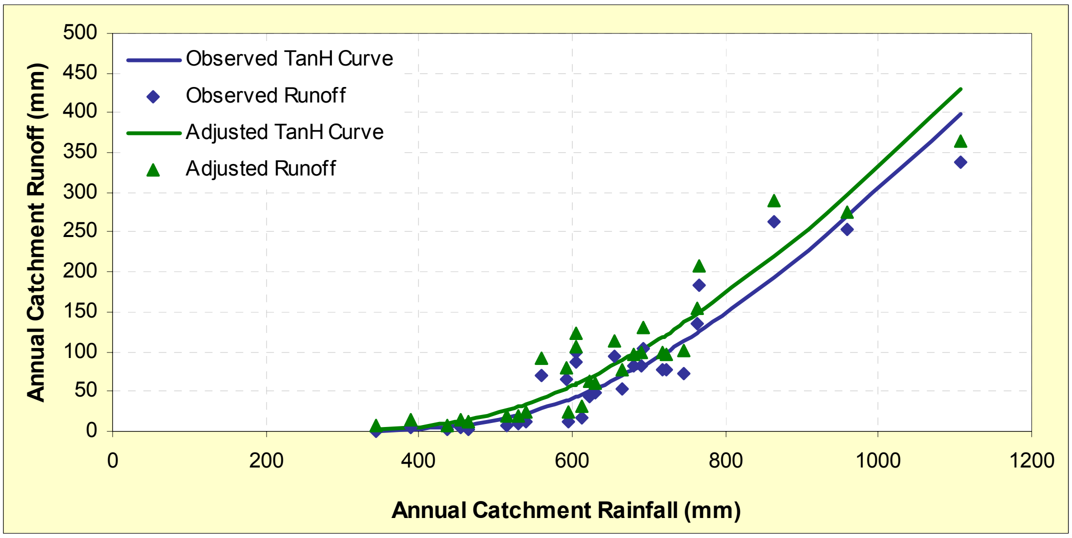


Figure 42 Observed and Adjusted Rainfall-Runoff Curve for the Mount Pleasant Catchment.

5.1.3 Total Catchment and Major Sub-Catchment Results

The effect of current and potential farm dam development was determined for the total Upper River Torrens catchment and each major sub-catchment. Mount Pleasant is the only sub-catchment with a streamflow gauge at its outlet. Therefore, the statistics of flow under current conditions, pre-farm dam development conditions and future potential development levels were determined from the modelled data for each other sub-catchment.

Results in this section were calculated for the period 1974 to 2002. Although the Kangaroo Creek, Cudlee Creek and Kersbrook Creek sub-catchments were not calibrated to data over this period it was considered that the selected parameters should provide a reasonable representation. This assumption allows a consistent comparison between all sub-catchments. The percentage reduction in flows due to the impact of farm dams was again determined as the difference between the modelled flow under the varying development conditions and is considered to be a reasonable estimate despite the lack of observed data (refer Section 5.1.1).

Annual Streamflow

The mean and median of the current, adjusted and potential development flows are presented in Table 24 and Table 25 for the Upper River Torrens catchment and for each major sub-catchment.

For the total catchment the results indicate that:

- under current conditions the annual mean flow is 45,983 ML, which has been reduced by 6% from the 49,043 ML produced under pre-farm dam development conditions;
- under future farm dam development, the current flow has the potential to reduce by a further 12% to 40,117 ML (18% from adjusted flow volume);
- reductions in the median annual flow are slightly higher than those for the mean flow with current and potential reductions of 7% and 22% respectively; and
- the mean annual volume of 3,060 ML currently captured by farm dams is much less than the total farm dam capacity of 5,750 ML (Section 2.3.1). This indicates that either the dam usage rate is less than 30%, meaning that there is a higher level of seasonal carryover and therefore the dam will capture less water before it is full and overflows; or alternatively, many dams within the catchment may not fill and overflow on an annual basis. In the case of the latter, stream reaches downstream of these dams are less likely to flow every year and may have been highly impacted by the presence of these dams.

The current and potential impact of farm dams at a sub-catchment level is varied and can be linked directly with current dam development and dam density as shown previously in Figure 7 (Section 2.3). The results show that:

- under current conditions, sub-catchments with a higher farm dam density such as Mount Pleasant, Birdwood and Footes Creek have the highest reductions in mean annual flows of 18%, 11% and 10% respectively;
- the median flow reductions of 22%, 13% and 20% for these sub-catchments were also significant and provide a better indication of the level of impact by dams on these catchments (mean values can be biased by one or two large annual flows that will increase the mean flow and hence reduce the mean impact to less than would be expected in an average year);

- the median annual flows from Hannaford Creek, Angas Creek, McCormick Creek and Millers Creek have been significantly reduced, resulting in reductions greater than 10% in over half of the sub-catchments;
- the Sixth Creek, Gumeracha and Kangaroo Creek sub-catchments currently have the lowest impact on annual flows from farm dams; and
- future development has the potential to reduce annual sub-catchment flows by between 19% and 36%.

Table 24 Modelled Estimates of the Current and Potential Impact of Farm Dam Development on Mean Annual Flow from the Upper River Torrens Catchment and Major Sub-Catchments.

	Current Mean Flow (ML)	Adjusted Mean Flow (ML)	Current Reduction (%)	Potential Mean Flow (ML)	Potential Reduction (%)
Mount Pleasant*	2073	2527	18	1963	22
Birdwood	6308	7058	11	5555	21
Hannaford Creek	1968	2114	7	1709	19
Angas Creek	2884	3155	9	2529	20
Gumeracha	4592	4687	2	3911	17
Footes Creek	1375	1530	10	1218	20
McCormick Creek	1223	1308	7	1050	20
Millers Creek	2958	3205	8	2596	19
Kenton Valley	1938	2068	6	1699	18
Cudlee Creek	2770	2885	4	2383	17
Kangaroo Creek	5002	5134	3	4406	14
Kersbrook Creek	5005	5340	6	4400	18
Sixth Creek	8414	8558	2	7141	17
Total Catchment	45983	49043	6	40117	18

* Values for Mount Pleasant sub-catchment were determined from observed flow data.

Table 25 Modelled Estimates of the Current and Potential Impact of Farm Dam Development on Median Annual Flow from Upper River Torrens Catchment and Major Sub-Catchments.

	Current Median Flow (ML)	Adjusted Median Flow (ML)	Current Reduction (%)	Potential Median Flow (ML)	Potential Reduction (%)
Mount Pleasant*	1851	2365	22	1687	29
Birdwood	5491	6288	13	4677	26
Hannaford Creek	1595	1832	13	1243	32
Angas Creek	2268	2731	17	1757	36
Gumeracha	3726	3808	2	2965	22
Footes Creek	1128	1400	20	901	36
McCormick Creek	989	1133	13	742	35
Millers Creek	2350	2777	15	1908	31
Kenton Valley	1527	1634	7	1199	27
Cudlee Creek	2364	2482	5	1932	22
Kangaroo Creek	3721	3824	3	3000	22
Kersbrook Creek	4446	4811	8	3812	21
Sixth Creek	7699	7843	2	6366	19
Total Catchment	40493	43525	7	34090	22

* Values for Mount Pleasant sub-catchment were determined from observed flow data.

Relating the flow reductions to farm dam density also highlights the significance of dam locations within the sub-catchments. The Kenton Valley and Angas Creek sub-catchments both have dam densities of 18 ML/km^2. However, the mean and median flow reduction from the Kenton Valley sub-catchment is 6% and 7% respectively, while the reductions from the Angas Creek sub-catchment are 9% and 17%. Because many farm dams in the Kenton Valley sub-catchment are concentrated in small areas in the upper reaches, there is a larger free-to-flow area than in the Angas Creek sub-catchment where farm dams are spread more evenly across the area (refer Figure 8).

Figure 43 illustrates the annual variability in runoff reduction due to farm dams under current development levels and potential future development levels for the total Upper River Torrens catchment. As for the gauged catchments in Section 5.1.2, higher impacts are observed during the significantly below average rainfall years. Under future development conditions runoff reductions have the potential to exceed 35%.

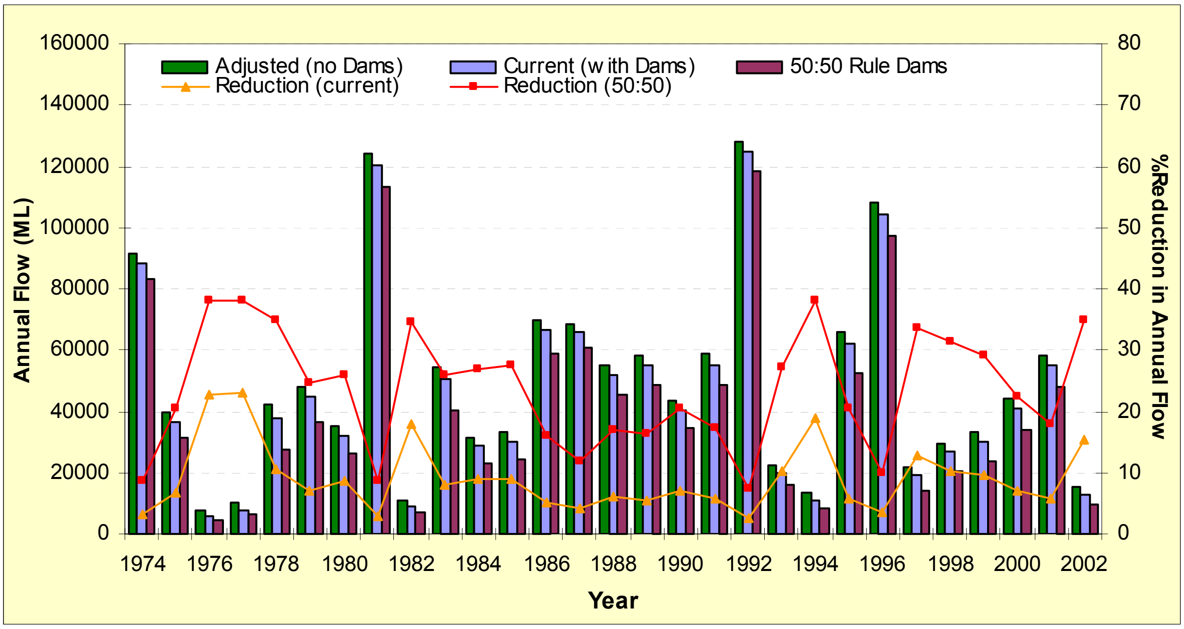


Figure 43 Modelled Estimates of the Current and Potential Impact of Farm Dam Development on Annual Runoff from the Upper River Torrens Catchment.

The annual variability in runoff reduction is presented for each sub-catchment in Appendix G.3 and in particular:

- during below average rainfall years, sub-catchments with high levels of dam development show flow reductions of between 30% and 80%;
- farm dams in the Mount Pleasant and Footes Creek sub-catchments capture more than 70% during drier years, while dams in Millers Creek and McCormick Creek capture in excess of 50% and 40% respectively;
- dams in the Sixth Creek, Kangaroo Creek, Cudlee Creek and Gumeracha sub-catchments generally capture less than 5%, even in lower rainfall years;
- future development is likely to reduce flows during below average as well as average rainfall years by more than 40% in 10 out of 13 sub-catchments; and
- reductions greater than 10% are likely during almost all years in all sub-catchments with a majority of sub-catchments showing possible reductions greater than 20% during most years.

Monthly Streamflow

Section 5.1.2 described the classification of months based on the magnitude of flow reductions and the significance of impacts on flow that occurs during these periods. Table 26 shows the range of current and potential reductions from farm dam development on mean monthly flow from each major sub-catchment and the total Upper River Torrens catchment.

Table 26 Modelled Estimates of the Current and Potential Impact of Farm Dam Development on Mean Monthly Flows from the Upper River Torrens Catchment and Major Sub-Catchments.

Sub-Catchment	Current Reduction (%)			Potential Reduction (%)		
	July to October	November to March	April to June	July to October	November to March	April to June
Mount Pleasant*	12-16	41-83	41-79	14-21	45-86	50-82
Birdwood	3-10	37-62	11-35	9-20	52-80	23-63
Hannaford Creek	2-7	32-44	14-40	8-25	46-47	37-47
Angas Creek	2-8	35-41	19-40	13-25	40-41	37-41
Gumeracha	0-2	14-26	2-20	8-23	32-33	31-33
Footes Creek	1-10	55-72	23-69	4-25	69-74	46-74
McCormick Creek	1-6	32-42	14-40	11-25	42-43	38-43
Millers Creek	1-8	40-53	16-48	5-24	58-60	41-60
Kenton Valley	1-5	30-43	14-35	4-24	50-53	40-51
Cudlee Creek	0-3	14-27	1-15	1-16	39-49	36-48
Kangaroo Creek	0-2	9-16	3-10	6-16	27-30	25-29
Kersbrook Creek	0-4	27-47	18-45	7-22	36-49	44-49
Sixth Creek	0-2	8-29	0-8	14-16	24-43	17-26
Total Catchment	1-5	20-34	11-19	9-21	35-46	32-43

* Values for Mount Pleasant sub-catchment were determined from observed flow data.

Current flow reductions from the total catchment range from 1% to 5% between July and October, to 11% to 19% between April and June and to 20% to 34% in the period November to March. The potential reductions under future development may be as high as 21%, 46% and 43% for the three periods respectively.

At a sub-catchment scale, flow reductions between July and October are highest in the Mount Pleasant, Birdwood and Footes Creek sub-catchments, exceeding 10%. These sub-catchments also have the most significant decreases in summer flows with the mean flow in the Mount Pleasant sub-catchment currently reduced by over 80%. Summer flows in most sub-catchments have reduced by over 25%. Flow reductions between April and June range from 10% to 80%.

Future farm dam development has the potential to reduce flows by between 50% and 80% over the summer period. Many sub-catchments may reach a 25% flow reduction during July to October, which, when considering that during this period the majority of the total annual flow occurs, would significantly reduce the total flow. A 30% to 80% reduction between April and June may result in very little, if any, flow from some sub-catchments between November and June.

Figure 44(a) shows the current and potential reduction in mean monthly flows over the year for the Upper River Torrens catchment and Figure 44(b) the same reductions but with statistical calculations excluding the data from 1992. As indicated in Section 5.1.2, rainfall during this year was much higher than average with November and December particularly wet months. These values bias the mean monthly flows and decrease the monthly flow reductions below those generally expected in an average year. The effect is greater in catchments where the flow reductions are higher. Both sets of mean monthly flow values have been included in Appendix G.3 for each sub-catchment for comparison and completeness.

Both figures highlight the high percentage reductions over the summer and autumn months with reductions in excess of 30% during January to March. The flow reduction of over 25% during April causes the onset of winter flows to be delayed. As the winter flows increase, the reduction in mean monthly flows from the entire catchment drops to around 1%, before increasing during November as rainfall and runoff decrease, and evaporation and dam water use increase.

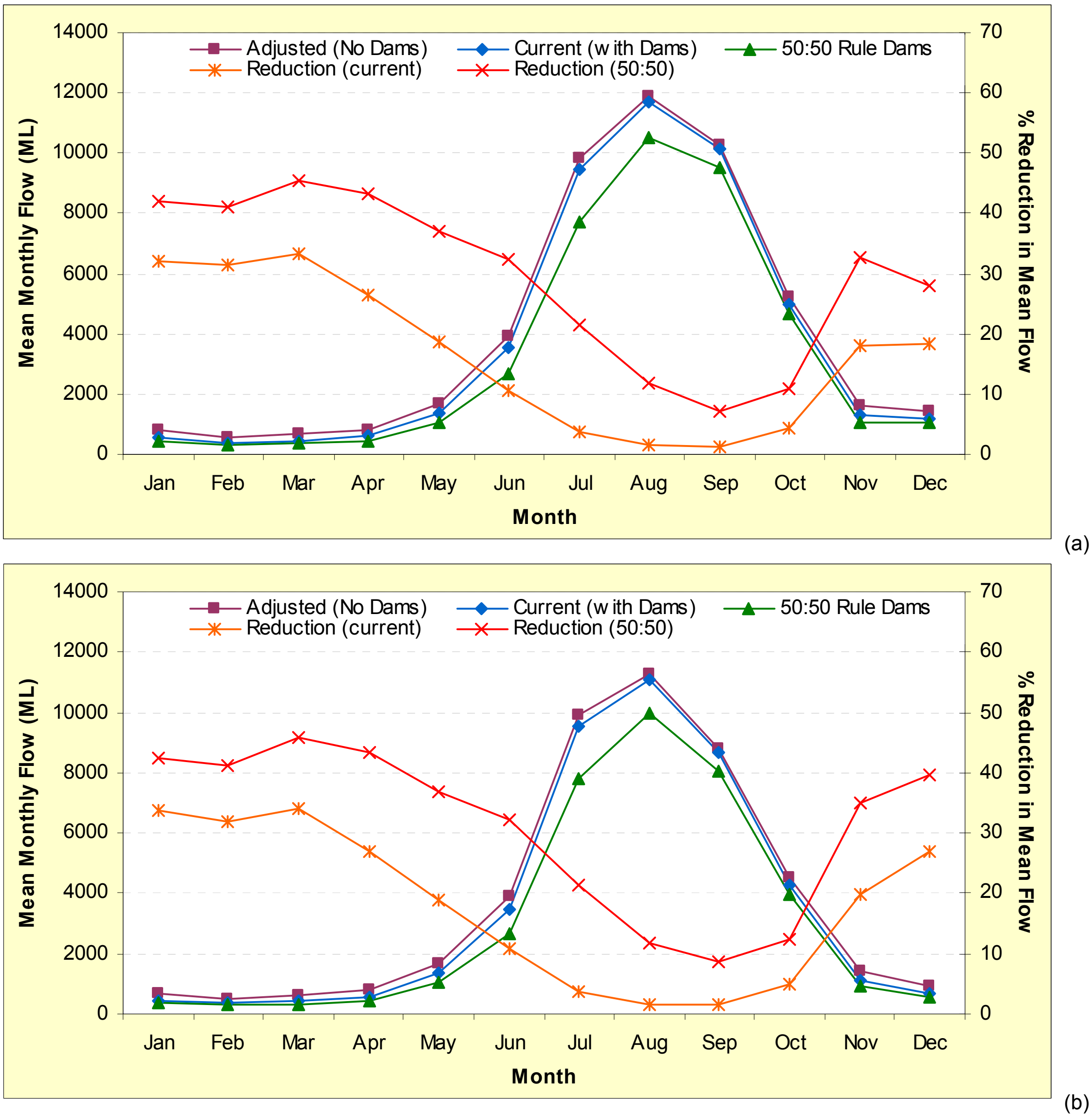


Figure 44 Modelled Mean Monthly Flow Variations under Current, Adjusted and Potential Farm Dam Development for the Upper River Torrens Catchment (a) all data (b) excluding 1992 data.

The patterns are very similar for each sub-catchment with the magnitude of the effects varying with the extent of dam development. In some cases the reductions for some months plateau to a maximum percentage reduction of flow. This maximum reduction may actually be reached at relatively lower levels of development.

Daily Streamflow

A flow frequency curve for the Upper River Torrens catchment is shown in Figure 45. This defines the volume of water that would pass Gorge Weir in the absence of water supply infrastructure. Under current conditions, the median daily flow from the catchment is 20 ML, a reduction of 25% from the adjusted flow if no farm dams were present. Under the 50:50 development rule this has the potential to drop to 17 ML/day.

The impact of current dam development is generally on the low flow range (below the 50th percentile or median flow) such that flows such as those less than 10 ML/day have been reduced to minimum levels under the current development conditions. This is because of the assumption that free to flow areas have been preserved. As dam development approaches the 50:50 rule, the impact is observed at higher flows.

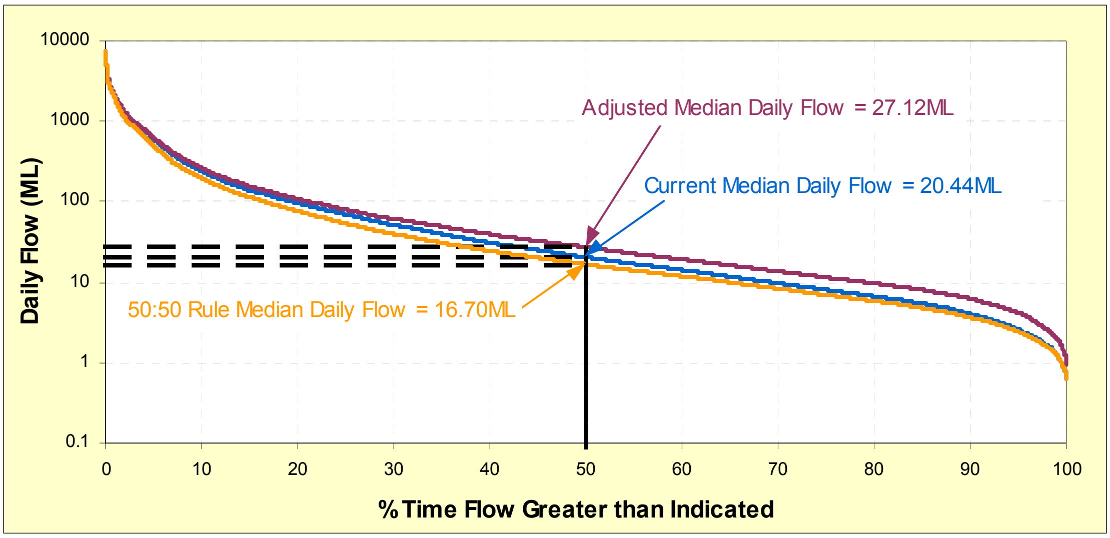


Figure 45 Modelled Flow Frequency Curves under Current, Adjusted and Potential Farm Dam Development Conditions for the Upper River Torrens Catchment.

Table 27 show the flow exceedance characteristics and Table 28 flow percentiles for each of the flow frequency curves. It is interesting to note that even under current farm dam development conditions, a daily flow in excess of 1 ML/day would occur for over 99% of the year and a flow greater than 10 ML/day for almost 70% of the year. Therefore, without the major reservoirs and diversion weirs, a reasonable flow would pass Gorge Weir for most of the year.

Table 27 Modelled Flow Exceedance Characteristics from the Current, Adjusted and Potential Farm Dam Development Flow Frequency Curves for the Upper River Torrens Catchment.

Flow Criteria	Current		Adjusted		Potential	
	% Year	No. Days	% Year	No. Days	% Year	No. Days
Flow ≥ 0.1 ML/day*	100	365	100	365	100	365
Flow ≥ 1 ML/day	99	363	100	365	99	363
Flow ≥ 10 ML/day	69	253	79	289	65	237
Flow ≥ 20 ML/day	51	185	59	215	45	165
Flow ≥ 50 ML/day	31	112	35	127	26	96
Flow ≥ 100 ML/day	19	71	21	78	17	60

* Flows below this are difficult to measure and model accurately.

Table 28 Modelled Flow Percentiles of the Observed, Adjusted and Potential Farm Dam Development Flow Frequency Curves for the Upper River Torrens Catchment.

Flow Percentile	Current Daily Flow (ML)	Adjusted Daily Flow (ML)	Current Reduction (%)	Potential Daily Flow (ML)	Potential Reduction (%)
10th	4.1	6.3	35	3.7	41
20th	6.7	9.7	31	5.9	40
50th	20.4	27.1	25	16.7	38
80th	96.1	107.8	11	76.6	29
90th	238.1	263.2	10	195.3	26

An analysis of daily flows including flow frequency curves, exceedance characteristics and flow percentiles are presented in Appendix G.3 for each sub-catchment and in particular:

- most sub-catchments show significant reductions in the low flow range, indicating that the likely reductions of the low, generally late summer and early autumn flows have already occurred under current development;
- the Mount Pleasant, Footes Creek and Kersbrook Creek sub-catchments all have extended periods without flow;
- the median daily flow has reduced by over 40% in most sub-catchments; and
- future development is likely to impact significantly on the medium to high flow range, with likely reductions in the 80th percentile of between 20% and 65% and in the 90th percentile of between 20% and 40%.

Rainfall-Runoff Relationships

Runoff coefficients were previously estimated for the gauged catchments under current and adjusted flow conditions (refer Section 5.1.2). Estimates of the runoff coefficients for each sub-catchment have subsequently been made from the modelled data and are presented in Table 29. The change in runoff coefficient varies depending on the level of dam development but in most catchments an increase of 1% to 3% in annual runoff reaching the sub-catchment outlet would occur for a given annual rainfall if dams were not present.

Table 29 Current and Adjusted Runoff Coefficients for Major Sub-Catchments.

Sub-Catchment	Average Annual Current Runoff Coefficient	Average Annual Adjusted Runoff Coefficient
Mount Pleasant*	0.105	0.131
Birdwood	0.169	0.192
Hannaford Creek	0.160	0.173
Angas Creek	0.136	0.151
Gumeracha	0.194	0.199
Footes Creek	0.169	0.191
McCormick Creek	0.160	0.173
Millers Creek	0.158	0.173
Kenton Valley	0.181	0.195
Cudlee Creek	0.176	0.182
Kangaroo Creek	0.147	0.151
Kersbrook Creek	0.161	0.169
Sixth Creek	0.197	0.201

* Values for Mount Pleasant sub-catchment were determined from observed and adjusted flow data.

5.2 *Predicted Impact from Increased Dam Water Use*

The amount of water used for annual irrigation was estimated at 30%, allowing for some annual storage carry-over and the assumption that many dams are currently not heavily used (refer Section 4.2.2). However, the implementation of future controls on farm dam development may lead to additional water use from existing dams in order to expand current irrigated areas.

This section examines the impact on catchment runoff if the annual dam water use increased from 30% to 50% or 70% of the total dam capacity. The resulting flows at annual, monthly and daily time scales are compared to current flows for the period 1974 to 2002.

5.2.1 Gauged Catchment Results

The impact of increased dam water use on catchment runoff was first analysed for the gauged catchments.

Annual Streamflow

The mean and median annual runoff under current and potential dam water use conditions for each gauged catchment are presented in Table 30. The reductions in annual flow are less than those that may occur with increased development under the 50:50 rule with the exception of Mount Pleasant. The potential reduction in the mean and median flows under increased development were 4% and 7% respectively, compared with 7% and 8% with increased dam water use. This is most likely because farm dam development is already high in the Mount Pleasant sub-catchment and hence there is less potential for further development. Therefore, more runoff is likely to be needed to replace water used from the dams during summer than for filling new or larger new dams.

Table 30 Impact of Increased Farm Dam Usage on Annual Flows from Gauged Catchments.

Gauged Catchment	Current Mean Flow (ML)	50% Dam Usage Mean Flow (ML)	Reduction[1] (%)	70% Dam Usage Mean Flow (ML)	Reduction[1] (%)
Mount Pleasant	2073	1978	5	1921	7
Sixth Creek	8367	8314	1	8263	1
Kersbrook Creek	2187	2086	5	1993	9
Gumeracha[2]	23491	22889	3	22384	5
Gauged Catchment	**Current Median Flow (ML)**	**50% Dam Usage Median Flow (ML)**	**Reduction[1] (%)**	**70% Dam Usage Median Flow (ML)**	**Reduction[1] (%)**
Mount Pleasant	1851	1770	4	1708	8
Sixth Creek	7667	7618	1	7571	1
Kersbrook Creek	1647	1539	7	1431	13
Gumeracha[2]	19456	19019	2	18715	4

[1] Reductions are from the observed flows.

[2] These values are modelled values under current and increased dam water usage conditions because of lack of observed data.

Figure 46 shows the high annual variability in runoff reduction for the Mount Pleasant gauged catchment. As with previous results, the impact is most noticeable during drier years when the reduction in flow may reach 25% with 50% dam water use and almost 40% if 70% of dam water is used. Results for each gauged catchment are presented in Appendix G.2.

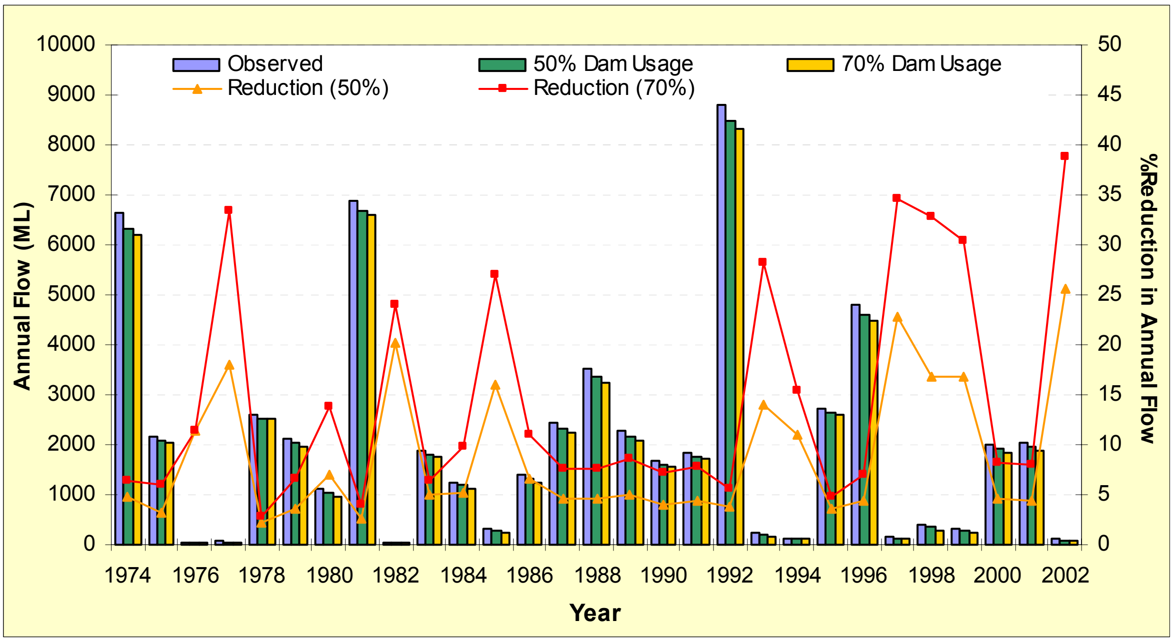


Figure 46   Impact of Increased Farm Dam Usage on Annual Runoff from the Mount Pleasant Gauged Catchment.

Monthly Streamflow

Section 5.1.2 described the classification of months based on the magnitude of flow reductions and the significance of impacts on flow that occurs during these periods. The impact on mean monthly flows from increased farm dam water use varied over the year in a similar pattern. Table 31 shows the range of mean monthly flow reductions under increased dam water use for each gauged catchment. Higher reductions occurred between November and March compared to between July and October. Reductions occur over summer because more water is required to replace the water used and less dams may spill or take longer to spill as a result. In addition, the higher reductions tended to continue into April and May, again because dams will contain less water at the end of summer than under a 30% usage condition, and more runoff is required to replace water used for irrigation before the dams will spill.

Table 31   Impact of Increased Farm Dam Water Use on the Mean Monthly Flows from Gauged Catchments.

Gauged Catchment	50% Usage Reduction (%)[1]			70% Usage Reduction (%)[1]		
	July to October	November to March	April to June	July to October	November to March	April to June
Mount Pleasant	4-5	0-12	9-12	6-8	0-17	15-20
Sixth Creek	0-1	2-4	1-4	0-1	2-4	1-4
Kersbrook Creek	1-5	0-47	29-100	3-11	0-47	42-100
Gumeracha[2]	1-3	6-13	5-10	2-6	11-21	8-20

[1] Reductions are from current flow.

[2] These values are modelled values under current and increased dam water usage conditions because of lack of observed data.

Kersbrook Creek showed a 100% reduction in flow in April. This is partly because the mean runoff is very small (~0.1 ML) during this month and any reduction reduces the flow to zero.

Figure 47(a) shows the mean monthly flows and reductions under current and increased dam water use conditions for the Mount Pleasant gauged catchment and Figure 47(b) with the data from 1992 excluded due to possible bias (refer Section 5.1.2). This highlights the large reductions during April and May, that may reach 40% if 70% of dam water is used. For this location, no reduction was observed during March, implying that the catchment area that currently contributes to runoff during March has remained the same and increased water use has no effect during this month. Dams that currently spill during March continue to do so during this month and have not been significantly impacted upon by the increased water use.

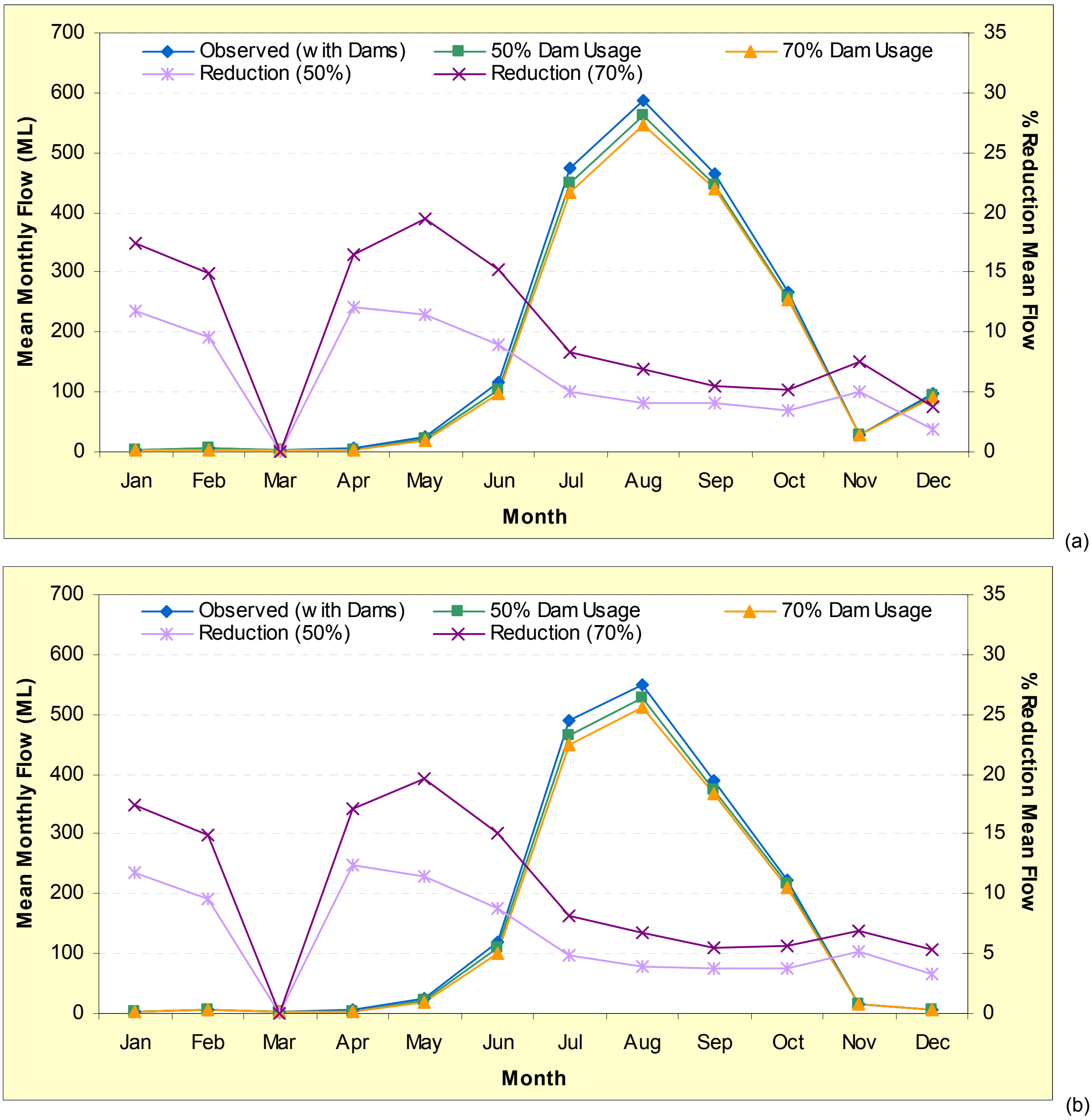


Figure 47 Impact on Mean Monthly Flow from Increased Farm Dam Usage for Mount Pleasant Gauged Catchment (a) all data (b) excluding 1992 data.

A similar analysis of monthly flows is presented for each gauged catchment in Appendix G.2. The impact of increased dam usage is lower than that from potential development in each of the Sixth Creek, Kersbrook Creek and Gumeracha Weir gauged catchments.

Daily Streamflow

Figure 48 shows the flow frequency curves for the Mount Pleasant gauged catchment under current and increased farm dam usage conditions. There is a slight decrease in the low to medium flows and decreases in the median daily flow of 9% for both water use levels. However, although 9% decrease in flow only equals 0.01 ML and may therefore not be considered a huge reduction, in the context of such small daily flows for most of the year, it may still be significant. The higher usage rates do not impact on the higher flows, which primarily occur during winter when the dams are more likely to be full.

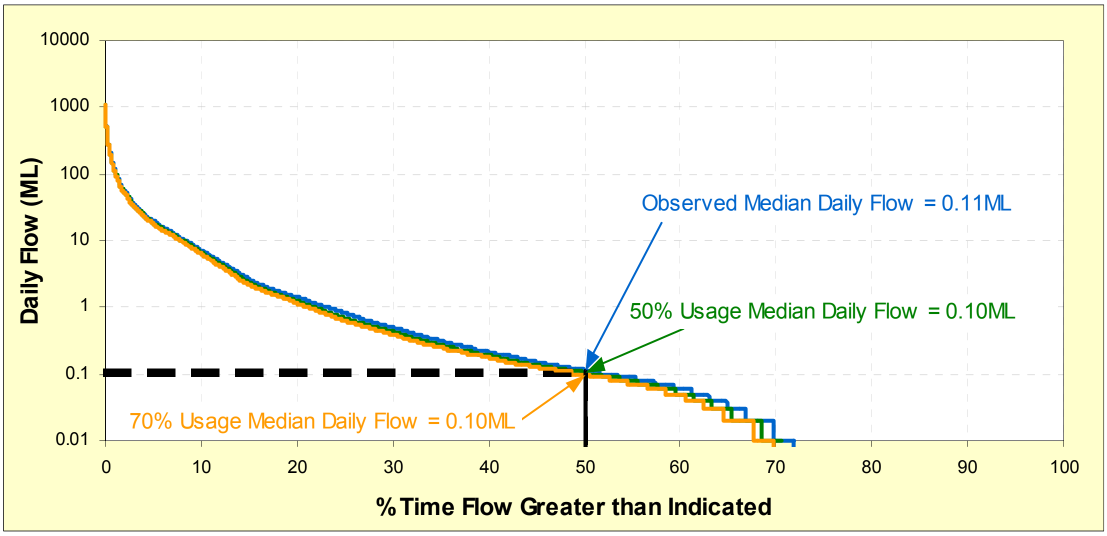


Figure 48 Flow Frequency Curves under Current and Increased Farm Dam Usage Conditions for the Mount Pleasant Gauged Catchment.

Table 34 shows some flow exceedance characteristics and Table 35 some flow percentiles for each of these curves. These show that there is generally not a huge reduction in the number of days that various sized flows are maintained. However, as was the case for the annual and monthly flows, the reduction here is actually greater than between current and potential development conditions because the catchment is already highly developed. Appendix G.2 presents a similar analysis for each gauged catchment where the impact from increased dam usage in each of the Sixth Creek, Kersbrook Creek and Gumeracha Weir gauged catchments is likely to be less than that under potential development.

Table 32 Flow Exceedance Characteristics of Observed and Increased Farm Dam Usage Flow Frequency Curves for the Mount Pleasant Gauged Catchment.

Flow Criteria	Current		50% Usage		70% Usage	
	% Year	No. Days	% Year	No. Days	% Year	No. Days
Flow ≥ 0.1 ML/day*	53	195	52	189	51	184
Flow ≥ 1 ML/day	23	84	22	80	21	78
Flow ≥ 10 ML/day	8	30	8	29	8	29
Flow ≥ 20 ML/day	5	18	5	17	5	16
Flow ≥ 50 ML/day	2	8	2	8	2	8
Flow ≥ 100 ML/day	1	4	1	4	1	4

* Flows below this are difficult to measure and model accurately.

Table 33 Flow Percentiles of the Observed and Increased Farm Dam Usage Flow Frequency Curves at the Mount Pleasant Gauged Catchment.

Flow Percentile	Current Daily Flow (ML)	50% Usage Daily Flow (ML)	Reduction (%)	70% Usage Daily Flow (ML)	Reduction (%)
10th	0.00	0.00	-	0.00	-
20th	0.00	0.00	-	0.00	-
50th	0.11	0.10	9	0.10	9
80th	1.42	1.25	12	1.15	19
90th	7.23	6.65	8	6.36	12

5.2.2 Total Catchment and Major Sub-Catchment Results

The effect of increased farm dam water use conditions on annual, monthly and daily flows were determined for the Upper River Torrens catchment and each major sub-catchment using the same procedures as in Section 5.1.3, that is, the statistics and results presented are determined using observed data for the Mount Pleasant sub-catchment and modelled data from the total catchment and remaining sub-catchments.

Annual Streamflow

The mean and median annual runoff under current and potential dam water use conditions from the catchment and each major sub-catchment are presented in Table 34 and Table 35. The reductions in annual flow due to increased dam usage are less than those predicted from increased farm dam development but are still significant, particularly for 70% usage, at a catchment wide scale. Both the mean and median annual flows from the catchment are reduced from the current mean and median annual flows by 2% and 4% for the 50% and 70% dam usage levels respectively. For 70% usage, this equates to a reduction of approximately 1600 ML/year and 1700 ML/year in the mean and median flow.

Table 34 Modelled Estimates of the Impact from Increased Farm Dam Usage on the Mean Annual Flow from the Upper River Torrens Catchment and Major Sub-Catchments.

Sub-Catchment	Current Mean Flow (ML)	50% Dam Usage Mean Flow (ML)	Reduction (%)	70% Dam Usage Mean Flow (ML)	Reduction (%)
Mount Pleasant*	2073	1978	5	1921	7
Birdwood	6308	6115	3	5948	6
Hannaford Creek	1968	1928	2	1896	4
Angas Creek	2884	2811	3	2746	5
Gumeracha	4592	4564	1	4537	1
Footes Creek	1375	1323	4	1277	7
McCormick Creek	1223	1201	2	1181	4
Millers Creek	2958	2889	2	2825	5
Kenton Valley	1938	1899	2	1863	4
Cudlee Creek	2770	2731	1	2692	3
Kangaroo Creek	5002	4954	1	4911	1
Kersbrook Creek	5005	4880	3	4766	5
Sixth Creek	8414	8362	1	8310	1
Total Catchment	45983	45110	2	44351	4

* Values for Mount Pleasant sub-catchment were determined from observed flow data.

Table 35 Modelled Estimates of the Impact from Increased Farm Dam Usage on the Median Annual Flow from the Upper River Torrens Catchment and Major Sub-Catchments.

Sub-Catchment	Current Median Flow (ML)	50% Dam Usage Median Flow (ML)	Reduction (%)	70% Dam Usage Median Flow (ML)	Reduction (%)
Mount Pleasant*	1851	1770	7	1708	8
Birdwood	5491	5285	4	5131	7
Hannaford Creek	1595	1564	2	1558	2
Angas Creek	2268	2206	3	2205	3
Gumeracha	3726	3700	1	3673	1
Footes Creek	1128	1066	6	1057	6
McCormick Creek	989	975	1	973	2
Millers Creek	2350	2298	2	2291	3
Kenton Valley	1527	1485	3	1442	6
Cudlee Creek	2364	2320	2	2278	4
Kangaroo Creek	3721	3677	2	3632	2
Kersbrook Creek	4446	4326	3	4205	5
Sixth Creek	7699	7650	1	7603	1
Total Catchment	40493	39623	2	38772	4

* Values for Mount Pleasant sub-catchment were determined from observed flow data.

At a sub-catchment level, reductions in the mean and median annual flow under both usage conditions vary but are generally less than 5%. The Mount Pleasant and Footes Creek sub-catchments have potentially the largest impact, as was the case under increased farm dam development.

Figure 49 illustrates the annual variability in runoff reduction, showing higher impacts during lower rainfall years where the percentage reduction exceeds 6% of the current annual flow for a dam usage of 70%.

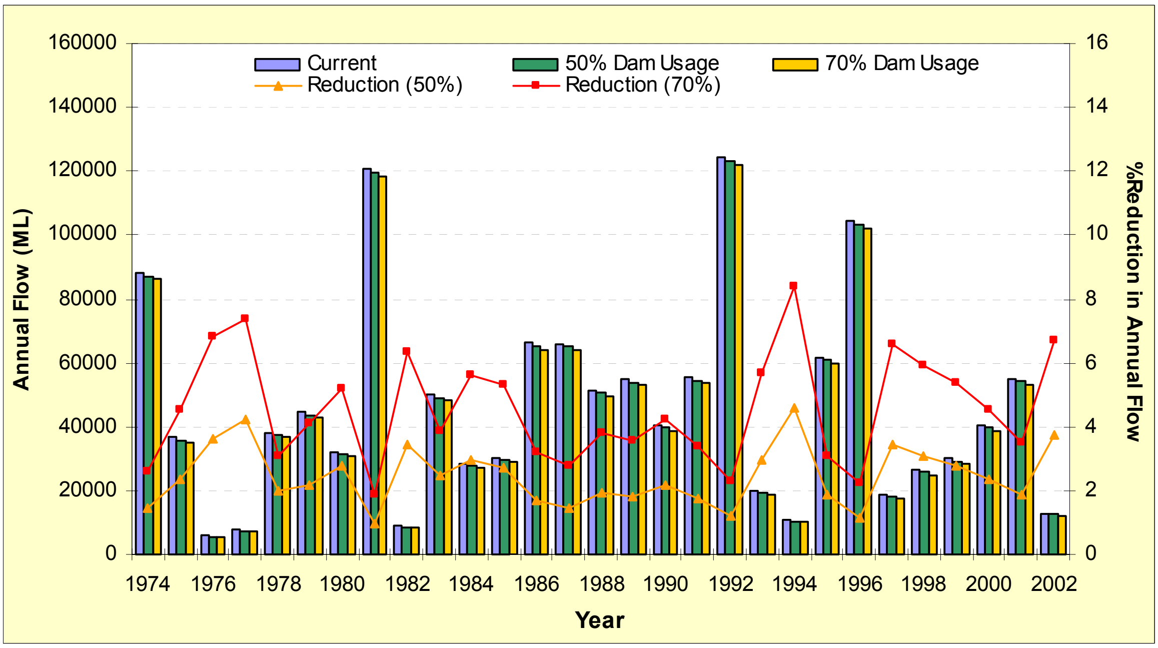


Figure 49 Modelled Impacts of Increased Farm Dam Usage on Annual Runoff from the Upper River Torrens Catchment.

The annual variability in runoff reduction is presented for each sub-catchment in Appendix G.3 and with exception of the highly developed sub-catchments of Mount Pleasant and Footes Creek, the impact is less than that likely with increased development.

Monthly Streamflow

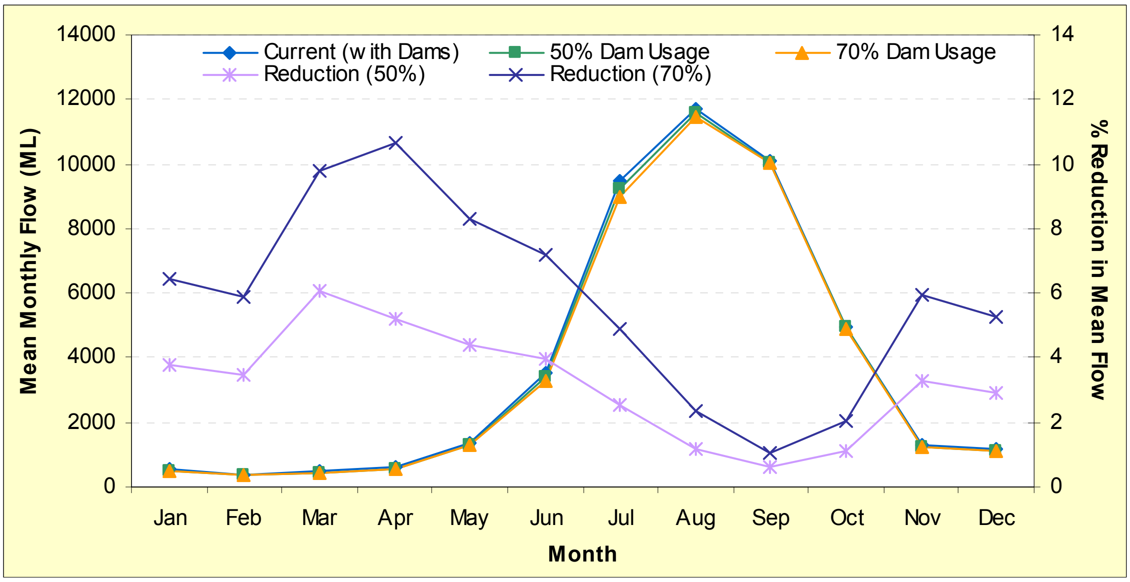
Table 36 shows the range of estimated reductions in mean monthly flows from increased farm dam usage. As for the gauged catchments, higher reductions occurred between November and March than between July and October. However, the higher reductions again tended to continue into April and May with increased runoff required during these months to replace the water used for irrigation over the summer.

Table 36 Modelled Estimates of the Impact of Increased Farm Dam Usage on Mean Monthly Flows from the Upper River Torrens Catchment and Major Sub-Catchments.

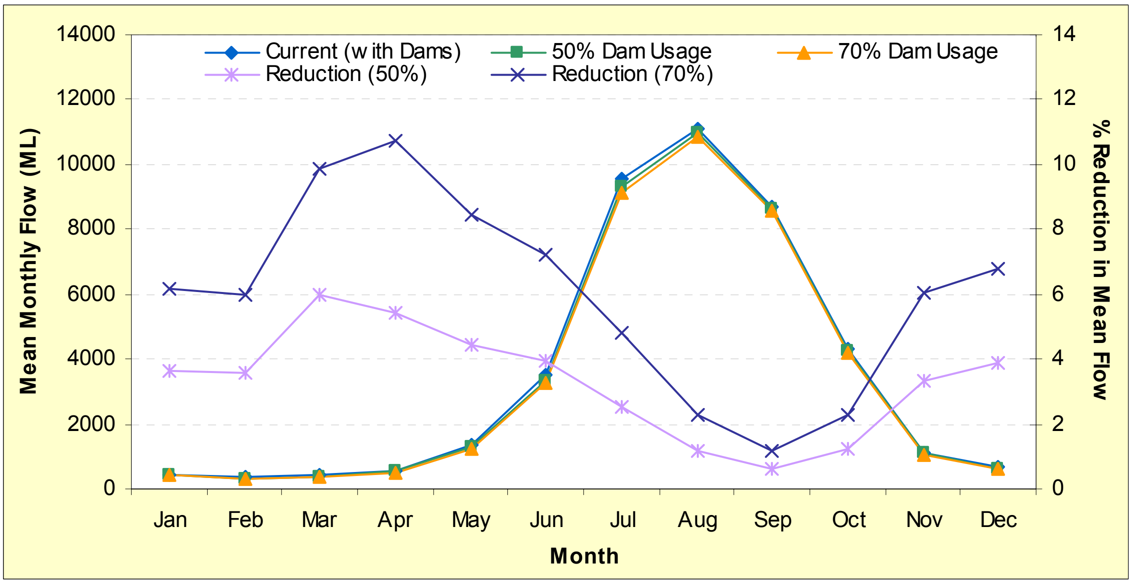
Sub-Catchment	50% Usage Reduction (%)			70% Usage Reduction (%)		
	July to October	November to March	April to June	July to October	November to March	April to June
Mount Pleasant*	4-5	0-12	9-12	6-8	0-17	15-20
Birdwood	1-3	9-31	3-15	2-5	16-50	6-34
Hannaford Creek	1-3	1-5	3-8	1-6	2-8	5-11
Angas Creek	1-4	0-3	0-6	3-8	0.-5	0-11
Gumeracha	0-1	3-4	2-4	0-1	4-6	3-8
Footes Creek	1-6	2-14	5-20	1-12	4-24	11-29
McCormick Creek	0-3	1-5	3-6	1-6	1-8	4-10
Millers Creek	1-4	3-7	4-8	1-7	5-12	8-13
Kenton Valley	1-3	3-4	4-5	1-6	6-7	7-9
Cudlee Creek	0-1	3-4	3-5	0-3	6-8	7-8
Kangaroo Creek	0-1	1-2	1-3	1-2	3-4	3-4
Kersbrook Creek	1-4	1-4	4-10	1-9	1-6	5-16
Sixth Creek	0-1	2-5	1-4	0-1	2-5	1-4
Total Catchment	1-3	3-6	4-5	1-5	5-10	7-11

* Values for Mount Pleasant sub-catchment were determined from observed flow data.

Figure 50(a) shows the estimated reduction in mean monthly flows over the year and Figure 50(b) with the data from 1992 excluded from calculations due to possible bias (refer Section 5.1.2). Both figures highlight higher reductions in March and April (a greater than 10% reduction for 70% usage) as was seen for the gauged catchments in Section 5.2.1. Because dams will contain less water than under a 30% usage condition, more runoff is required to fill the dams before they spill. As has been mentioned previously, this leads to a delay in the start of the higher flows and effectively reduces the winter flow season. However, as for the annual flows, the impact is generally less than is likely with increased development.



(a)



(b)

Figure 50 Modelled Mean Monthly Flow Variations under Increased Farm Dam Usage for the Upper River Torrens Catchment (a) all data (b) excluding 1992 data.

Daily Streamflow

Figure 51 shows the flow frequency curves for the Upper River Torrens catchment under the current and 70% farm dam usage conditions. There is little difference between these two curves and the 50% dam usage flow frequency curve and so the latter was not shown here. There are slight decreases in the low to medium flows with a 7% reduction in the median flow.

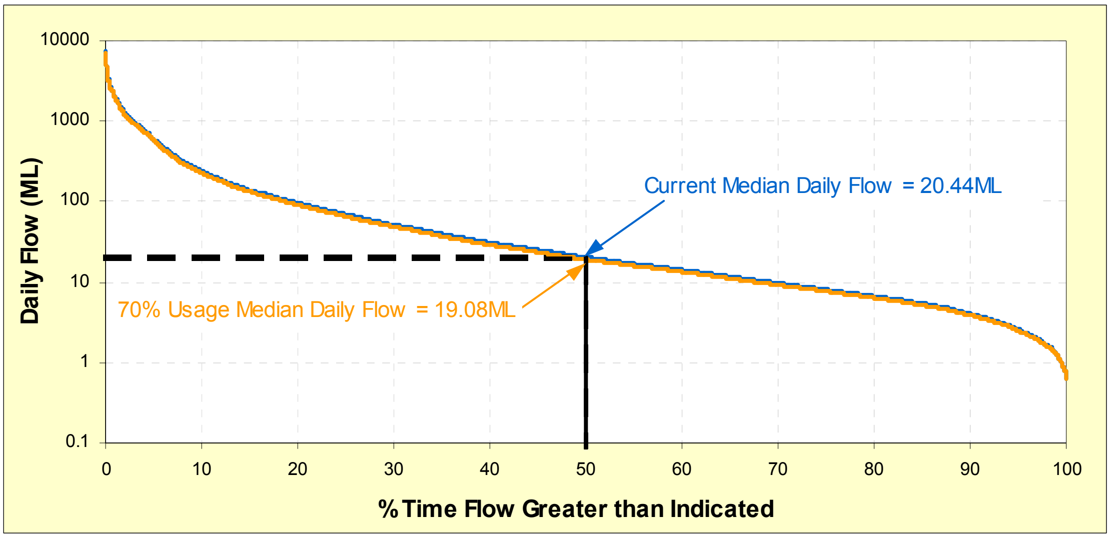


Figure 51 Flow Frequency Curves under Current and 70% Farm Dam Usage Conditions for the Upper River Torrens Catchment.

Table 37 shows the flow exceedance characteristics and Table 38 the flow percentiles for these curves in addition to the 50% dam usage flow frequency curve. There are generally not large reductions in the number of days that each of the various sized flows occur. The impact of increased dam usage for the catchment is less than that under potential farm dam development. As with previous results, the impact of increased usage on daily flows at a sub-catchment scale is generally less than that likely with increased development. The analysis for each sub-catchment is presented in Appendix G.3.

Table 37 Flow Exceedance Characteristics of Observed and Increased Farm Dam Usage Flow Frequency Curves for the Upper River Torrens Catchment.

Flow Criteria	Current		50% Usage		70% Usage	
	% Year	No. Days	% Year	No. Days	% Year	No. Days
Flow ≥ 0.1 ML/day *	100	365	100	365	100	365
Flow ≥ 1 ML/day	99	363	99	363	99	363
Flow ≥ 10 ML/day	69	253	68	250	68	247
Flow ≥ 20 ML/day	51	185	49	181	49	178
Flow ≥ 50 ML/day	31	112	30	110	30	108
Flow ≥ 100 ML/day	19	71	19	69	19	68

* Flows below this are difficult to measure and model accurately.

Table 38 Flow Percentiles of the Observed and Increased Farm Dam Usage Flow Frequency Curves for the Upper River Torrens Catchment

Flow Percentile	Current Daily Flow (ML)	50% Usage Daily Flow (ML)	Reduction (%)	70% Usage Daily Flow (ML)	Reduction (%)
10th	4.1	3.9	3	3.9	5
20th	6.7	6.5	3	6.4	5
50th	20.4	19.6	4	19.1	7
80th	96.1	93.2	3	91.00	5
90th	238.1	232.6	2	226.3	5

5.3 Effect of Extended Dry Periods

The analysis of catchment rainfall in Section 3.1.2 showed both short and long term rainfall patterns. Over the last 100 years there have been extended periods of both above average and below average rainfall. However, while above average rainfall is generally welcome so long as flooding does not occur, below average rainfall or periods of drought cause difficulties to water supply operators and farmers alike.

In the records examined, the lowest average rainfall for any three-year period was 567 mm, occurring between 1976 and 1978. This is 25% lower than the long term mean annual rainfall of 756 mm. Although it cannot be assumed that the flow available during these years would be available during a subsequent three-year period of similar average rainfall, the level of water resource availability does provide insight into the possible impact from periods of extended below average rainfall.

Over this dry period, the mean annual runoff from the catchment was approximately 17,200 ML, a reduction of 14% from the mean pre-farm dam development runoff over the same period when farm dams trapped around 2,850 ML each year. More importantly, it is a 63% reduction from the long term mean annual runoff of 46,000 ML under current development conditions. This means that an additional 28,800 ML of water would need to be pumped from the River Murray during each of the three years to make up the shortfall. Under future development, farm dams are likely to have captured an extra 4,340 ML during each of these years, requiring 33140 ML to be pumped each year from the River Murray.

Under drought conditions it is likely that the water resources generated in all catchments in the Mount Lofty Ranges would be significantly reduced. Therefore, increased pumping from the River Murray would also be required in all pipelines. This may push the limits of allowable extraction under the Murray-Darling Basin Commission Cap.

5.4 Effect on Water Supply Reservoirs

All runoff occurring in the Upper River Torrens catchment has the potential to enter a water supply reservoir, whether by diversion from either Gumeracha or Gorge Weirs or by direct inflow into either Kangaroo Creek or Millbrook reservoirs. Therefore, the maximum impact of current and potential farm dam development on catchment yield is identical to the reductions presented in the previous sections for total catchment runoff.

Farm dams only impact upon water supply in years when the reservoirs do not spill and during such years, reductions may have wider implications in terms of providing a reliable water supply to Adelaide. As the average volume of water pumped from the River Murray is approximately 19,000 ML/year, then almost 16% of water currently pumped is to replace water captured by farm dams. Additional water supply is also likely to be sourced from the River Murray and hence a further 3,400 ML/year may be required if dam development increased to its potential under the 50:50 rule. The financial and environmental costs to pump this extra supply, which would increase further during extended dry periods, highlights the need to explore alternative options if additional water supply is required for Adelaide.

6. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

This technical report contains an assessment of the surface water resources within the Upper River Torrens catchment. It covers the methodology and results of this assessment, from the analysis of hydrological and catchment data to the construction of a hydrological catchment model and the evaluation of the current and potential impacts of farm dams. This section provides some conclusions from the assessment and recommendations for ensuring the sustainability of water resources within the catchment.

6.1 Data

There were a number of sources of data used in this study, which can be broadly categorised as hydrological data (rainfall, evaporation and streamflow) and catchment data (farm dam information, water supply and bulk water transfer data).

6.1.1 Hydrological Data

Rainfall Data

Rainfall data from six Bureau of Meteorology stations were used to calibrate and evaluate a hydrological catchment model. In particular:

- Data sets were of a good length (100 years at most sites), reasonable quality and provided a reasonable representation of catchment rainfall;
- Four stations were well distributed along the main river channel, but only two were located at higher elevations in the upper areas of the sub-catchments. An analysis of the magnitudes of monthly rainfall between the two groups of stations showed that there were little differences between November to March totals in comparison to the remainder of the year. This suggested that the higher rainfall months (April to November) are primarily responsible for higher annual rainfalls; and
- Maintenance of stations at higher elevations within the catchment would provide more information as to the spatial variability of rainfall with elevation and ultimately improve the rainfall-runoff modelling process.

Evaporation Data

The availability of long term daily pan evaporation data in the Mount Lofty Ranges is limited and there are no stations located in the Upper River Torrens catchment. For this study, evaporation data was calculated using the Priestley-Taylor method (Priestley and Taylor, 1972) with data from Nuriootpa. However, evaporation is an important component of catchment hydrology and the maintenance of stations located within the catchment that record both pan evaporation data and the climate variables required to calculate evaporation from empirical equations should be investigated.

Streamflow Data

Historical records of streamflow in the Upper River Torrens catchment are extremely limited and an assessment of the sustainable resources is complicated by this. The data available shows high inter-annual streamflow variability. In particular:

- Only two gauging stations have good long term records, these recording the runoff from the Mount Pleasant (29 years) and Sixth Creek (25 years) sub-catchments. Because these catchments have the lowest and highest rainfall and runoff respectively they do not provide a good representation of rainfall-runoff relationships over the entire catchment;

- A third gauging station measuring water level from approximately half of the Kersbrook Creek sub-catchment has only 10 years of data. The rating curve used to transform water level into streamflow requires further validation in the medium to high flow range;
- The Gumeracha Weir and Gorge Weir sites contain reasonable water level records but must be used in conjunction with other water supply diversion and transfer data if they are to provide a useful record of runoff. While this was possible for a short (eight year) period for Gumeracha Weir, the data from Gorge Weir was unable to be used;
- The ability to accurately record low flow data is required at the Mount Pleasant, Sixth Creek and Gumeracha Weir gauging stations, which could be achieved by modifying the existing control sections; and
- An improved rating for measuring medium to high flow data is required at Kersbrook Creek. The current rating only covers low flow and more gaugings are required during high flow events.

6.1.2 Catchment Data

Farm Dam Information

A physical survey of farm dam capacities and surface areas was undertaken in parallel with this study for many of the larger dams. This information was therefore used where available and the storage capacities calculated using a surface area to volume relationship for the remaining dams. It was found that:

- there are approximately 1350 farm dams across the catchment with a total storage volume of 5750 ML;
- dam density is 17 ML/km^2 for the catchment but varies between 6 ML/km^2 and 36 ML/km^2 between sub-catchments. At a stream reach scale, dam densities are as high as 100 ML/km^2 (equating to 100 mm of runoff) with some reaches in the Mount Pleasant, Birdwood, Footes Creek and Kersbrook Creek sub-catchments particularly under pressure from dam development; and
- the physical dam volume survey provided invaluable information that was incorporated into the model. The values estimated using surface area to volume relationships both under- and over-estimated dam capacities by up to 120%. Better model calibration and estimation of surface water resources using the more accurate farm dam information highlighted the need to obtain as much field surveyed information as possible.

Current development levels have not exceeded the 50:50 development rule limits under the State Water Plan (2000) at a sub-catchment level, but a number of areas are highly developed and are approaching or exceeding these levels at a property scale (McMurray, 2001). This is particularly apparent in the lower rainfall and hence lower runoff areas of the catchment.

Water Supply Infrastructure and Operations Information

The Upper River Torrens catchment is a major component of the water supply system for Adelaide and most catchment runoff enters the Millbrook and Kangaroo Creek Reservoirs. The main channel of the River Torrens is also used as a transfer aqueduct to facilitate the movement of water from the River Murray to the water supply network. There is limited data on water supply operations (such as reservoir and weir releases and reservoir spills) currently recorded, reducing the usefulness of some existing stations that measure water level (Millbrook and Kangaroo Creek Reservoirs and Gumeracha and Gorge Weirs).

In particular:

- To use available water level information at Gumeracha Weir, daily discharges from the Mannum-Adelaide Pipeline at the Mount Pleasant and Angas Creek scours must be recorded. While on average 19,000 ML of water is pumped and discharged from the M-A Pipeline each year, including 14,000 ML through the scours at Mount Pleasant and Angas Creek, SA Water have only kept daily records of these discharges since 2000 and the data reliability is unknown. It is important that this data is recorded accurately so that the natural runoff from the Gumeracha Weir catchment can be calculated;
- Water released from Kangaroo Creek Reservoir down to Gorge Weir and the spill from Millbrook Reservoir is not currently measured and a water balance at Kangaroo Creek Reservoir was not possible. As a result, the natural runoff from the catchment upstream of the reservoir was not able to be accurately measured and modelled. This information is important not only for catchment modelling but also for maintaining the environment downstream and should be recorded; and
- Water released from Gorge Weir is not recorded and hence a water balance at the outlet of the Upper River Torrens catchment was not possible. As for the Kangaroo Creek water balance, this is required to determine the natural runoff from the catchment upstream and for the environment downstream.

6.2 Model Calibration

A hydrological catchment model with conceptual water balance model was constructed for the catchment using the WaterCress modelling platform. Calibration was undertaken using data from four streamflow gauging stations. In particular:

- Confidence in the available data to accurately represent low, medium and high flows was only possible for two gauged catchments (Mount Pleasant and Sixth Creek). Together these only cover around 20% of the total catchment and represent the driest and wettest sub-catchments;
- There was less confidence in the medium to high flow data from Kersbrook Creek and in the low to medium flow data from Gumeracha Weir;
- There are no direct measurements of runoff that enters or water that is released or spills from the reservoirs, preventing a water balance to be achieved and estimates of natural runoff to be made;
- Despite difficulties in data availability, the model reproduces the observed daily, monthly and annual data satisfactorily at each station. While some deficiencies were found in the reproduction of daily flows less than 1 ML/day, many of these flows occur during late summer and early winter; and
- Parameters were assumed for non-gauged sub-catchments from gauged catchments with similar land use, topography and rainfall patterns.

Requirements for future works to improve model calibration and water resource assessment for the catchment are presented in Section 6.4.

6.3 Model Scenario Evaluation

The calibrated hydrological catchment model for the Upper River Torrens catchment was used to evaluate current and potential development impacts on catchment runoff. In particular:

- The effect of current farm dam development;
- The possible impact from potential development under the 50:50 rule;
- The potential impact from increased water usage from current farm dams;
- The effect of a three year below average rainfall period; and
- The impact that farm dams have had on the supply of water for Adelaide.

6.3.1 Current Impact of Farm Dam Development

The current impact of farm dam development was defined as the difference in runoff between current (with dams) and pre-farm dam development (without dams) conditions. The results were calculated over the period between 1974 and 2002, with annual results indicating that:

- at a catchment scale, farm dams intercept an average of 3,060 ML of runoff each year and a median of 3,032 ML/year. These represent 6% and 7% reductions in the mean and median annual runoff respectively;
- there is a high inter-annual variability in the percentage reduction of annual runoff, from marginal reductions of less than 4% during higher rainfall years up to reductions greater than 20% during drier years;
- the mean annual volume of 3,060 ML currently captured by farm dams is much less than the total farm dam capacity of 5,750 ML, indicating that there will either be a high level of seasonal carryover storage under 30% dam usage and therefore the dam will capture less water before it is full and overflows; or alternatively, many dams within the catchment may not fill and overflow on an annual basis;
- at a sub-catchment scale the current impact is varied, but linked with the dam densities such that the Mount Pleasant, Birdwood and Footes Creek sub-catchments have reductions in the mean annual flow of 18%, 11% and 10% respectively and in the median annual flow of 22%, 13% and 20% respectively; and
- the Angas Creek, Millers Creek, Hannaford Creek and McCormick Creek sub-catchments in addition to the area upstream of Millbrook Reservoir also had large farm dam densities at a stream reach scale. This was translated into significant reductions in the median annual flow of 17%, 15%, 13%, 13% and 15% respectively.

The impact of farm dams show significant seasonal variation, with results showing that:

- reductions of total flow volume was least during November to March, but greatest in terms of the percentage reduction in mean flow. At a catchment scale the reductions varied between 20% and 34% during this period, but most sub-catchments experience reductions greater than 35% in each month over this period. While this period contributes only a small percentage to the total annual flow, considerable reductions during this period may seriously affect the survival of water dependent ecosystems;
- reductions between April and June are less than over summer but are still significant as they delay the onset of winter flows downstream and shorten the length of the higher flow season. Reductions of 11% to 19% were found for the mean monthly catchment flow but these reached 79% and 69% in the Mount Pleasant and Footes Creek sub-catchments during some months; and

- the impact of dams in terms of percentage reduction of mean flow is lowest during the period between July and October and ranged between 1% and 5% for the catchment. At a sub-catchment scale only the Mount Pleasant, Birdwood and Footes Creek sub-catchments experience higher reductions, the greater being 12% to 16% in Mount Pleasant. However, while the percentage flow reduction may be low, the actual flow reduction volume may be quite high and the winter flow peaks significantly reduced.

The effect of farm dams on daily flow patterns such as the volume and duration of flows have the most direct consequences for aquatic ecosystems. The results showed that:

- a 25% reduction in the median daily flow from the catchment and reductions ranging from 9% to 70% for individual sub-catchments. The Footes Creek, Birdwood and Mount Pleasant sub-catchments again had the highest reductions of 70%, 60% and 54% respectively; and
- the largest impacts have been reductions in the duration of the low to medium flows that would occur without farm dams. This results in an extension of the “no-flow” period in later summer, for example, without farm dams, the Mount Pleasant sub-catchment would cease to flow for approximately 20% of the year but with current dam development this has increased to 30%. Alternatively there may be an increase in the lower flows at the expense of the medium flows such as has occurred at a catchment scale. Without farm dams a flow of 10 ML/day would have occurred for 289 days a year but now only occurs for 253 days a year and as such, flows less than 10 ML/day have increased.

6.3.2 Potential Impact of Farm Dam Development

The potential impact of farm dam development under the 50:50 rule was defined as the difference in runoff between pre-farm dam development (without dams) and potential (50:50 dams) conditions, with the impact determined over the period from 1974 to 2002. Future development under the 50:50 rule was determined at a sub-catchment scale and the additional farm dam capacity added to areas already containing farm dams. This assumes that areas where farm dams would be beneficial have already been developed, at least to a minimum level with small dams. Consequently, upper limits of farm dam runoff capture are also based on an assumption that future development will not reduce the current free to flow areas and the results presented herein are based on this. However, it should be noted that if further development occurs in such free to flow areas then much larger volumes of runoff may be captured and the impact would increase, particularly during summer months when these are generally the only areas contributing to catchment flow.

At an annual time scale, the results showed that:

- farm dams may potentially intercept a further 5,866 ML/year of catchment runoff to reduce the mean annual flow by 18% of the pre-farm dam development flow. The median annual flow may also be significantly reduced, by a further 6,403 ML/year to produce a total reduction of 22% from the pre-farm dam development flow;
- the high inter-annual variability in the percentage reduction of annual runoff is accentuated under increased development, from reductions of around 10% during higher rainfall years up to reductions of almost 40% during drier years;
- the mean annual volume of 8,930 ML that may potentially be captured is much less than the increased total farm dam capacity of 20,512 ML, again suggesting that there is a lower level of seasonal carryover storage in comparison to the increased volume or that currently, many dams do not fill and overflow each year and may in fact overflow less frequently in the future; and

- at a sub-catchment scale the potential percentage flow reductions are similar. Almost all have reductions in the mean annual flow of at least 15% and five sub-catchments have mean reductions of over 20%. Reductions in the median annual flow vary from 19% to 36% between sub-catchments.

The impact of increased development on mean monthly flows depended significantly on the current levels of dam development in terms of capacity and also the proportion of the catchment that currently captured runoff. The results show that:

- reductions from the catchment may be as high as 21% between July and October, 46% between November and March, and 43% between April and June. July has the highest monthly flow and the calculated reduction of 22% from the pre-farm dam development flows results in a significant volume reduction of over 2,100 ML;
- there is the potential for flow reductions of between 50% and 80% over the summer period at a sub-catchment scale. Many sub-catchments may also reach a 25% flow reduction during July to October with a significantly reduced total annual flow. A 30% to 80% reduction between April and June may result in very little, if any, flow from some sub-catchments between November and June;
- those sub-catchments with a lower proportion of runoff currently diverted into farm dams generally had lower reductions across the year than those with widespread dam distribution;
- sub-catchments including Footes Creek, McCormick Creek and Angas Creek had very small reductions in summer flows above those caused by current dam development. This indicates that much of the expected flow reduction under the 50:50 rule has already occurred under current dam development; and
- an upper limit to the monthly flow reductions was reached for up to six months in many of the sub-catchments and the maximum reduction may actually be reached at lower levels of development.

At a daily time scale the results show that:

- an additional 13% reduction in the median daily flow from the catchment is likely and would signify a total reduction of 38% from the median pre-farm dam development flow. The main reductions are likely to be in the medium flow range as much of the lower flow reductions have already occurred under current development conditions;
- currently a flow of at least 10 ML/day occurs for 253 days a year but under future development this may decrease to 237 days per year. Flows of at least 20 ML/day have currently reduced from 215 days per year to 185 days per year but this may possibly reduce to 165 days per year under future development;
- additional reductions in the median daily flow from individual sub-catchments range from 1% to 26% and result in reductions of up to 72% from the pre-farm dam development flow. The Footes Creek, Birdwood and Mount Pleasant sub-catchments again had the highest reductions of 72%, 69% and 63% respectively; and
- those sub-catchments with the highest additional reductions in median daily flow are generally those that currently have lower levels of farm dam development. Because the flow from most sub-catchments has a high variability, the median daily flow is in the low flow range. Therefore, since most of the current flow reductions have occurred in this range, the median value has almost reached its potential reduction.

6.3.3 Impacts From Increased Farm Dam Water Use

The potential impact of increased farm dam water use was defined as the difference in runoff between current (30% usage) and increased (50%, 70% usage) conditions. In particular, the annual results for a 70% dam usage show that:

- at a catchment scale, farm dams may intercept an additional 1,630 ML of the mean runoff each year to compensate from increased usage while the median runoff may be reduced by 1,720 ML/year. These represent 4% additional reductions in both the mean and median annual runoff, equating to a 10% and 11% reduction in the mean and median annual pre-farm development flow; and
- the reduction in the mean and median annual flows at a sub-catchment time scale varied from 1% to 7% and 1% and 8% respectively. The annual impact was generally less than those possible from increased dam development, with the exception of the Mount Pleasant sub-catchment. The high current level of dam development means that there is less potential for further dam development and more runoff is likely to be needed to replace water used from the dam than for filling new or larger dams.

At a monthly time scale the results show that:

- higher reductions in mean monthly flows occurred between November and March than between July and October, but unlike the increased development scenarios, reductions between April and June were often as high or higher than over summer. Increased runoff is required during these months to replace water used for irrigation over summer;
- at a catchment scale, increased dam usage may reduce current mean flows by 1% to 5% between July and October, 5% to 10% between November and March, and 7% to 11% between April and June;
- reductions between July and October at a sub-catchment level are generally less than 10% of the current flows and less than may occur under future development. However, sub-catchments including Birdwood, Footes Creek and Mount Pleasant may experience reductions in some months between November and June that are greater than those under increased development conditions; and
- those sub-catchments that currently have lower levels of development have generally small reductions in mean monthly flows.

At a daily time scale the results show that:

- an additional reduction of 7% in the median daily catchment flow is possible with increased farm dam usage although there was little noticeable change to the flow frequency curve. A flow of at least 10 ML/day may be reduced from 253 days a year to 247 days per year and flows of at least 20 ML/day from 185 days per year to 178 days per year; and
- at a sub-catchment scale, reductions in the median daily runoff was generally between 2% and 5% of current flows and there was only small overall reductions in the flow frequency curves. The Mount Pleasant sub-catchment has the highest possible reduction of 9% reduction and the only sub-catchment where the effect on daily flow characteristics is greater for increased dam usage than for potential development.

6.3.4 Effect of Extended Dry Periods

The level of water resource availability during extended periods of below average rainfall provides insight into the possible impacts to water supply operators. In the records examined, the lowest average rainfall for any three-year period was 25% less than the long term mean annual rainfall. Over this period there was a 63% reduction in the mean annual runoff when compared to long term estimates. An additional 28,800 ML of water would need to be pumped from the River Murray in each of the three years and under future development this may increase to 33,100 ML. This would place considerable stress on the River Murray environment, highlighting the need for Adelaide's water supply to be less dependent on this source. Additionally, under drought conditions it is likely that the water resources generated in all catchments in the Mount Lofty Ranges would be significantly reduced and increased pumping from the River Murray would likely be required in additional catchments to the River Torrens. This may push the limits of allowable extraction under the Murray-Darling Basin Commission Cap.

6.4 Technical Recommendations

The model and results that have been generated during this study, form the basis for the implementation of management options to ensure the sustainable use of water resources within the catchment. The best estimates possible have been produced with the limited data that is currently available. Additional information is required to gain a better estimation of the natural runoff from the catchment and hence a more solid appreciation of the availability and sustainability of water resources. A number of measures that need to be instigated include:

- the maintenance of existing, recently established rainfall stations at the higher elevations within the catchment is required. Over time these will provide more information as to the spatial variability of rainfall with elevation. Additional rainfall pluviograph stations, particularly at higher elevations, would also ultimately improve the rainfall-runoff modelling process;
- the establishment and maintenance of at least one climate station located within the catchment that records both pan evaporation data and the climate variables required to calculate evaporation from empirical equations;
- further validation of the rating curve at the Kersbrook Creek gauging station in the medium to high flow range;
- an upgrade of the Gumeracha Weir gauging station or the construction of a new station upstream to allow better measurement of the lower flow range;
- additional streamflow data to calibrate the model over all areas of the catchment. DWLBC has established a gauging station in the Torrens main channel below Gumeracha Weir to address the lack of recorded streamflow data in part, but diversions to and discharges from water supply reservoirs and pipelines are not adequately quantified (refer Section 6.1.2). The value of the catchment in supplying water to Adelaide warrants a greater emphasis to be placed on resource measurement.

  Streamflow monitoring in areas that are not affected by water supply operations would be particularly beneficial. There are a number of streamflow gauging stations (Angas Creek, Millers Creek and Cudlee Creek) currently operated by the Bureau of Meteorology as flood warning sites. However, field-based rating curves have not been established and the monitoring equipment appears unreliable for accurate streamflow recording. It may be a cost effective option to determine rating curves at these stations and have a cost sharing agreement with the Bureau of Meteorology for the operation of these stations;
- manual gaugings for rating purposes are often neglected due to cost constraints but this information is important, particularly to the modelling of high flows. A monitoring program that includes regular gaugings would significantly benefit model calibration and water resource estimation;

- continuously recorded data on water supply operations including reservoir releases and spills are required to estimate natural runoff and calibrate the model in some areas. This is detailed in Section 2.5; and
- the physical farm dam survey highlighted many deficiencies in the current methods used to estimate farm dam capacity. While it may not be cost effective to physically survey all farm dams within the catchment, better estimates of dam capacities may be achieved through the incorporation of dam wall height into the surface area to capacity relationship and should be further investigated.

6.5 Environmental Considerations

This study did not directly asses the status of or the impacts on the habitats of water dependent ecosystems. However, the main outcomes of the study, that is, the impact of farm dams and water supply infrastructure on the pre-farm dam development flow regime, have necessitated a number of management recommendations to ensure the protection and sustainability of water resources in the catchment. These include the following:

- While the current impact of dams is a 7% reduction in median annual catchment runoff, controls on further farm dam development in areas that still contribute runoff directly to the stream network ("free to flow" areas) should be the highest priority. Future development in such areas will capture the low and medium flows and may prevent streams from flowing for many months of the year. This could have a devastating effect on the sustainability of existing ecosystems that depend on those flows;
- An increase in the size and duration of low and medium flows could be achieved by installing low-flow by-pass structures to farm dams. These allow only the higher flows to be captured by the dams and hence result in more low to medium flow events to flow through the catchment. Because of the importance of low flows on the sustainability of aquatic ecosystems, it would be prudent to incorporate such low-flow bypass structures on all new dam developments;
- Estimates of the increased impact of changes in the way water is managed in farm dams (existing and future development) indicate that the management of water use from dams may be just as important as the management of dam development. This issue includes conjunctive surface water and groundwater use. Water allocation planning will need to give careful consideration to this issue;
- The appropriateness of the 50:50 rule for farm dam capacity and water capture needs further examination. It is possible that the 50:50 rule applied on an annual basis is not conservative enough for long term water resource sustainability. Further farm dam development not only reduces the water available for the environment but also reduces that available for the water supply system. Increased pumping from the River Murray will not only have an economic impact but is likely to have an additional adverse impact on this environment due to the method it is supplied.

  It must be emphasised that the total capacity of farm dams constitutes only a small fraction of total catchment storage and these dams capture only a small proportion of total catchment runoff. Most runoff is captured by the reservoirs and diverted out of the catchment for water supply. Hence, water supply infrastructure and operations represent a more significant impact on flow than do farm dams;
- It is important to quantify the ecological impact of changes to the flow regime due to farm dams and water supply infrastructure and operations. Further studies are required to achieve this. Under its catchment plan, the TCWMB is developing a program to assess and monitor the ecological state of the catchment, with the intention of providing for

environmental flows. Ongoing assessments and monitoring of environmental parameters throughout the system is crucial to not only quantify current impacts, but to enable the establishment of strategies to prevent further ecosystem degradation, and for the future planning of environmental water allocations; and

- As a direct result of the pumping and discharge of water from the River Murray into the River Torrens, the natural flow variability has been removed, chlorinated water is discharged into the local system and there is a potential for the transfer of non-native fish, invertebrates and parasites. There are also potential biological impacts associated with the release of water from reservoirs, particularly if there are large temperature differentials between the reservoir water and the stream. This can have a severe biological impact on the survival of native fish species. While the major infrastructure associated with water supply has significant benefits for South Australia and Adelaide in particular, the reservoirs and associated weirs and pipelines have the largest impact on native ecosystems because they change the natural flow regime so exclusively. A detailed ecological study and the monitoring of environmental parameters directly downstream of reservoirs and scour points, and within the aqueduct section of the river is required. Such a study would include consideration of the current operation of the water supply system. In particular:
  (1) Recognising system constraints, the transfer of all water from the pipeline directly into Millbrook Reservoir would help protect the in-stream environment and overcome the need to utilise the River Torrens as a transfer aqueduct; and
  (2) The incorporation of targeted water releases for the environment from Millbrook and Kangaroo Creek Reservoirs and from Gumeracha and Gorge Weirs should be considered. These structures trap all flow from upstream and current releases for water supply appear to provide only pulses of water for short periods of time.

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APPENDIX A FARM DAM DEVELOPMENT

Farm dams are water storage structures that are generally constructed in rural areas to capture surface runoff generated from the catchment areas upstream. The water stored in farm dams then provides an additional source of water (to rainfall and pumped groundwater) for domestic water supplies, stock watering and irrigation, and enables security of supply during the drier, summer months. Those dams used for stock and domestic purposes are generally smaller (often less than 5ML) than those used for irrigation.

Section 2.3.1 provided an analysis of the level of farm dam development within the Upper River Torrens catchment. The distribution of farm dams over a number of size classes was shown at a catchment level. At a sub-catchment level, the distribution of farm dams over the same size classes are shown in Table A1.

Table A1 Classification of Farm Dams within Major Sub-Catchments by Capacity.

Sub-Catchment	Dam Size Classification (ML)							
	< 0.5	0.5 - 2	2 - 5	5 - 10	10 - 20	20 - 50	> 50	Total
Mount Pleasant	3[1] (1.1)[2]	68 (98)	14 (50)	10 (73)	5 (79)	7 (274)	3 (347)	110 (922)
Birdwood	8 (3.1)	153 (218)	39 (125)	20 (141)	3 (43)	9 (243)	3 (437)	235 (1211)
Hannaford Creek	5 (1.9)	39 (54)	13 (39)	6 (49)	4 (68)	2 (49)	-	69 (260)
Angas Creek	5 (1.7)	101 (137)	30 (91)	12 (88)	6 (89)	1 (23)	1 (63)	156 (493)
Gumeracha	6 (2.3)	41 (53)	16 (51)	4 (29)	2 (26)	-	-	69 (160)
Footes Creek	-	15 (22)	6 (20)	6 (38)	1 (18)	2 (75)	2 (124)	32 (297)
McCormick Creek	4 (1.7)	26 (32)	4 (15)	1 (8)	1 (13)	3 (67)	-	39 (136)
Kenton Valley	5 (2.2)	51 (69)	14 (41)	10 (69)	2 (30)	1 (22)	-	83 (233)
Millers Creek	5 (2.1)	87 (111)	25 (77)	8 (53)	4 (69)	3 (67)	2 (113)	134 (493)
Cudlee Creek	6 (2.3)	46 (61)	11 (36)	13 (94)	2 (30)	-	-	78 (223)
Kangaroo Creek	6 (1.7)	45 (58)	12 (41)	5 (30)	3 (37)	1 (23)	1 (106)	73 (297)
Kersbrook Creek	6 (2.3)	78 (108)	44 (133)	20 (138)	7 (104)	5 (192)	1 (65)	161 (742)
Sixth Creek	16 (4.0)	61 (78)	29 (89)	7 (49)	-	2 (64)	-	115 (284)

[1] Number of dams in size category
[2] Total storage capacity of size class

APPENDIX B LAND USE AND IRRIGATION

B.1 Land Use

Land use data provides information on the principal manner in which specific areas of land are managed, for example, horticulture, forestry and livestock. Such data affects the amount of rainfall that will become runoff, for example, areas of native bushland and forest generally produce less runoff than grassed areas used for grazing livestock (Zhang, 1999). It is therefore an important component to consider when determining pressures on water resources within a region.

Section 2.4 provided a series of aggregated land use categories derived from the land use data obtained from the *Land status data mapping for the Mount Lofty Ranges Watershed* project (Bradley and Billington, 2002). The relative areas and the spatial distribution of each aggregated land use category over the Upper River Torrens catchment were shown. Tables B1 and B2 show the relative areas of each land use category within each sub-catchment and as a proportion of each sub-catchment area. Figures B1 to B5 then show the distribution of each land use category (with the exception of mining and water bodies) between sub-catchments. Differences between the areas of each sub-catchment (refer Section 2.4.1) implies that the same area of a particular land use may cover a larger proportion of one sub-catchment than another. Therefore, these provide a good description of the spatial distribution of each land use category across the catchment and the importance of each one to individual sub-catchments.

Table B1 Area of Aggregated Land Use Categories (1 to 5) per Sub-Catchment (km^2).

	Livestock (Broadscale Grazing)		Livestock (Intensive Grazing)		Forestry (Exotic Vegetation)		Forestry (Native Vegetation/ Protected areas)		Protected Area/ Recreation	
Mount Pleasant	21.1[1]	(85.0)[2]	neg[3]		0.2	(0.7)	0.4	(1.5)	0.6	(2.3)
Birdwood	44.8	(90.8)	1.1	(2.3)	0.7	(1.4)	0.6	(1.3)	0.1	(0.2)
Hannaford Creek	10.8	(73.2)	2.2	(14.6)	0.1	(0.4)	0.5	(3.5)	0.4	(3.0)
Angas Creek	20.0	(75.9)	4.0	(15.2)	0.2	(0.7)	1.0	(3.9)	0.2	(0.6)
Gumeracha	19.5	(65.8)	-[4]		2.4	(8.0)	0.9	(2.9)	2.4	(8.1)
Footes Creek	5.5	(59.5)	0.3	(3.0)	-		1.6	(17.0)	-	
McCormick Creek	7.4	(81.2)	0.1	(0.6)	-		0.4	(4.4)	0.2	(1.9)
Kenton Valley	9.8	(79.3)	0.4	(3.0)	0.2	(1.2)	0.4	(2.8)	0.2	(1.5)
Millers Creek	18.1	(81.2)	0.2	(1.0)	0.3	(1.3)	0.5	(2.4)	neg	
Cudlee Creek	12.9	(65.7)	0.2	(0.8)	1.8	(9.5)	3.9	(20.1)	neg	
Kangaroo Creek	17.5	(46.1)	0.1	(0.1)	1.0	(2.7)	5.9	(15.6)	10.7	(28.1)
Kersbrook Creek	15.4	(43.0)	neg		3.7	(10.4)	6.2	(17.3)	6.9	(19.2)
Sixth Creek	13.5	(32.0)	-		1.1	(2.7)	18.3	(43.3)	3.2	(7.5)

[1] Total area of specific land use (km^2).
[2] Land use area as a percentage of sub-catchment area.
[3] Negligible area (less than 0.04 km^2).
[4] No land use of this type in this sub-catchment

Table B2 Area of Aggregated Land Use Categories (6 to 10) per Sub-Catchment (km^2).

	Vines		Horticulture/ Floriculture		Residential/ Industrial		Mining		Water Bodies	
Mount Pleasant	1.2[1]	(4.8)[2]	0.3	(1.3)	0.6	(2.4)	neg		0.5	(1.9)
Birdwood	0.3	(0.6)	0.2	(0.4)	0.8	(1.7)	0.1	(0.2)	0.6	(1.3)
Hannaford Creek	0.2	(1.2)	0.2	(1.4)	-[4]		0.2	(1.2)	0.1	(1.0)
Angas Creek	0.1	(0.5)	neg[3]		0.4	(1.4)	neg		0.3	(1.3)
Gumeracha	1.6	(5.5)	0.8	(2.6)	0.3	(0.9)	neg		0.1	(0.4)
Footes Creek	1.2	(12.4)	0.6	(6.0)	-		neg		0.2	(1.8)
McCormick Creek	0.9	(10.2)	neg		neg		-		0.1	(1.2)
Kenton Valley	0.6	(4.4)	0.6	(4.5)	0.3	(2.2)	-		0.2	(1.2)
Millers Creek	1.9	(8.5)	0.9	(3.9)	0.1	(0.4)	-		0.3	(1.2)
Cudlee Creek	0.3	(1.3)	0.3	(1.6)	neg		-		0.2	(0.9)
Kangaroo Creek	0.3	(0.8)	0.7	(1.8)	0.6	(0.4)	0.4	(1.1)	0.8	(3.2)
Kersbrook Creek	-		1.0	(2.8)	0.3	(0.8)	0.1	(0.1)	2.2	(6.2)
Sixth Creek	0.8	(1.8)	4.7	(11.0)	0.5	(1.3)	neg		1.2	(0.4)

[1] Total area of specific land use (km^2).
[2] Land use area as a percentage of sub-catchment area.
[3] Negligible area (less than 0.04 km^2).
[4] No land use of this type in this sub-catchment

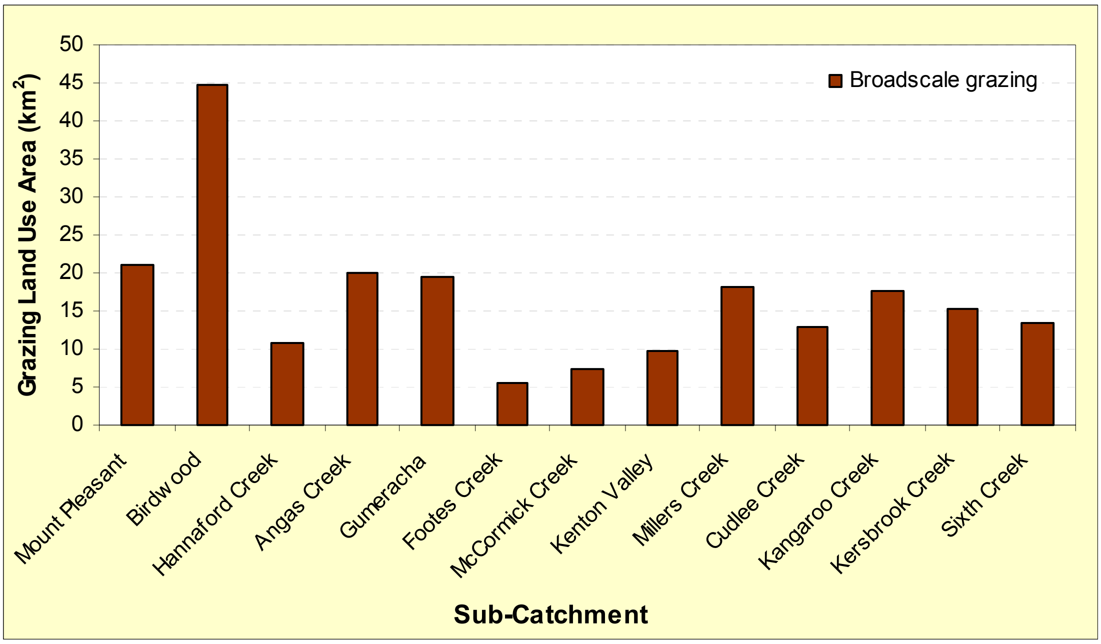


Figure B1 Distribution of Broadscale Grazing Land Use Between Sub-Catchments.

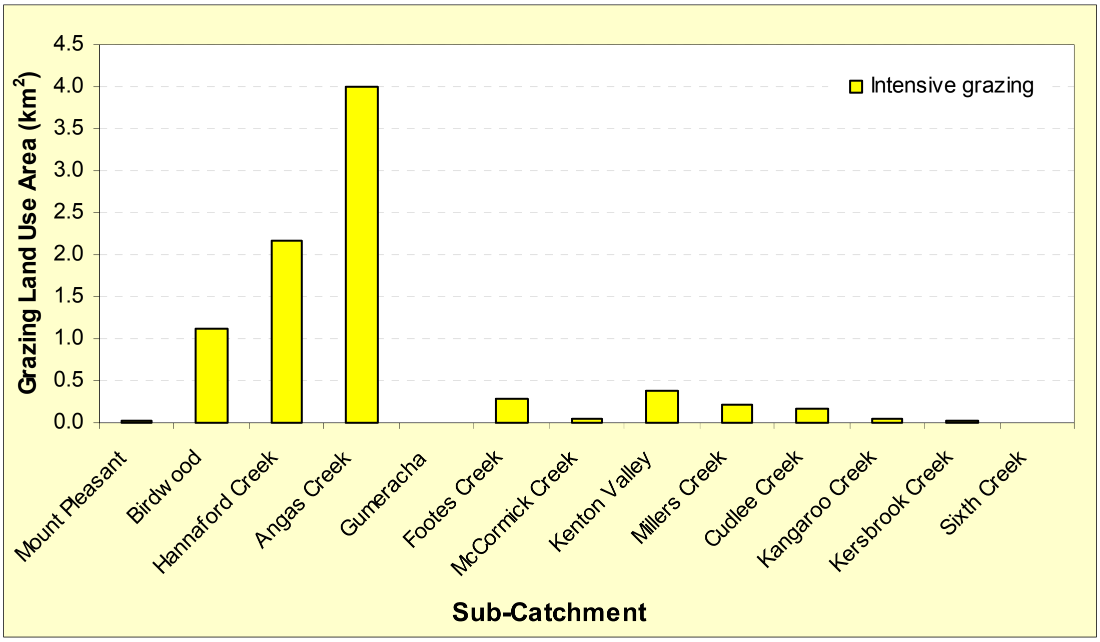


Figure B2 Distribution of Intensive Grazing Land Use Between Sub-Catchments.

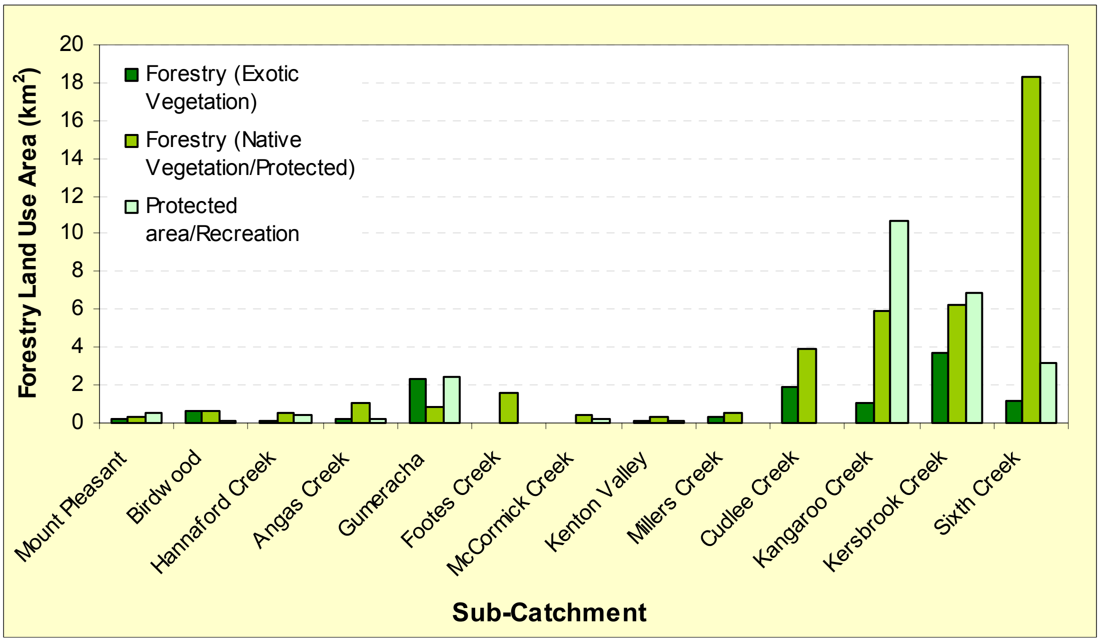


Figure B3 Distribution of Forestry (Exotic and Native Vegetation) and Protected Areas/Recreation Land Uses Between Sub-Catchments.

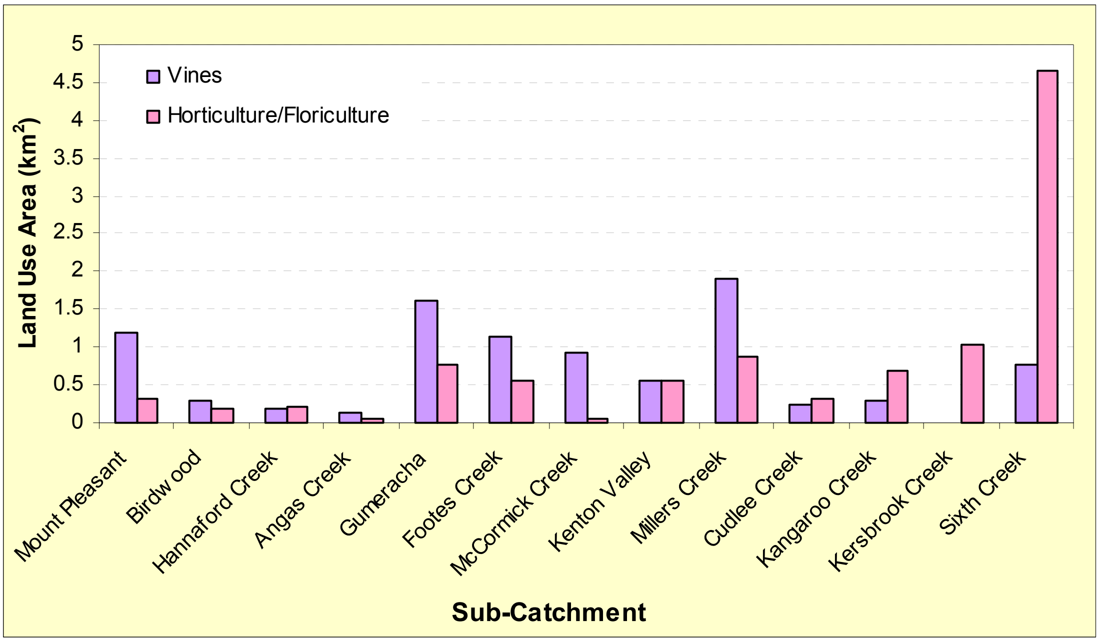


Figure B4 Distribution of Viticulture and Horticulture/Floriculture Land Uses Between Sub-Catchments.

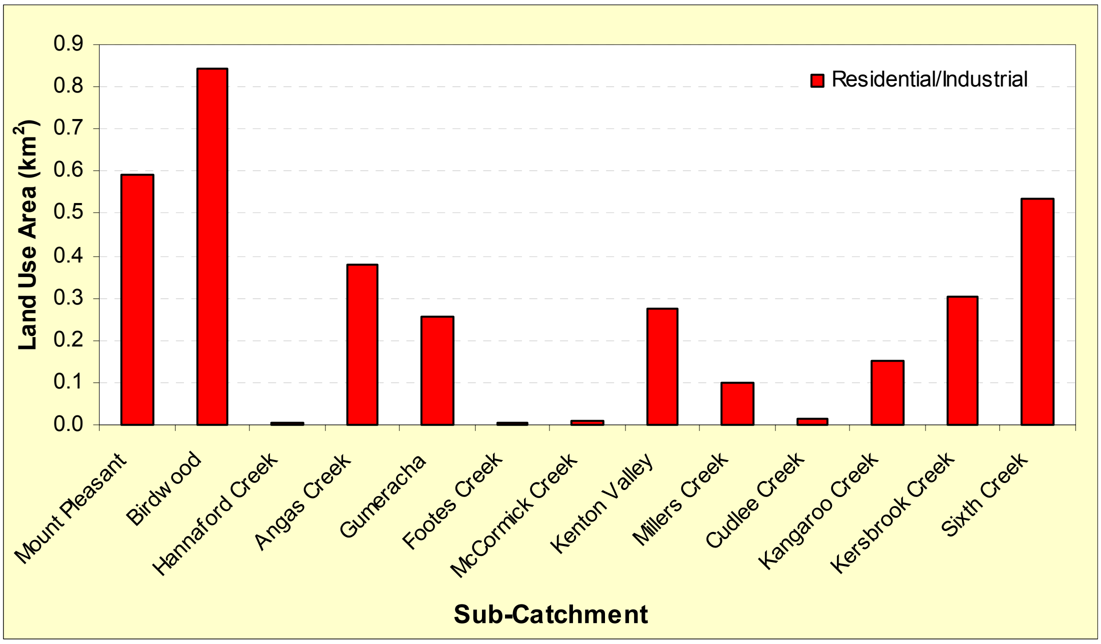


Figure B5 Distribution of Residential/Industrial Land Uses Between Sub-Catchments.

Broadscale grazing is the primary land use within most sub-catchments, with the largest areas and proportions of total sub-catchment area found in Birdwood, Mount Pleasant, Angas Creek, Gumeracha and Millers Creek. The exceptions are in the Sixth Creek, Kersbrook Creek and Kangaroo Creek sub-catchments where the majority of the forestry (native vegetation) and protected/recreation areas are located. These land uses cover large proportions of each of these sub-catchments, although the sizes of the individual areas of broadscale grazing are still comparable to and often more than those in other sub-catchments.

The Kersbrook Creek, Gumeracha and Cudlee Creek sub-catchments have the largest areas of forestry (exotic vegetation) while intensive grazing is found primarily in the Angas Creek, Hannaford Creek and Birdwood sub-catchments. Areas of vines are located mainly in the central portion of the catchment (Millers Creek, Gumeracha and Footes Creek sub-catchments) although in recent years viticulture development has expanded to include the upper portions of the Mount Pleasant and Sixth Creek sub-catchments. The Sixth Creek sub-catchment also has a large proportion of horticulture and floriculture. The distribution of mining across the catchment was not included here because there are only small areas of mining in the entire catchment, the largest of these being the CSR Montacute Quarry in the Kangaroo Creek sub-catchment. The distribution of water bodies is discussed in Section 2.3 and Appendix A on farm dam development.

B.2 Irrigation Requirements

Water usage for irrigation is not monitored in the Upper River Torrens catchment and as such estimates have to be made, usually from land use data as discussed in Section 2.4.2. Areas of land assumed to be irrigated were those containing land uses of intensive grazing, viticulture and horticulture and floriculture with application volumes of 5.5 ML/Ha, 2.0 ML/Ha and 4.0 ML/Ha respectively. This produced a total estimated irrigation requirement of 10,340 ML for an area of 2,780 Ha across the Upper River Torrens catchment. Figure B6 shows the distribution of this estimated irrigation requirement between sub-catchments and indicates that Angas Creek, Sixth Creek, Hannaford Creek and Birdwood have the largest irrigation usage.

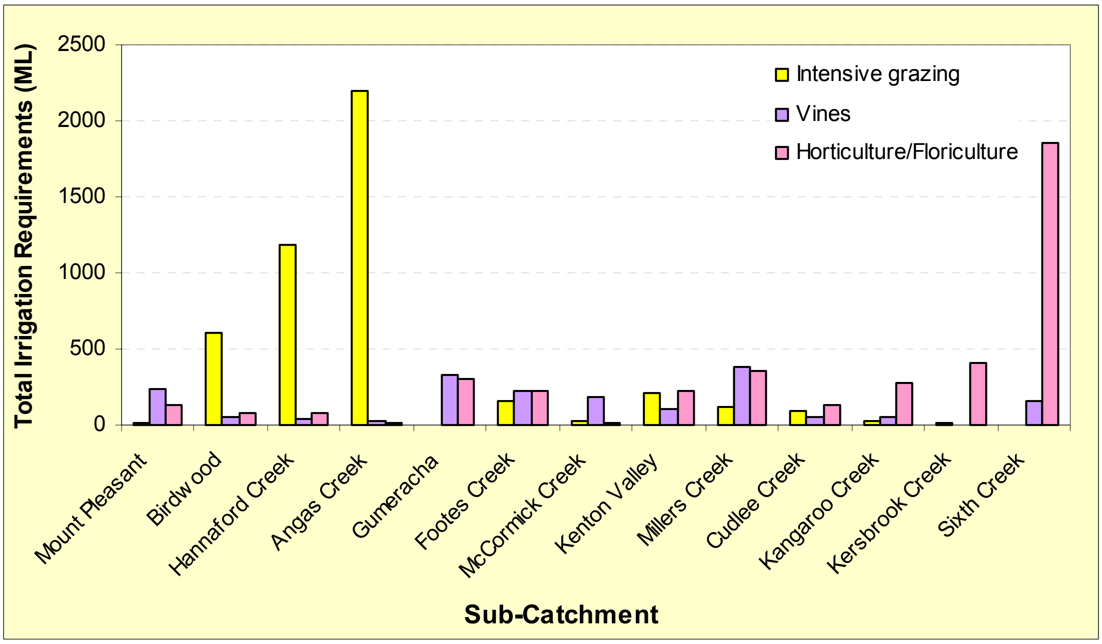


Figure B6 Distribution of Irrigation Requirements Between Sub-Catchments.

APPENDIX C RAINFALL ANALYSIS

C.1 Data Availability and Processing

Daily rainfall data in South Australia is collected by the Bureau of Meteorology (BoM) and DWLBC. Table C1 shows the stations that were used during the data processing stage of the hydrological analysis for the Upper River Torrens catchment. Additional sites (023005, 023027, 023726, 023748, 023829) to those used as input for hydrological modelling (023705, 023719, 023731, 023737, 023750, 023803) were required to disaggregate accumulated data, infill missing data and check the homogeneity of the records (refer below). The choice of additional sites was based on both the length of record and correlation between monthly and daily rainfall values.

Table C1 Rainfall Stations used for Hydrological Analysis.

Station Number	Location	Period of Record	Percentage of Missing (Accumulated) Data
023005	Adelaide (Glen Osmond)	1902-2002	14.3 (4.8)
023027	Adelaide (Thorndon Park)	1902-2002	8.8 (1.0)
023705	Birdwood Department of Transport	1902-2002	3.8 (0.5)
023719	Gumeracha District Council	1902-2002	1.4 (8.2)
023726	Lobethal	1902-2002	1.0 (11.6)
023731	Cudlee Creek (Millbrook)	1914-2002	0.6 (1.4)
023737	Mount Pleasant	1902-2002	2.1 (6.6)
023748	Adelaide (Tea Tree Gully Council)	1902-2002	1.9 (8.9)
023750	Uraidla	1902-2002	0.7 (7.8)
023803	Ashton Co-op	1933-2002	30.8 (2.8)
023829	Woodside	1902-2002	0.4 (6.2)

Table C2 shows the generally high correlation between monthly rainfall values at each pair of stations. Double mass analysis is conducted at a monthly time scale and so correlation at this scale is important. The correlation between daily rainfall values shown in Table C3 is also relatively high. Lower correlations on a daily basis is to be expected due to localised rainfall events. Daily correlations are important when choosing sites to infill missing data, disaggregate accumulated data and for extending data records. Those sites used for these purposes had the highest correlation at a daily scale.

Table C2 Correlation of Monthly Rainfall Between Stations.

	023005	023027	023705	023719	023726	023731	023737	023748	023750	023803	023829
023005	1										
023027	0.948	1									
023705	0.905	0.910	1								
023719	0.917	0.921	0.977	1							
023726	0.921	0.911	0.970	0.967	1						
023731	0.933	0.942	0.967	0.975	0.967	1					
023737	0.875	0.882	0.967	0.946	0.942	0.932	1				
023748	0.937	0.951	0.916	0.929	0.909	0.949	0.892	1			
023750	0.947	0.925	0.930	0.938	0.952	0.957	0.891	0.927	1		
023803	0.953	0.949	0.918	0.926	0.937	0.953	0.875	0.926	0.972	1	
023829	0.903	0.898	0.962	0.949	0.967	0.951	0.947	0.909	0.937	0.916	1

Table C3 Correlation of Daily Rainfall Between Stations.

	023005	023027	023705	023719	023726	023731	023737	023748	023750	023803	023829
023005	1										
023027	0.824	1									
023705	0.724	0.791	1								
023719	0.756	0.820	0.913	1							
023726	0.772	0.773	0.854	0.863	1						
023731	0.768	0.866	0.901	0.931	0.854	1					
023737	0.696	0.745	0.902	0.859	0.820	0.835	1				
023748	0.789	0.889	0.810	0.838	0.777	0.886	0.766	1			
023750	0.825	0.823	0.814	0.836	0.838	0.869	0.764	0.811	1		
023803	0.779	0.831	0.778	0.798	0.768	0.842	0.722	0.813	0.879	1	
023829	0.753	0.759	0.836	0.833	0.907	0.837	0.822	0.761	0.823	0.768	1

Accumulated Data

Accumulated data occurs when a value has not been recorded on a particular day(s) but the cumulative total has been recorded on a subsequent day. These records may be disaggregated over the total number of missing days. SKM (2000) disaggregated the rainfall data at the stations used for this study for the period up to 1998 using the method described in Porter and Ladson (1993). This method was also used to disaggregate the data within the period 1999-2002.

The method assumes that the influence of the rainfall at nearby stations to the station where accumulated data is to be disaggregated is inversely proportional to their distance from the station. Therefore, if station S has rainfall accumulated over m days, and complete data is available from n nearby rainfall stations, the rainfall (R) on day j (where $j=1,\cdots,m$) at station S is given by:

$$R_{jS} = \frac{\sum_{j=1}^{m} R_{jS} \cdot \sum_{k=1}^{n} \{P_{jk} / d_k\}}{\sum_{k=1}^{n} \{1/d_k\}} \qquad \text{(C.1)}$$

where:

$\sum_{j=1}^{m} P_{jS}$ = total rainfall accumulated over m days at station S;

d_k = distance between station S and station k (where $k=1,\cdots,n$); and

P_{jk} = proportion of rainfall that fell on day j at station k.

Using a number of nearby gauges reduces the uncertainty from using data from a single station. For this study, the closest 15 rainfall stations to the station of interest were examined. In each case, data was available from at least one of these stations. If this had not been the case, additional stations could be considered or the data distributed uniformly over the period of accumulation. If the latter method is used and the data is used to calibrate a rainfall-runoff model, comparisons between the observed and modelled streamflow hydrograph resulting from that period of rainfall should be viewed with caution, particularly if the accumulated rainfall volume is large.

Missing Data

Data may be completely missing from a record due to a number of reasons including recording errors, the temporary closing of the station or station relocation. SKM (2000) infilled missing data at stations used for this study for the period up to 1998 using data from a nearby station. The nearby station was chosen as the one with the highest correlation between daily values that had data concurrent with the missing period. To infill the missing period, the daily rainfall value at the nearby station was then adjusted by the ratio of the concurrent mean annual rainfalls of the two stations.

This method may also use more than one nearby station and is referred to as the *normal-ratio method* (McCuen, 1998). If station S has missing data and complete data is available from n nearby rainfall stations, the rainfall (R) at station S is given by (McCuen, 1998):

$$R_S = \sum_{k=1}^{n} \omega_k R_k \qquad \text{(C.2)}$$

where:

$\omega_k \quad = \dfrac{A_S}{n A_k}$;

$A_S \quad =$ average annual rainfall at station S; and

$A_k \quad =$ average annual rainfall at station k (where $k = 1, \cdots, n$).

This method is preferred if differences between the average annual rainfall at the stations are larger than 10%. Differences greater than 10% are observable between stations in the Upper River Torrens catchment. This method was also used to infill data at stations with missing data during the period 1999-2002, using a single nearby station.

Data Consistency

To identify the occurrence, magnitude and nature of trends within long time series records the double mass curve technique (Grayson *et al*., 1996) is often used. It is constructed by plotting the accumulated values of two time series against each other. A break in slope or a gradual change in curvature or slope will reveal a change in the constant proportionality between the two sets of data. This indicates the presence of a trend such as in measured rainfall due to, for example, changes in instrument exposure at a station resulting from the growth of obstructive vegetation. The method is often used to establish the presence of such changes within rainfall records and adjustments can subsequently be made to affected data sets to ensure consistency of record.

The consistency of each rainfall record used for hydrological modelling in this study was confirmed by constructing a double mass curve using an average of the monthly rainfall from eight regional stations. Using an average of a number of records reduces inconsistencies that may be present in any one record.

Although there are no definite guidelines surrounding the magnitude at which a change in slope between two sets of data becomes significant, a change in slope of 5% or more is generally considered to indicate inconsistencies in the data. There are also a number of methods for determining the slope that should be used to correct the inconsistent sections. One alternative is to use the average slope of the entire period of record. However, if there are sudden, very large changes in slope (for example greater than 50%), the overall statistics of the data may not reflect the actual rainfall pattern at that station. In such cases it is preferable to adjust these sections or periods, to the section that is considered to best represent the rainfall pattern at that site. This is often the section with the longest period of consistent data.

This method was used here and the procedure is best explained with an example. Figure C1 shows the double mass curve for Birdwood (023705) against the average of eight regional stations. The process used is then described as follows:

- Changes in slope of the data were determined and eight sections s1 to s8 were defined at this station.
- The average slope within each section was calculated as shown in Table C4.
- The sections with the most consistent and similar slope were defined as the "homogeneous" section of the data, in this case sections s6 to s8, and do not require adjustment. The average slope of these three sections was then calculated.
- The difference of the homogeneous section slope to those in sections s1 to s5 were determined as shown in Table C4;
- The differences between these slopes are considered significant and correction factors calculated. These factors are defined as the ratio of the homogeneous slope to the ratio in each section s1 to s5 and are shown in Table C4.
- The factors were then used to adjust the inconsistent sections s1 to s5 and produce a consistent set of data for the entire period of record.

The data for the stations examined here did not exhibit extremely large changes in slope although there were a number of significant inconsistencies. The procedure described above was carried out on data from each station. The double mass curves with the sections of varying slope are presented for each station in Figures C2 to C6, with the analysis of the slopes and corrections factors in Tables C5 to C9.

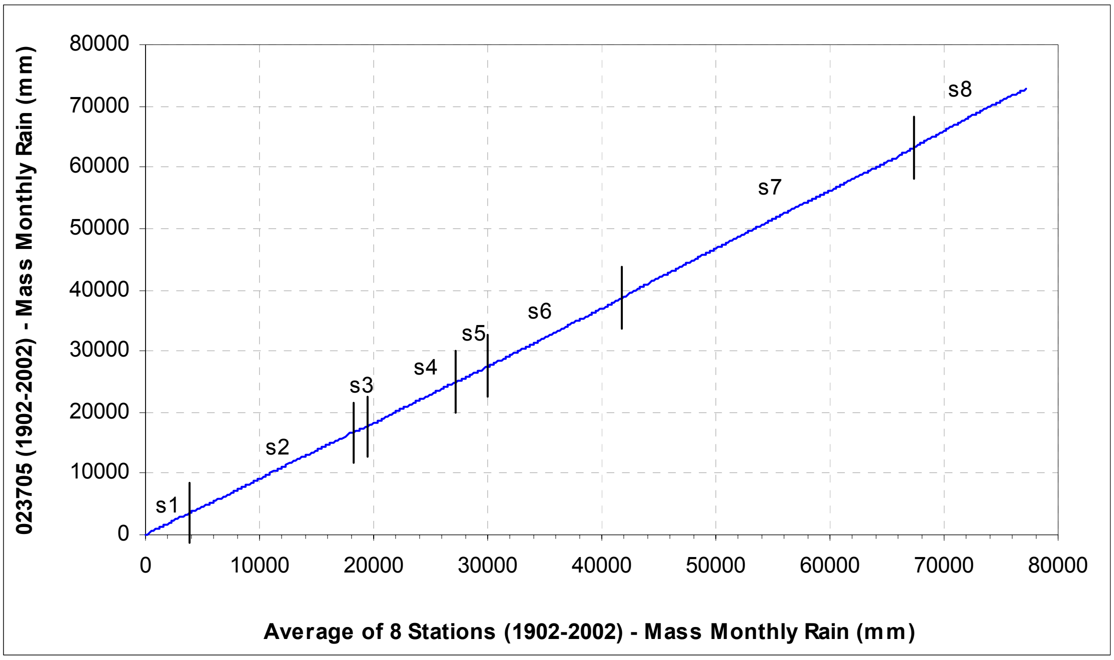


Figure C1 Double Mass Curve for Birdwood (023705) against an Average of Stations 023005, 023027, 023719, 023726, 023737, 023748, 023750 and 023829.

Table C4 Double Mass Analysis for Birdwood (023705).

Section	Section Slope	Difference in Slope to Homogeneous Section (%)[1]	Factor	Section Start	Section End
s1	0.922	-3.913	1.041	01/1902	10/1906
s2	0.914	-4.721	1.050	11/1906	02/1924
s3	0.800	-16.635	1.200	03/1924	08/1925
s4	0.911	-5.009	1.053	09/1925	05/1936
s5	0.891	-7.106	1.076	06/1936	02/1940
s6	0.956	-	1.000	03/1940	05/1955
s7	0.960	-	1.000	06/1955	07/1989
s8	0.969	-	1.000	08/1989	12/2002

[1] Homogenous section for station 023705 is the average slope of sections s6 to s8 and equals 0.960.

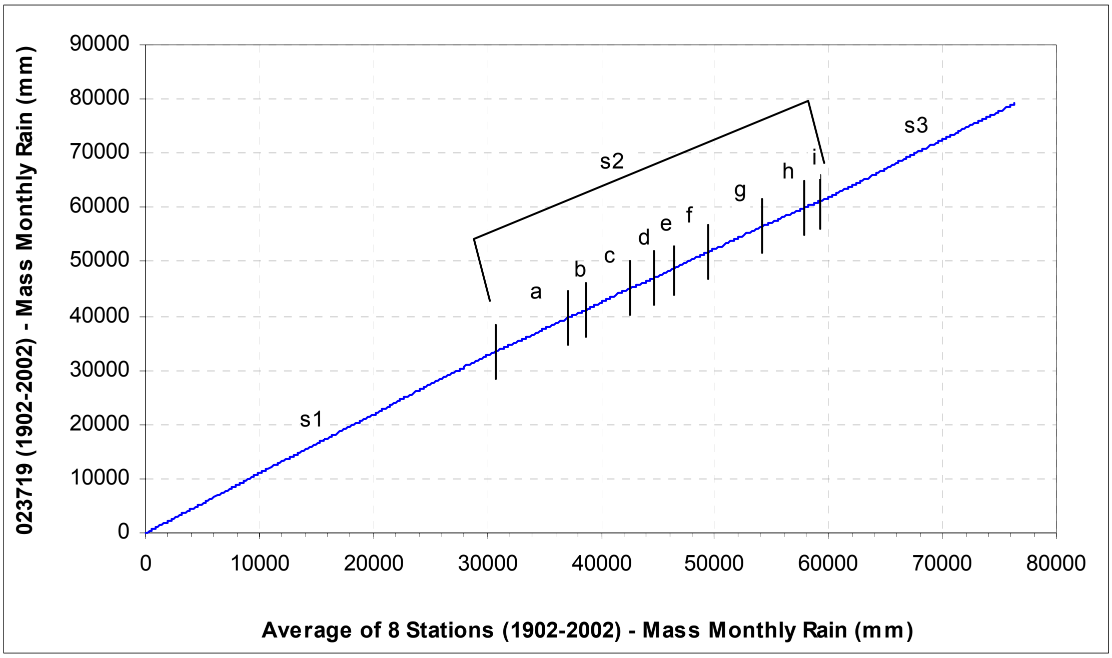


Figure C2 Double Mass Curve for Gumeracha (023719) against an Average of Stations 023005, 023027, 023705, 023726, 023737, 023748, 023750 and 023829.

Table C5 Double Mass Analysis for Gumeracha (023719).

Section	Section Slope	Difference in Slope to Homogeneous Section (%)[1]	Factor	Section Start	Section End
s1	1.087	-	1.000	01/1902	09/1941
s2a	0.989	-9.077	1.100	10/1941	05/1950
s2b	0.910	-16.278	1.194	06/1950	04/1952
s2c	1.021	-6.083	1.065	05/1952	08/1956
s2d	0.903	-16.975	1.204	09/1956	03/1960
s2e	1.006	-7.453	1.081	04/1960	05/1962
s2f	1.004	-7.621	1.082	06/1962	06/1966
s2g	0.998	-8.235	1.090	07/1966	04/1972
s2h	0.925	-14.905	1.175	05/1972	03/1977
s2i	0.897	-17.472	1.212	04/1977	05/1979
s3	1.040	-4.359	1.046	06/1979	12/2002

[1] Homogenous section for station 023719 is the average slope of section s1 and equals 1.087.

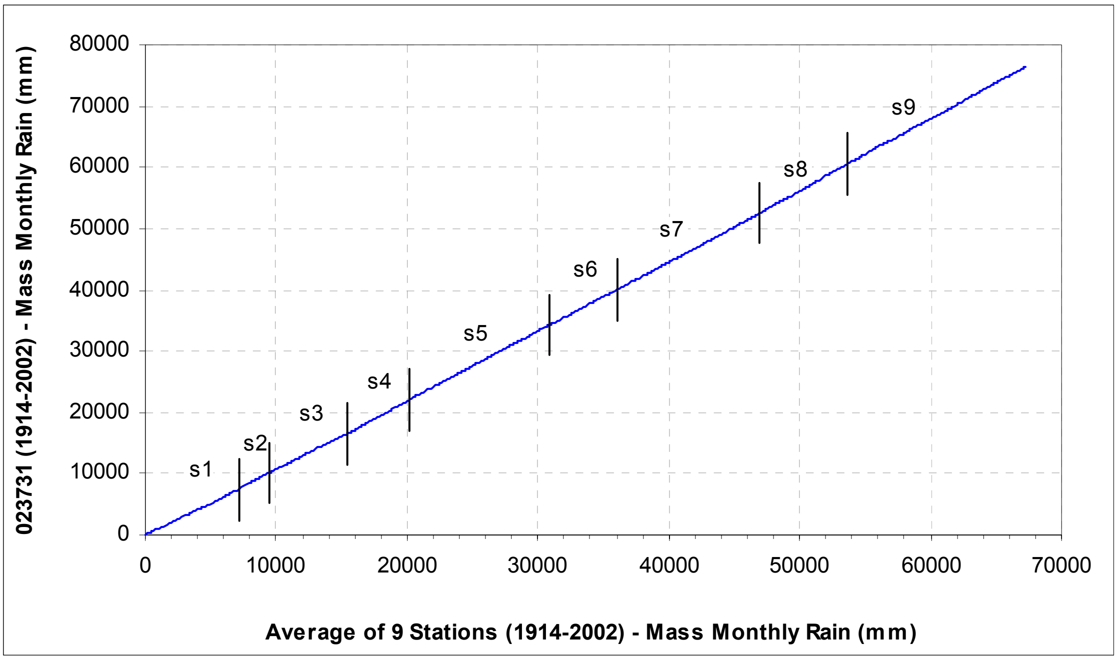


Figure C3 Double Mass Curve for Cudlee Creek (023731) against an Average of Stations 023005, 023027, 023705, 023719, 023726, 023737, 023748, 023750 and 023829.

Table C6 Double Mass Analysis for Cudlee Creek (023731).

Section	Section Slope	Difference in Slope to Homogeneous Section (%)[1]	Factor	Section Start	Section End
s1	1.046	-8.162	1.089	01/1914	08/1922
s2	1.150	0.996	0.990	09/1922	04/1925
s3	1.064	-6.544	1.070	05/1925	04/1933
s4	1.176	3.285	0.968	05/1933	10/1939
s5	1.139	-	1.000	11/1939	10/1953
s6	1.118	-1.863	1.019	11/1953	07/1960
s7	1.142	0.312	0.997	08/1960	08/1974
s8	1.200	5.381	0.949	09/1974	05/1984
s9	1.166	2.357	0.977	06/1984	12/2002

[1] Homogenous section for station 023731 is the average slope of section s5 and equals 1.139. An alternative homogenous section was evaluated as the average slope of sections s2, s5, s6, s7 and s9 and equals 1.146. This produced similar results to using s5 alone.

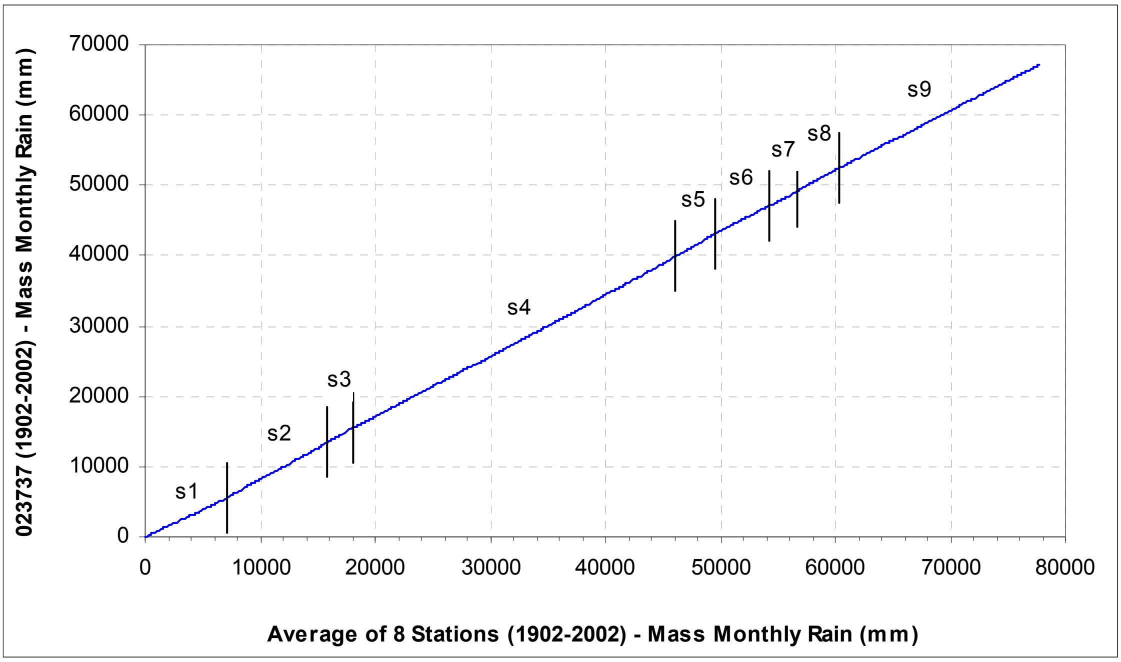


Figure C4 Double Mass Curve for Mount Pleasant (023737) against an Average of Stations 023005, 023027, 023705, 023719, 023726, 023748, 023750 and 023829.

Table C7 Double Mass Analysis for Mount Pleasant (023737).

Section	Section Slope	Difference in Slope to Homogeneous Section (%)[1]	Factor	Section Start	Section End
s1	0.773	-11.110	1.125	01/1902	05/1910
s2	0.911	4.724	0.955	06/1910	08/1921
s3	0.930	6.983	0.935	09/1921	10/1923
s4	0.870	-	1.000	11/1923	07/1960
s5	0.966	11.109	0.900	08/1960	04/1965
s6	0.842	-3.122	1.032	05/1965	04/1971
s7	0.851	-2.108	1.022	05/1971	02/1974
s8	0.896	3.061	0.970	03/1974	07/1979
s9	0.844	-2.928	1.030	08/1979	12/2002

[1] Homogenous section for station 023737 is the average slope of sections s4 and equals 0.870.

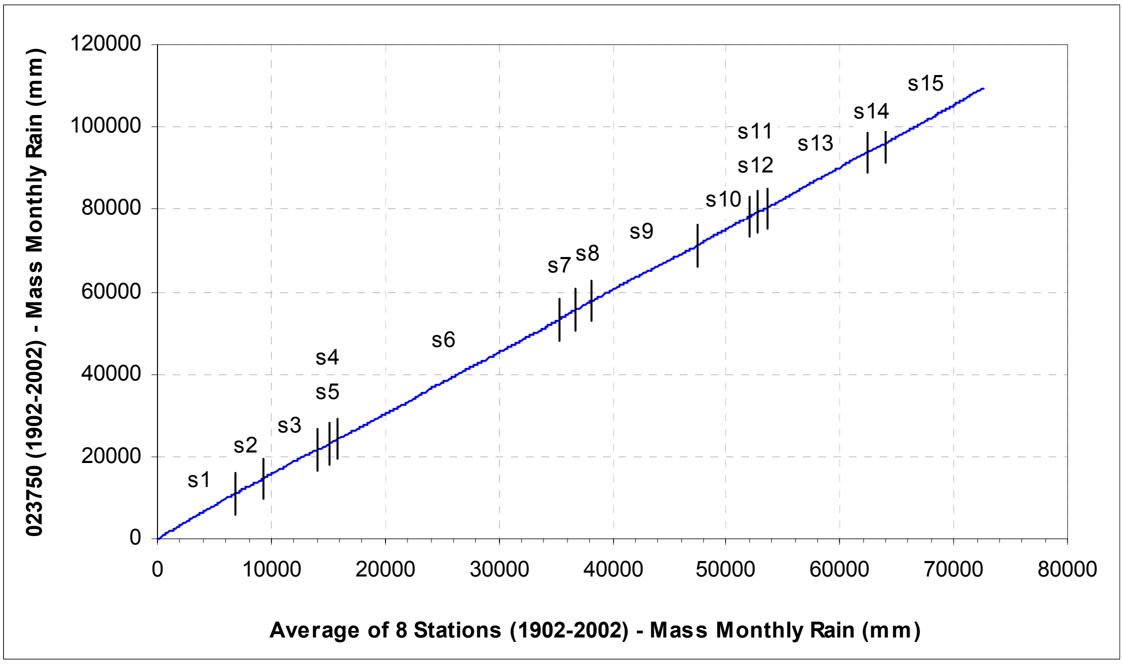


Figure C5 Double Mass Curve for Uraidla (023750) against an Average of Stations 023005, 023027, 023705, 023719, 023726, 023737, 023748 and 023829.

Table C8 Double Mass Analysis for Uraidla (023750).

Section	Section Slope	Difference in Slope to Homogeneous Section (%)[1]	Factor	Section Start	Section End
s1	1.620	7.369	0.931	01/1902	09/1910
s2	1.418	-6.018	1.064	10/1910	04/1915
s3	1.489	-1.321	1.013	05/1915	10/1920
s4	1.363	-9.692	1.107	11/1920	04/1922
s5	1.591	5.452	0.948	05/1922	04/1923
s6	1.492	-1.091	1.011	05/1923	04/1950
s7	1.626	7.783	0.928	05/1950	03/1952
s8	1.528	1.264	0.988	04/1952	10/1953
s9	1.453	-3.670	1.038	11/1953	11/1966
s10	1.522	0.902	0.991	12/1966	01/1973
s11	1.493	-1.012	1.010	02/1973	12/1973
s12	1.123	-25.573	1.344	01/1974	09/1974
s13	1.539	1.984	0.981	10/1974	04/1988
s14	1.366	-9.486	1.105	05/1988	07/1990
s15	1.573	4.289	0.959	08/1990	12/2002

[1] Due to the many sections identified in this record, no single homogenous section was chosen. Instead, the average slope of the entire record for station 023750 was used and equals 1.509.

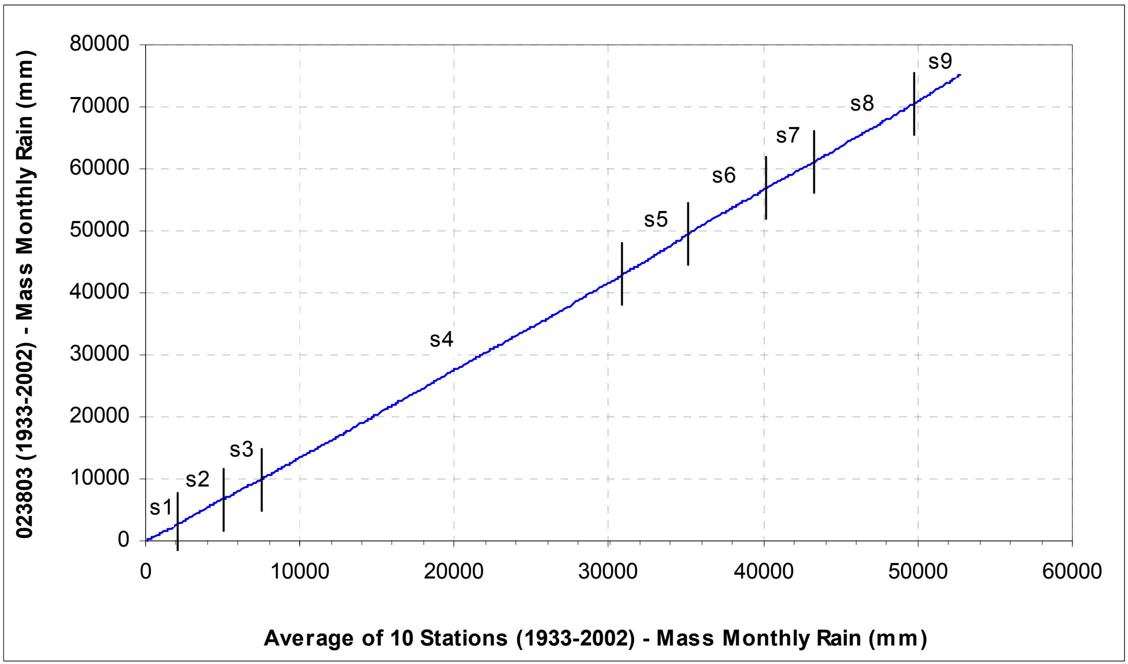


Figure C6 Double Mass Curve for Ashton Co-op (023803) against an Average of Stations 023005, 023027, 023705, 023719, 023726, 023737, 023748, 023750 and 023829.

Table C9 Double Mass Analysis for Ashton Co-op (023803).

Section	Section Slope	Difference in Slope to Homogeneous Section (%)[1]	Factor	Section Start	Section End
s1	1.278	-9.572	1.106	01/1933	09/1935
s2	1.397	-1.138	1.012	10/1935	10/1939
s3	1.264	-10.581	1.118	11/1939	12/1942
s4	1.413	-	1.000	01/1943	05/1973
s5	1.537	8.744	0.920	06/1973	04/1979
s6	1.453	2.854	0.972	05/1979	03/1986
s7	1.383	-2.103	1.021	04/1986	05/1990
s8	1.447	2.366	0.977	06/1990	10/1998
s9	1.575	11.461	0.897	11/1998	12/2002

[1] Homogenous section for station 023803 is the average slope of sections s4 and equals 1.413.

C.2 *Data Analysis*

Analysis of the rainfall data at each of the stations to be used in the hydrological model was undertaken at annual, monthly and decadal time scales. In addition, the statistics and trends of the rainfall from stations used to disaggregate accumulated data, infill missing data and for homogeneity analysis were also examined.

Annual Rainfall

The mean and median annual rainfall and the standard deviation of the mean annual rainfall for each station is shown in Table C10. Figures C7 to C12 then show the annual rainfall trends and residual mass curves for the rainfall from stations used for catchment modelling. As indicated in Section 3.1.2, the results are similar at all locations with decreasing trends in annual rainfall over the last 100 years. In addition, the results for data from the other station locations shown in Table C10 were similar to those shown here, indicating significant regional trends.

Table C10 Annual Statistics

Station	Mean (mm)	Median (mm)	Standard Deviation (mm)
Glen Osmond (023005)	627	618	135
Thorndon Park (023027)	581	565	133
Birdwood (023705)	734	739	169
Gumeracha (023719)	823	814	184
Lobethal (023726)	884	889	198
Cudlee Creek (023731)	859	863	196
Mount Pleasant 023737)	668	657	160
Tea Tree Gully (023748)	669	642	157
Uraidla (023750)	1083	1067	237
Ashton (023803)	1064	1054	229
Woodside (023829)	804	796	187

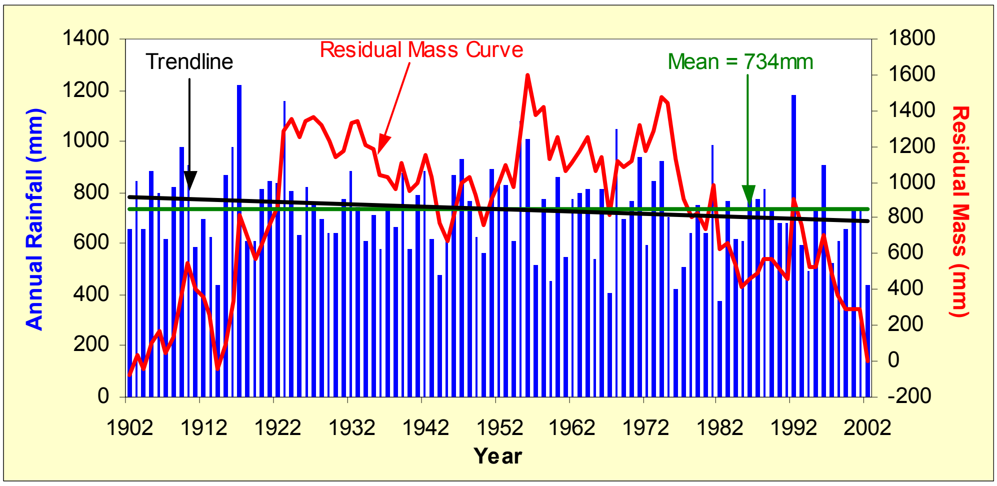


Figure C7 Annual Rainfall Totals and Variability at Birdwood (023705).

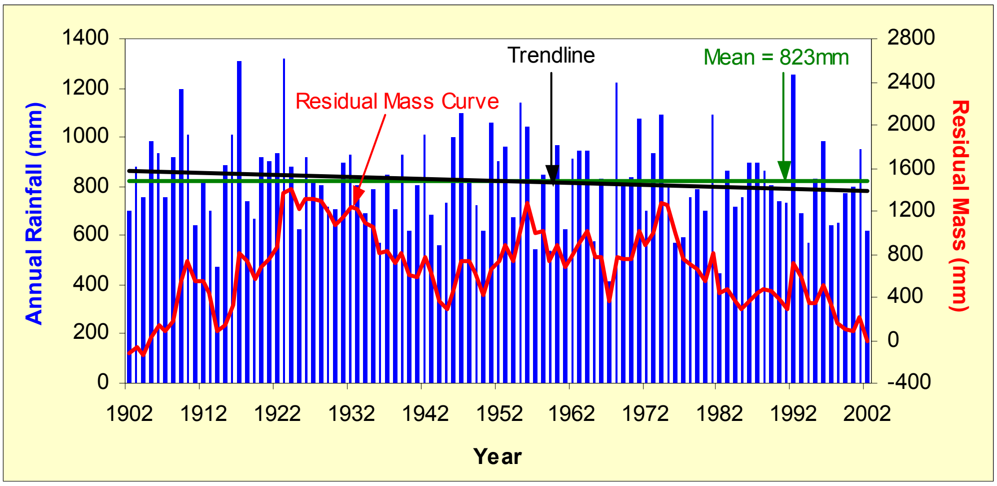


Figure C8 Annual Rainfall Totals and Variability at Gumeracha (023719).

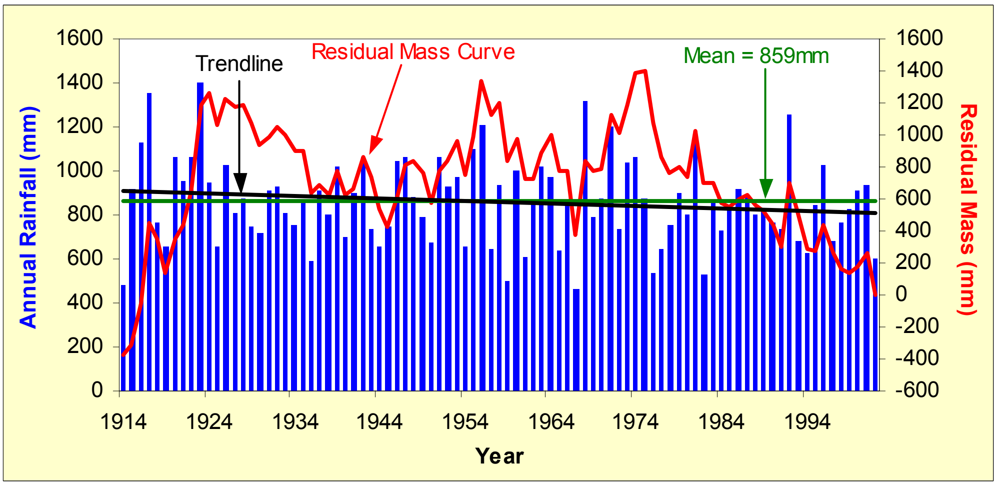


Figure C9 Annual Rainfall Totals and Variability at Cudlee Creek (023731).

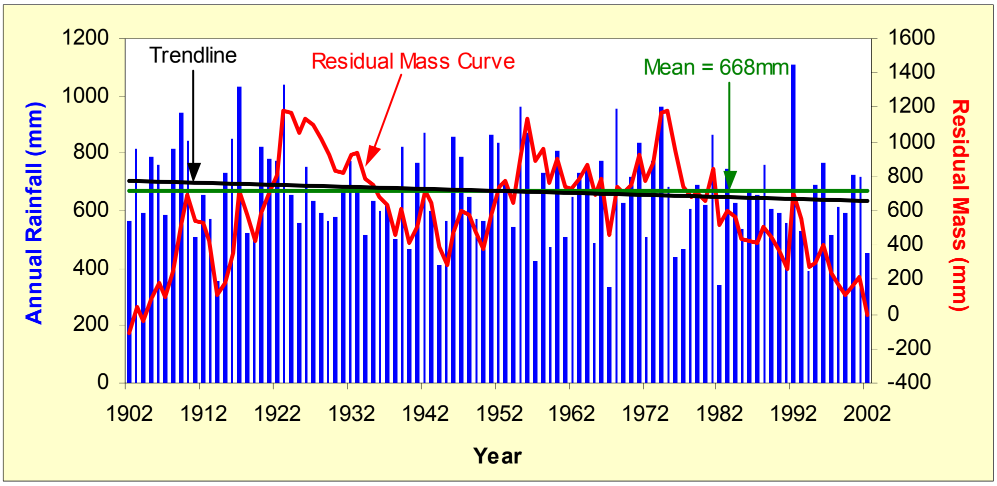


Figure C10 Annual Rainfall Totals and Variability at Mount Pleasant (023737).

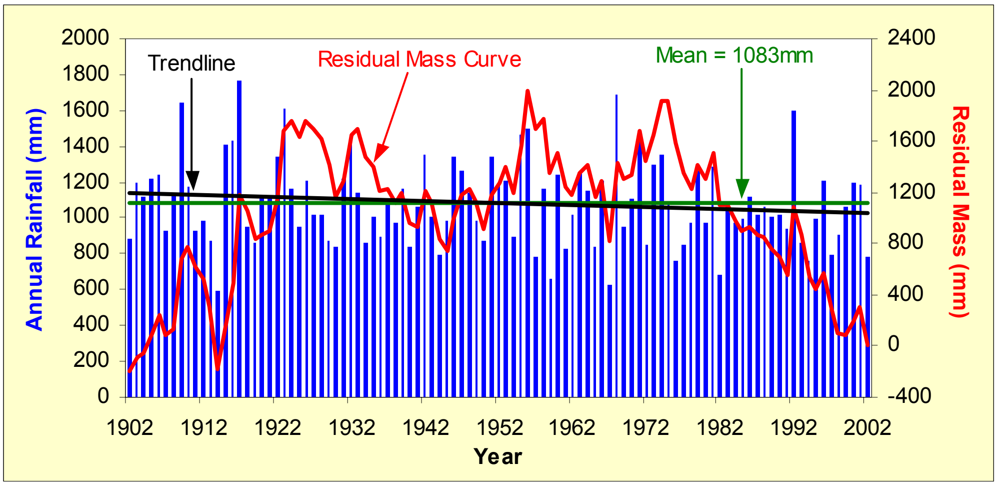


Figure C11 Annual Rainfall Totals and Variability at Uraidla (023750).

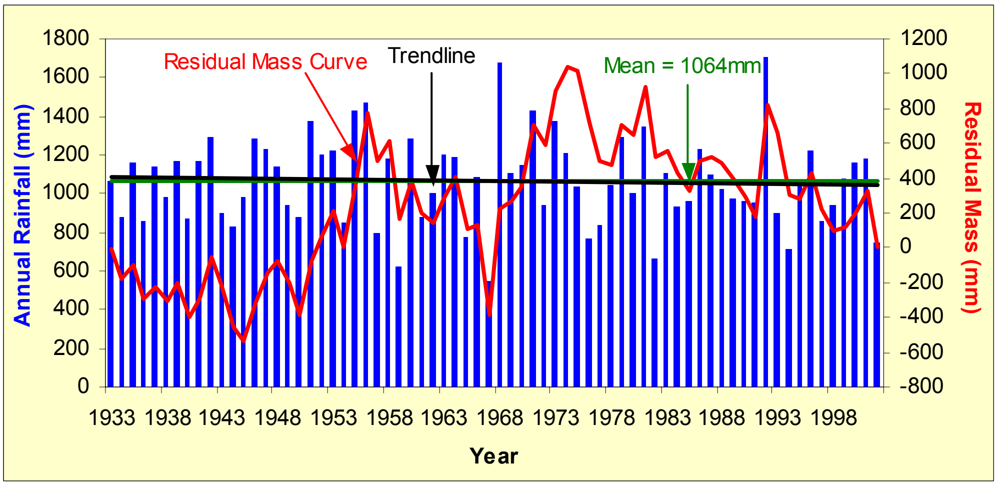


Figure C12 Annual Rainfall Totals and Variability at Ashton (023803).

Monthly Rainfall

The monthly residual mass curves for the rainfall from each station used for catchment modelling are shown in Figures C13 to C18. As discussed previously in Section 3.1.2, the trends found in the June rainfall appear at all locations shown here. These appear to have the dominant influence on the trends in annual rainfall and may lead to a delay in the onset of winter rainfall and subsequent runoff. The trends in the May and September rainfall are also apparent at each of the sites. The apparent differences seen in the data from Ashton (023803) shown in Figure C18 are due to the data commencing in 1933. However, the downward trend from around 1935 to 1955 is clearly seen here as for the other locations.

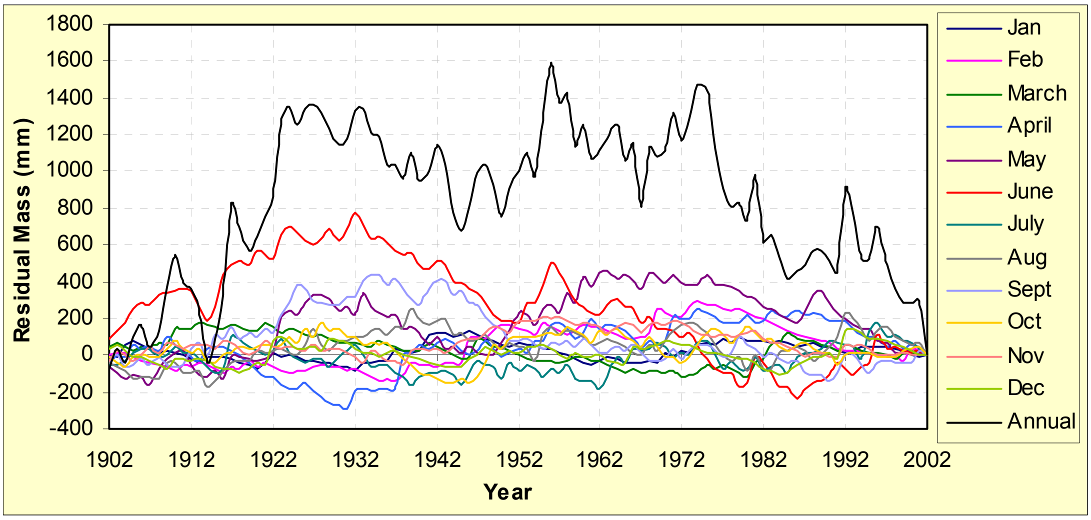


Figure C13 Monthly Residual Mass Curve for Birdwood (023705).

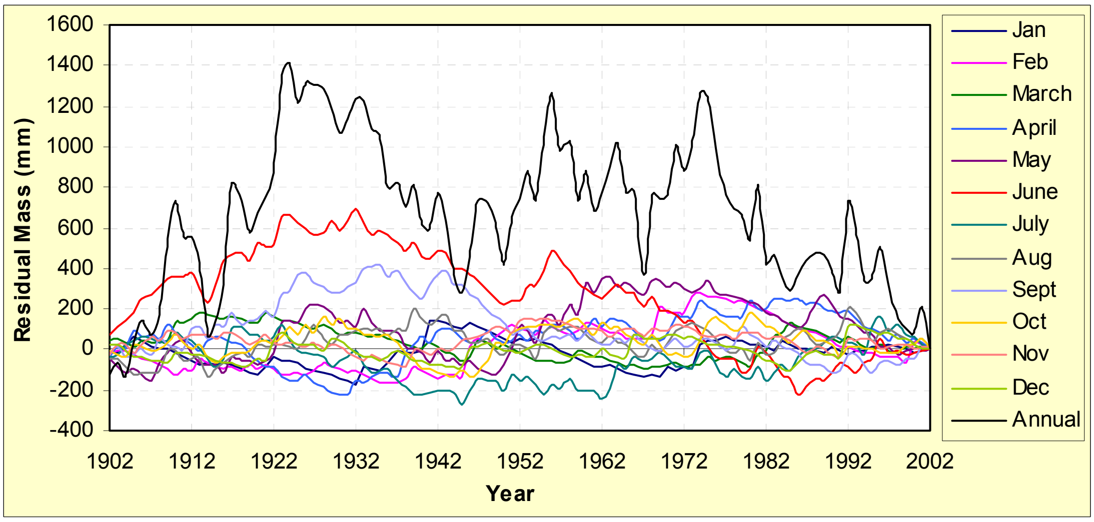


Figure C14 Monthly Residual Mass Curve for Gumeracha (023719).

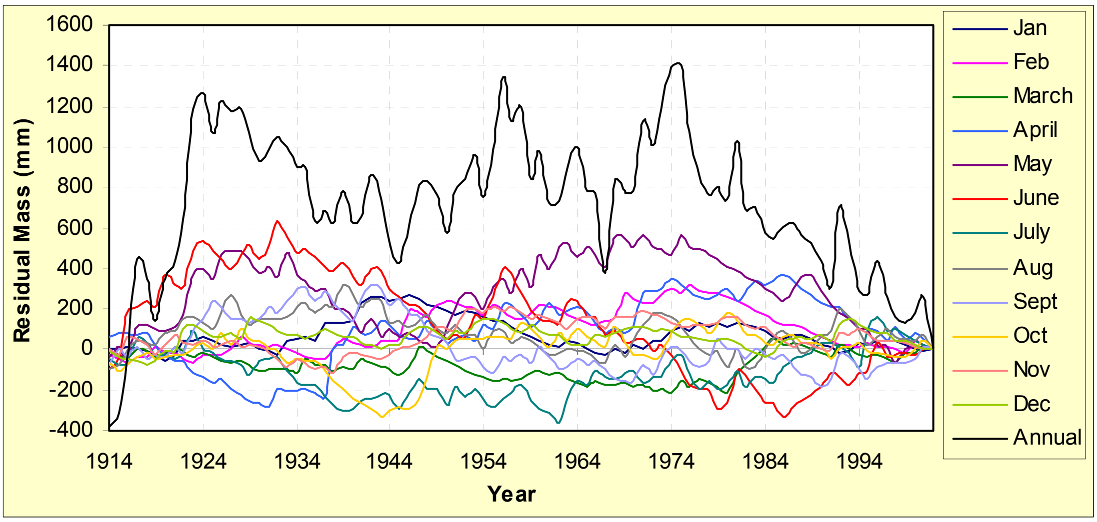


Figure C15 Monthly Residual Mass Curve for Cudlee Creek (023731).

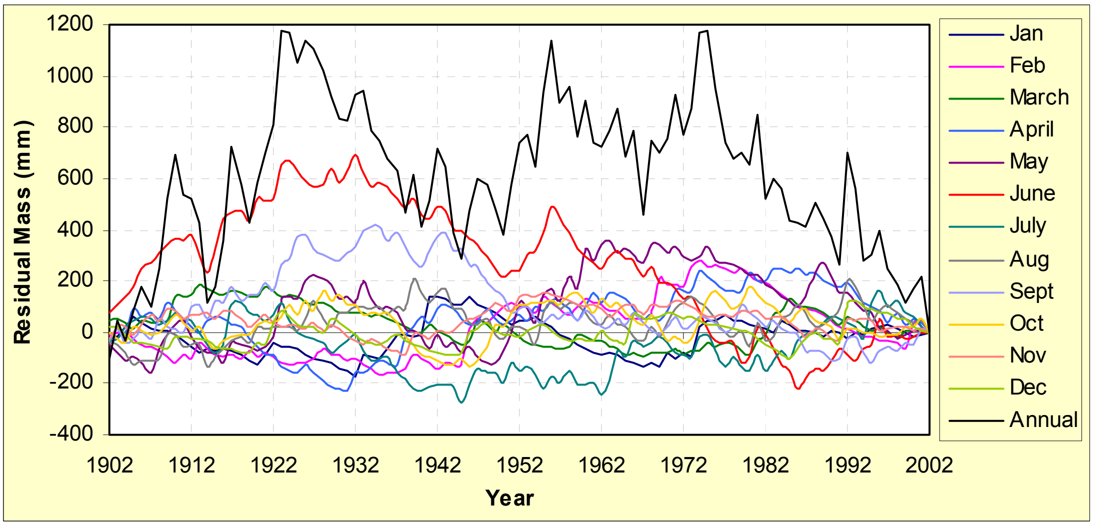


Figure C16 Monthly Residual Mass Curve for Mount Pleasant (023737).

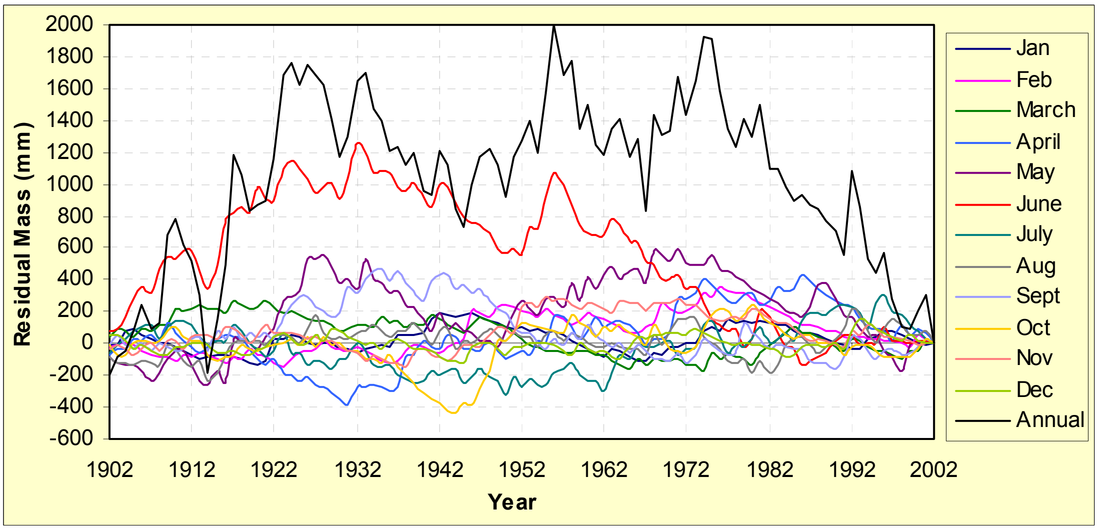


Figure C17 Monthly Residual Mass Curve for Uraidla (023750).

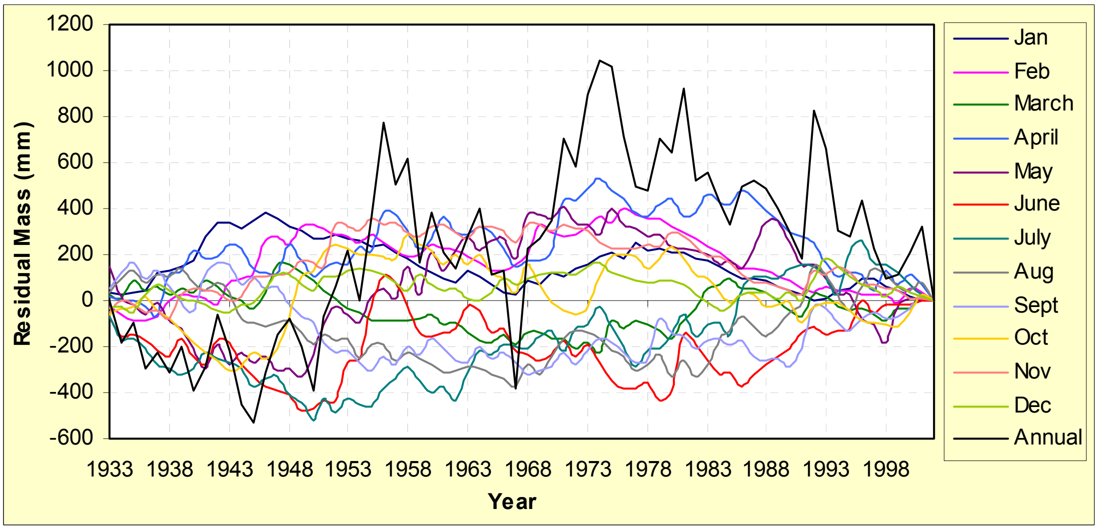


Figure C18 Monthly Residual Mass Curve for Ashton (023803).

Section 3.1.2 also presented the long term decreasing trend evident in the May and June monthly totals in the average catchment rainfall. Figures C19 to C24 present the most prominent trends from each station used for modelling. A decreasing trend in June monthly totals was evident for almost all stations. The only exception to this decreasing June trend was for Ashton (023803) where a slight increase in June rainfall and decrease in April and May rainfall was evident. This may be due to a shortened record beginning at 1933 rather than 1902. Although May and September rainfall also showed a long term decreasing trend at a number of stations, it was usually not as significant as for June rainfall. July showed a slight increasing trend at some stations (023719, 023731, 023803).

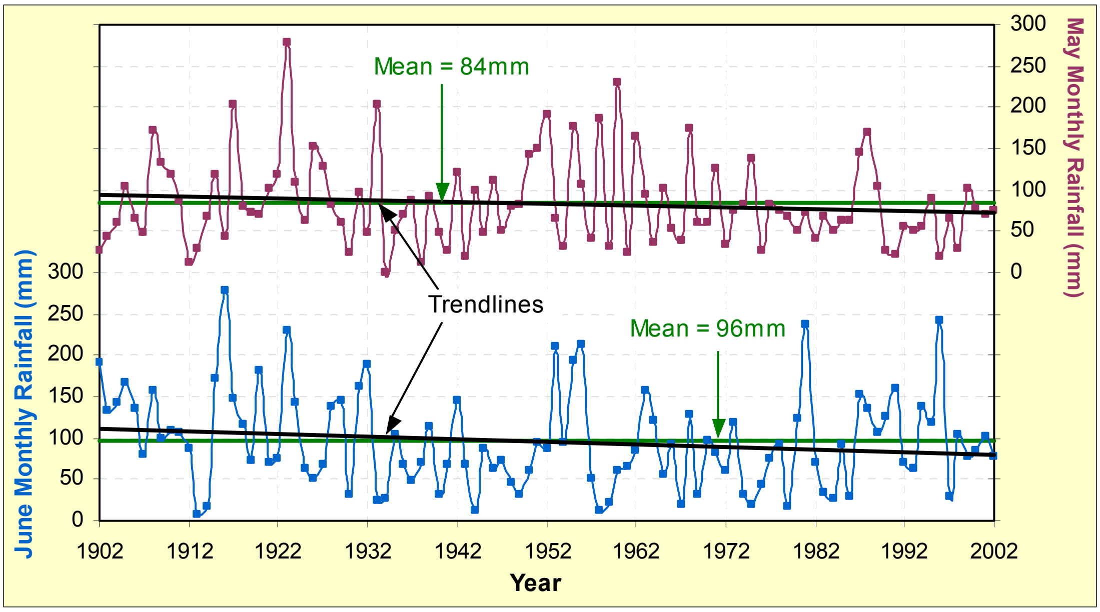


Figure C19 May and June Monthly Rainfall Totals and Trends for Birdwood (023705).

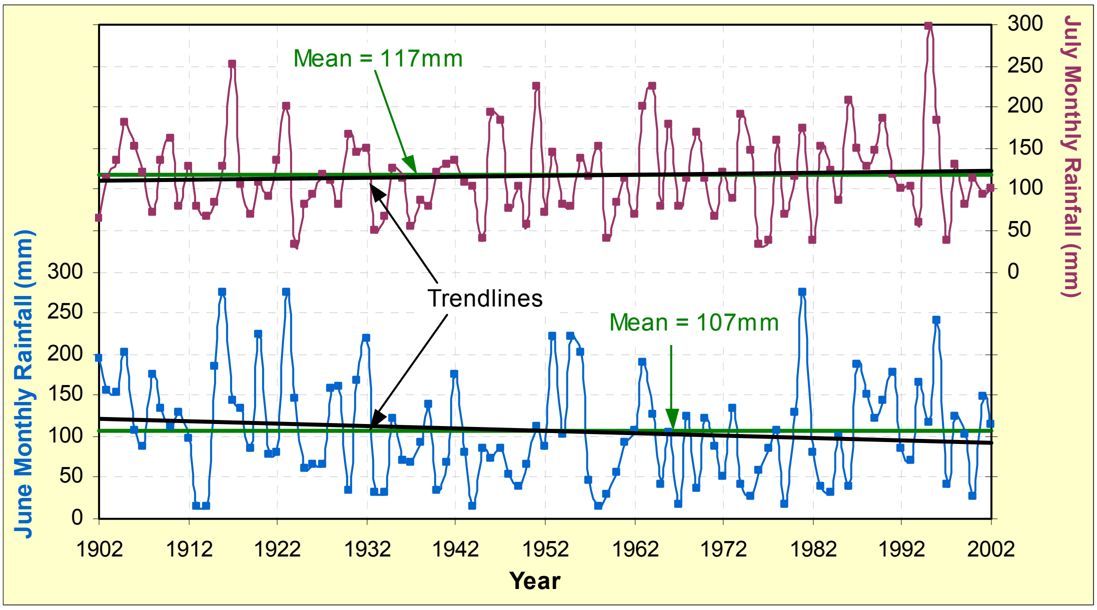


Figure C20 June and July Monthly Rainfall Totals and Trends for Gumeracha (023719).

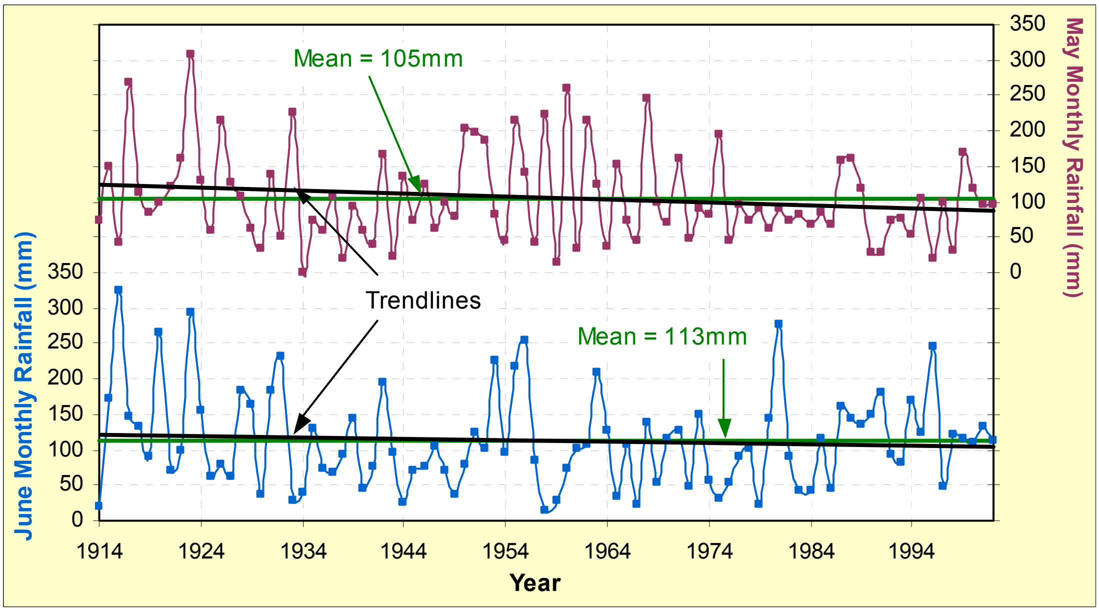


Figure C21   May and June Monthly Rainfall Totals and Trends for Cudlee Creek (023731).

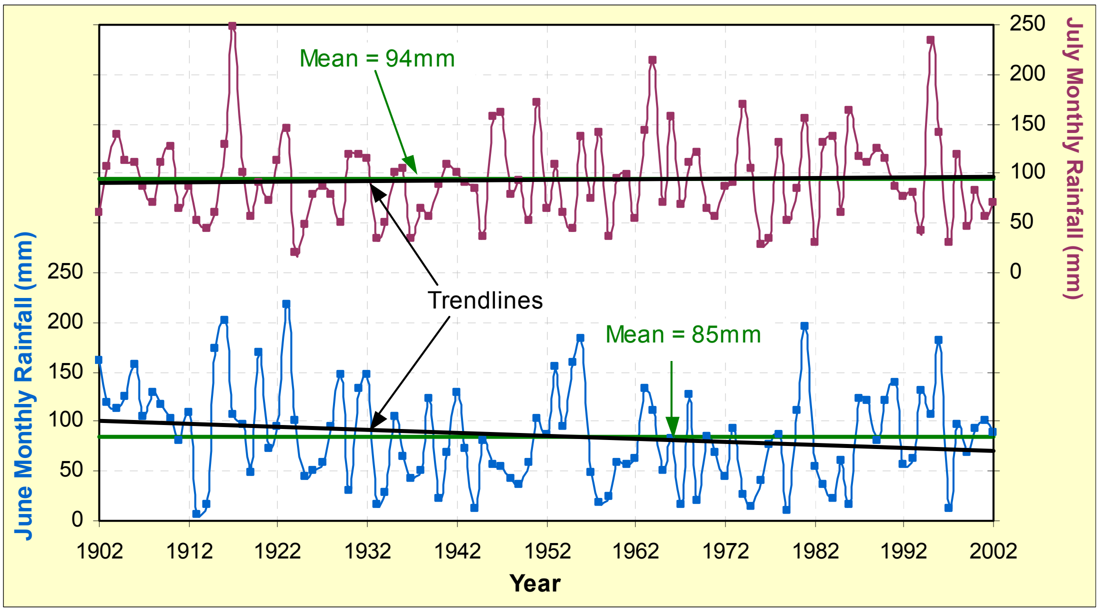


Figure C22   June and July Monthly Rainfall Totals and Trends for Mount Pleasant (023737).

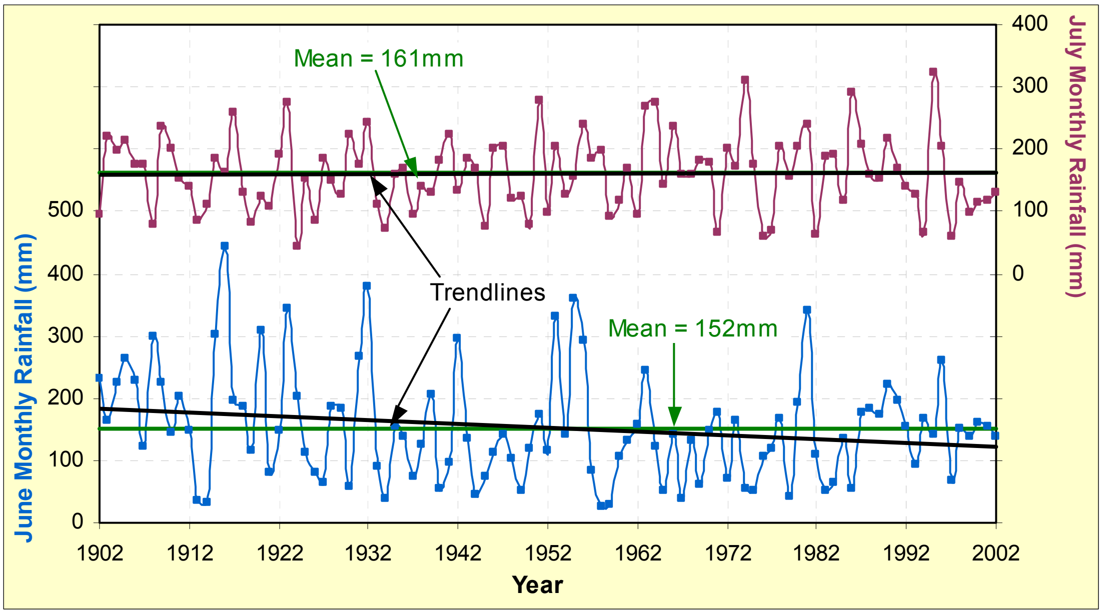


Figure C23 June and July Monthly Rainfall Totals and Trends for Uraidla (023750).

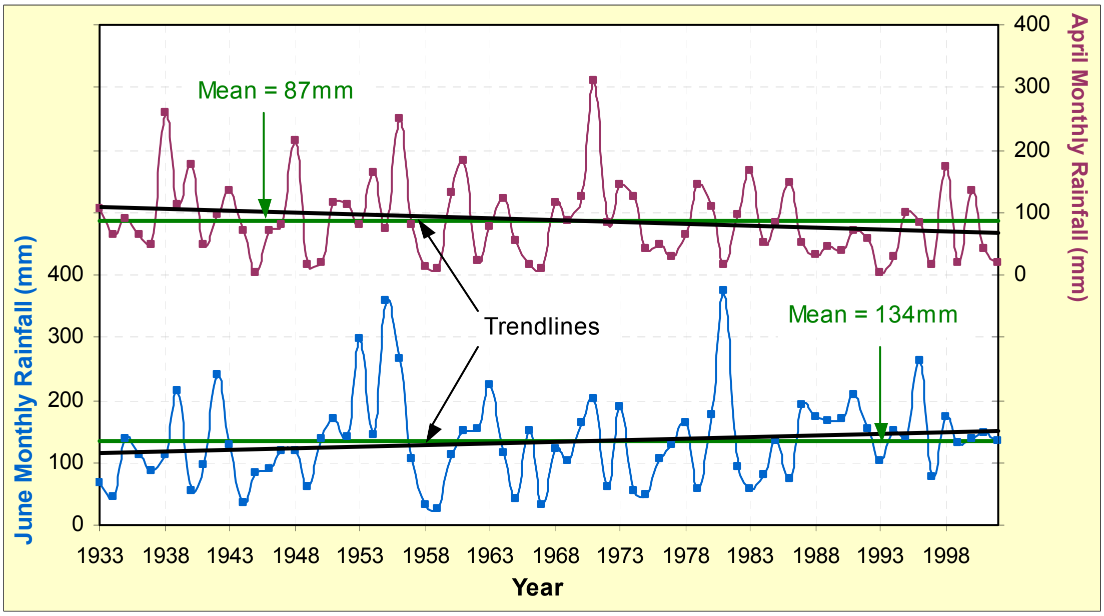


Figure C24 June and July Monthly Rainfall Totals and Trends for Ashton (023803).

Decadal Rainfall Analysis

A decadal rainfall analysis of the data at each site used for catchment modelling revealed significant statistical trends as was discussed in Section 3.1.2. Figures C25 to C30 show this analysis for data from the stations used for catchment modelling. In each case, average rainfall was significantly above the long term mean in the ten year periods 1916 to 1925, 1946 to 1955, 1966 to 1975 and below the long term mean in the periods 1936 to 1945, 1956 to 1965 and 1976 to 1985. The ten year moving average clearly highlights the high (peaks) and low (troughs) rainfall decades with successive above average rainfall peaks in both the ten year moving average and the mean decade rainfall decreasing over the last 100 years.

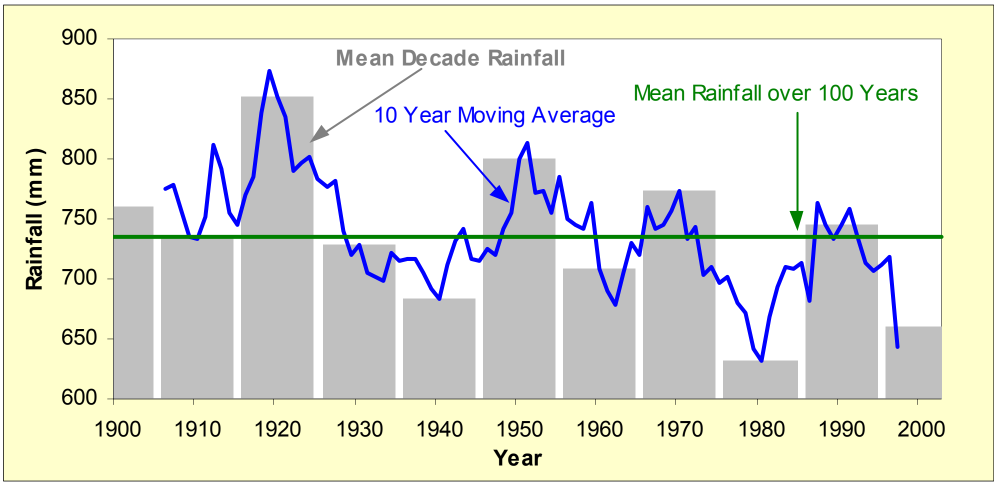


Figure C25 Decadal Rainfall Pattern for Birdwood (023705).

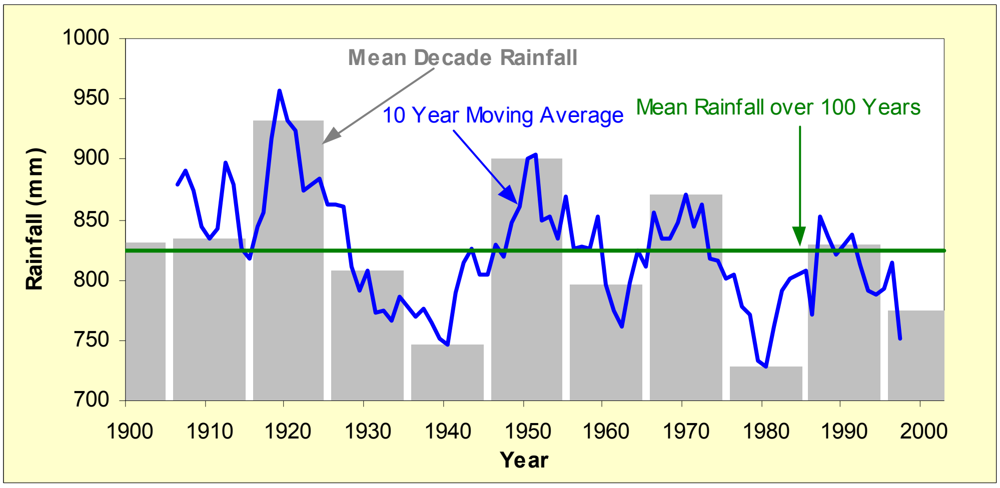


Figure C26 Decadal Rainfall Pattern for Gumeracha (023719).

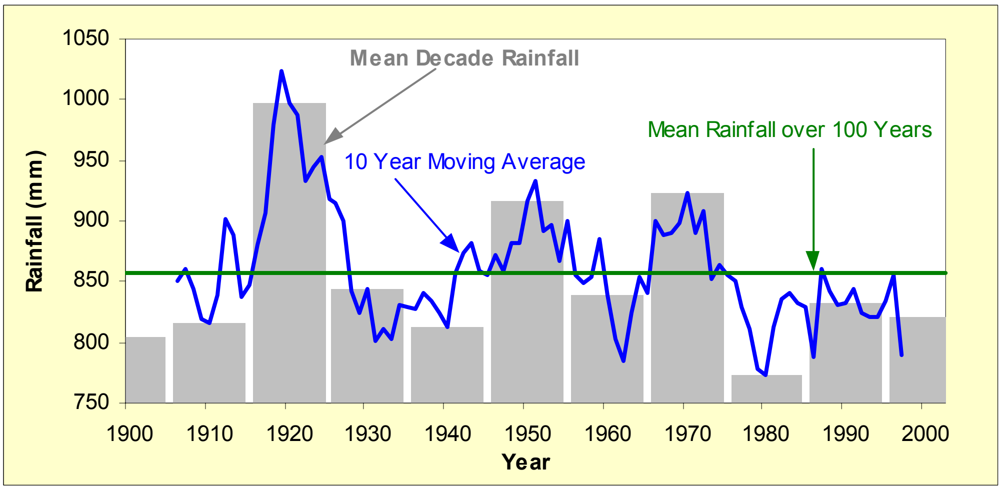


Figure C27 Decadal Rainfall Pattern for Cudlee Creek (023731).

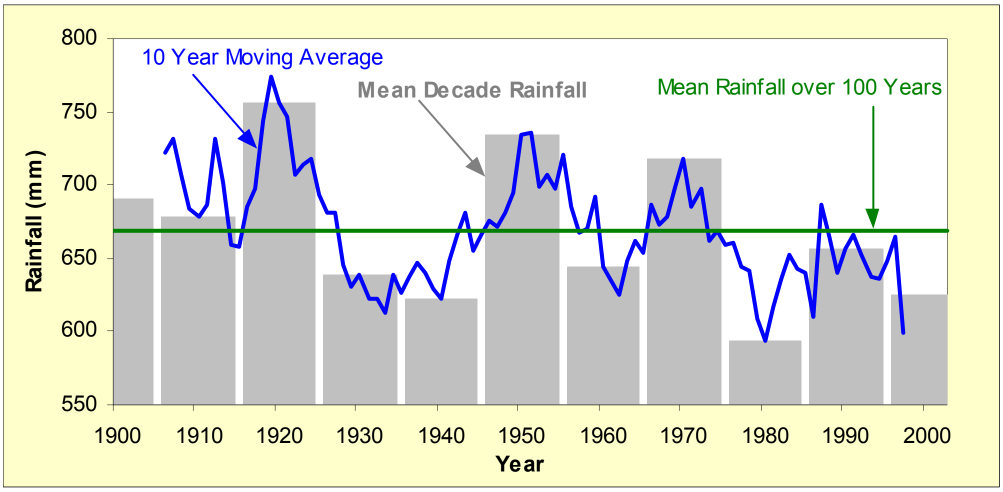


Figure C28 Decadal Rainfall Pattern for Mount Pleasant (023737).

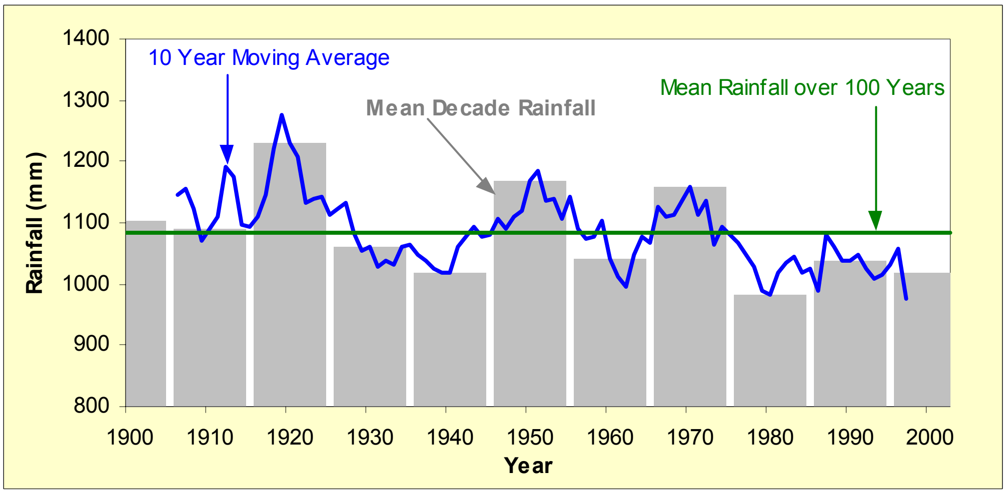


Figure C29 Decadal Rainfall Pattern for Uraidla (023750).

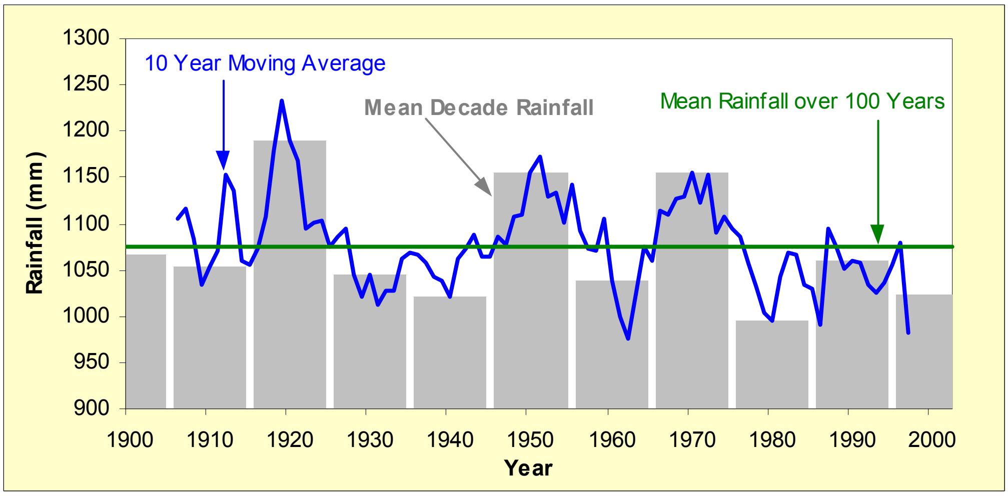


Figure C30 Decadal Rainfall Pattern for Ashton (023803).

APPENDIX D EVAPORATION

Evaporation is the transfer of moisture into the atmosphere, whether from a free water surface such as a dam or reservoir, a soil surface or by the process of transpiration from plants. Accurate estimates are essential for hydrologic water-balance calculations because it influences the amount of rainfall that is intercepted by vegetation and absorbed by the soil before surface runoff will occur, or captured by dams and reservoirs before they fill, overflow and upstream runoff will move down through the catchment.

D.1 Data Generation Method

Evaporation data (mm/day) was generated using the Priestley-Taylor method (Priestley and Taylor, 1972), using sunshine hours data and temperature data. This is a radiation based model and can be written as:

$$E_p = \frac{\alpha\ (R_n + G)\,\Delta}{\lambda\,(\Delta + \gamma)} \tag{D.1}$$

where:

R_n = net radiation at the surface (MJ m^{-2} d^{-1});

G = soil heat flux (MJ m^{-2} d^{-1});

α = constant, equal to 1.3 for Australian conditions (Bates, 2000);

Δ = slope of the saturation vapour pressure versus temperature curve (kPa °C^{-1});

λ = latent heat of vaporisation of water (MJ kg^{-1}); and

γ = psychrometric constant (kPa °C^{-1});

Solar radiation is not widely monitored in Australia and often has to be estimated, spatially interpolated or extrapolated using relationships between solar radiation and sunshine hours and temperature. In this case, a method using sunshine hours and temperature was used. A complete description and equations used are described in Heneker (2002) and uses information from Smith (1991), Shuttleworth (1993), Allen *et al*. (1998) and Bates (2000).

D.2 Data Availability and Processing

Daily sunshine hours data and temperature data is collected by the Bureau of Meteorology (BoM). Table D1 shows the stations that were used during the data processing stage to calculate an evaporation data set. Sites 023321 and 023373 measuring sunshine hours and temperature were directly used in the evaporation calculations, with temperature data from other sites (023020, 023343) and cloud cover data (023321, 023343, 023373) used to infill missing data (described below).

Table D1 Climate Stations used for Calculating Evaporation.

Station Number	Location	Data Type	Period of Record	Percentage of Missing Data
023020	Roseworthy Agricultural College	Temperature	01/1957-06/1997	14.7
023321	Nuriootpa Comparison	Sunshine Hours	01/1959-03/1999	0.3
		Cloud Cover	01/1957-02/1999	0.1
		Temperature	01/1957-02/1999	0.3
023343	Rosedale (Turretfield)	Cloud Cover	01/1962-08/2000	0.9
		Temperature	01/1962-12/2002	1.9
023373	Nuriootpa Viticultural	Sunshine Hours	03/1999-12/2002	0.5
		Cloud Cover	09/1996-12/2002	0.4
		Temperature	09/1996-12/2002	2.0

Missing Data

Missing sunshine hours records were estimated from a fitted third order polynomial (Chiew and McMahon, 1991) between sunshine hours data and cloud cover data at the same location (where possible). Because of concurrent missing data in the sunshine and cloud cover data from Nuriootpa Comparison (023321), cloud cover data from Rosedale (023343) was required to infill a small number of missing values. Regression relationships were required for each month to ensure a reasonable correlation between variables. Figures D1 and D2 show these relationships between the sunshine and cloud cover data at Nuriootpa Comparison (023321) for January and September. Although there appears a reasonable spread of values for each month, the majority of values lie around the curves. Cloud cover data is the average value of between one and eight measurements for each day. Days with only one measurement have the potential to deviate further from the regression relationship.

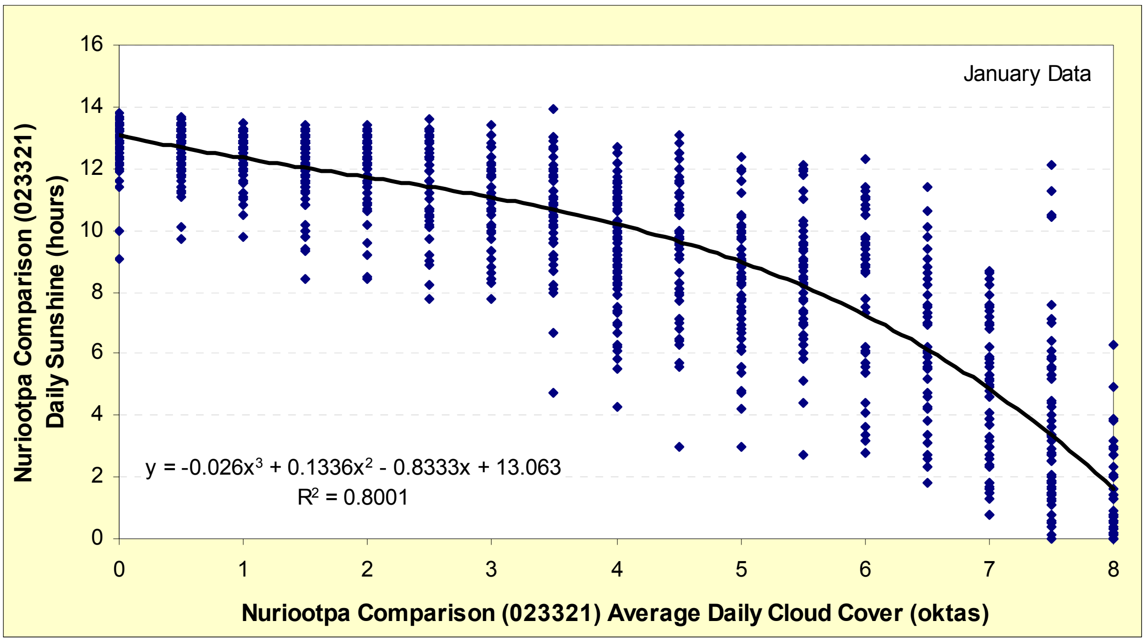


Figure D1 Regression Relationship between Daily Sunshine and Average Daily Cloud Cover at Nuriootpa Comparison (023321) for January.

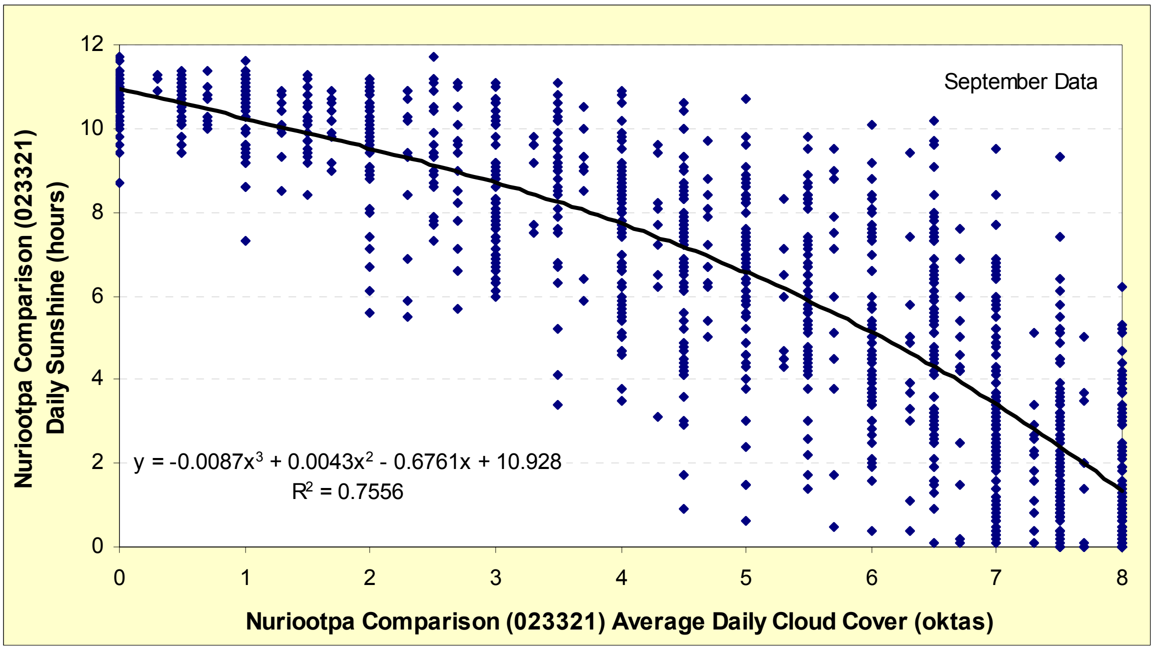


Figure D2 Regression Relationship between Daily Sunshine and Average Daily Cloud Cover at Nuriootpa Comparison (023321) for September.

To infill missing temperature records a linear relationship was formed with a nearby site, in particular, missing temperature data from Nuriootpa Comparison (023321) was infilled using data from Nuriootpa Viticultural (023373), Roseworthy Agricultural College (023020) and Rosedale (023343), while Rosedale data (023343) was also used to infill missing data from Nuriootpa Viticultural (023373). The regression relationships between the daily maximum and minimum temperature records each had a good correlation on an annual basis. If this had not been the case, monthly relationships would have been used. Figures D3 and D4 show these relationships between Nuriootpa Comparison (023321) and Rosedale (023343).

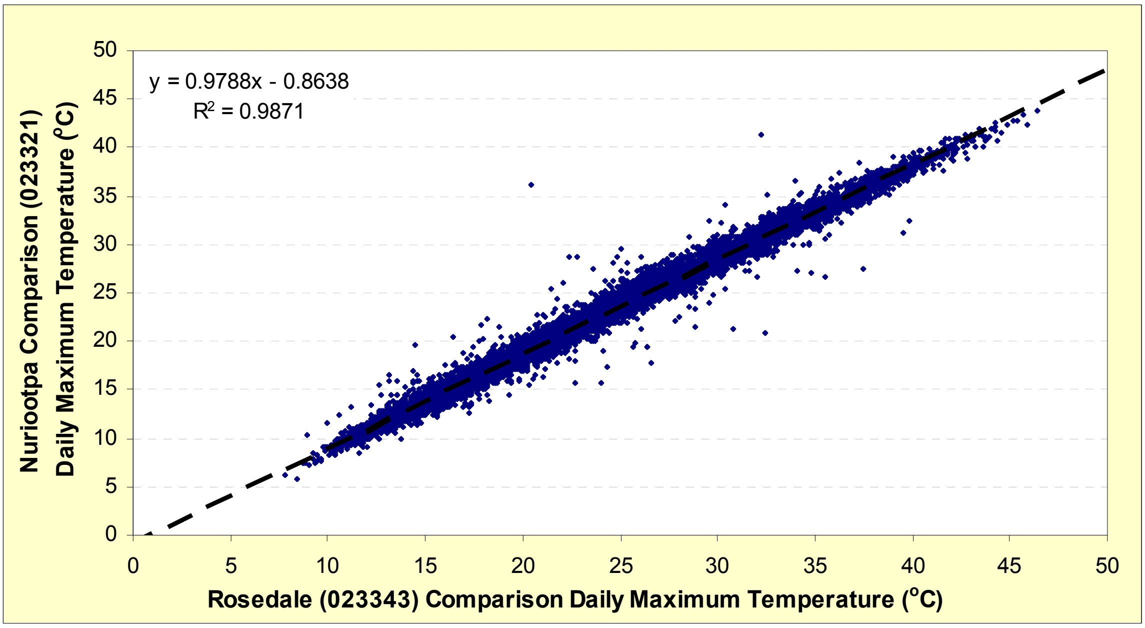


Figure D3 Regression Relationship between Daily Maximum Temperature at Nuriootpa Comparison (023321) and Rosedale (023343).

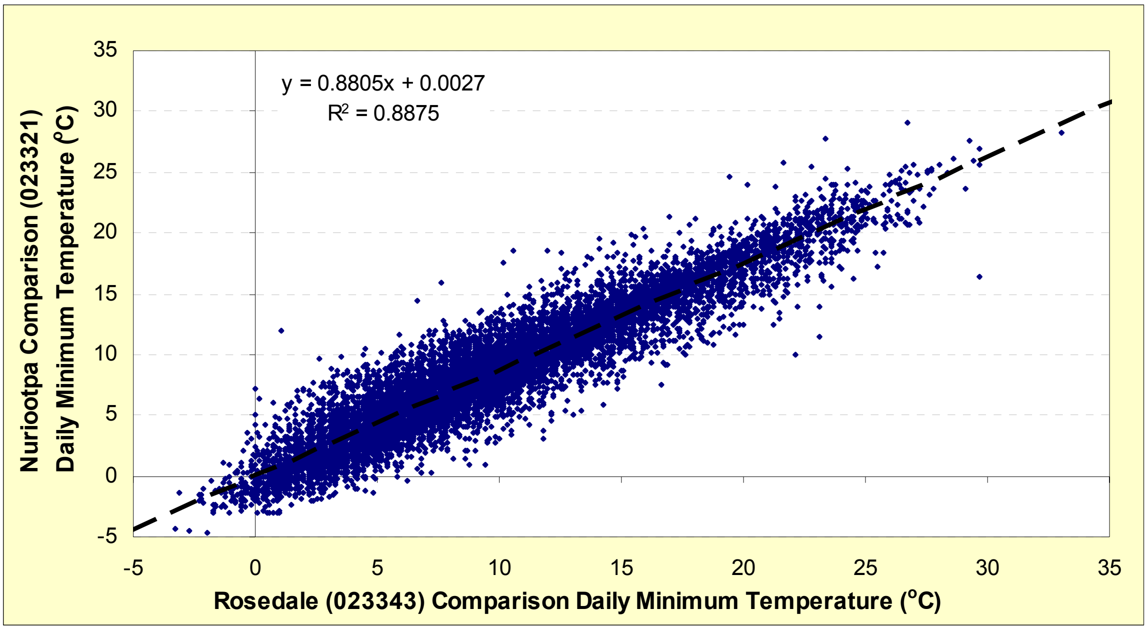


Figure D4 Regression Relationship between Daily Minimum Temperature at Nuriootpa Comparison (023321) and Rosedale (023343).

D.3 Data Analysis

Analysis of the calculated evaporation data was undertaken at annual and monthly time scales. In addition, the statistics and trends of the sunshine and temperature data used to calculate the evaporation were also examined.

As presented in Section 3.2.2, the annual evaporation data showed an increasing trend over the 44 years of record. An analysis of monthly trends indicated a significant increasing trend in evaporation for almost all months.

A shorter record (1972 to 1998) of pan evaporation data is also available at Nuriootpa (023321/023373) with only 10 days (0.1%) of data missing. An analysis was undertaken to determine if a similar trend existed in this data. The results are shown in Figure D5, where the same increasing trend can be seen. The mean of this data is 1698mm, the median 1127mm and the standard deviation 150mm. The higher standard deviation than for the derived evaporation indicates a larger variability of values around the mean.

In comparison to vegetative and soil surfaces, some of this variability can be attributed to:

- increased reflection of solar radiation from the water surface;
- the storage of heat within the pan that may cause significant evaporation during the night and heat transfer through the sides of the pan may also occur; and
- differences in turbulence, temperature and humidity of the air immediately above the pan.

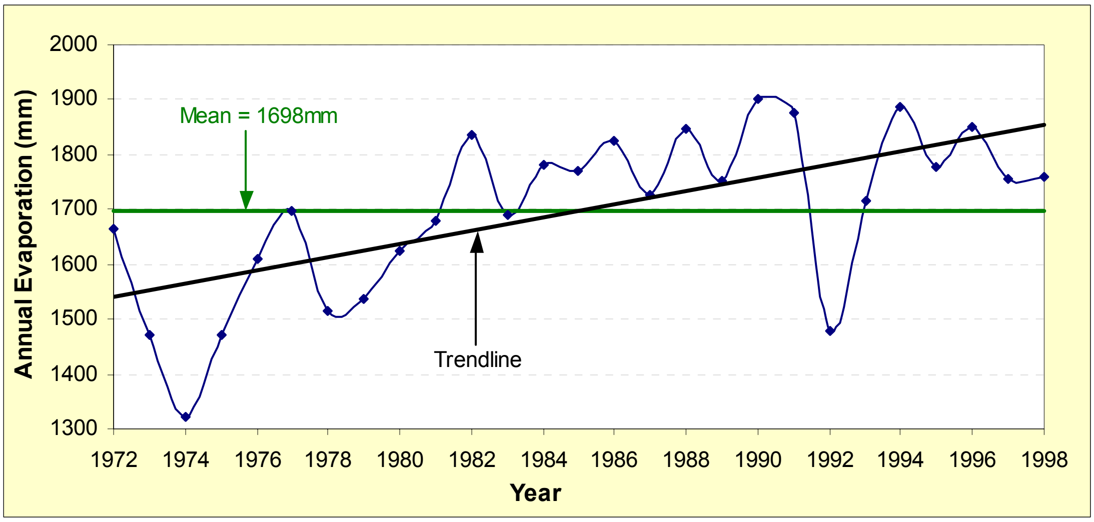


Figure D5 Annual Pan Evaporation Totals and Long Term Trends at Nuriootpa (023321/023373).

Examination of the sunshine and temperature data used to derive the evaporation data for catchment modelling was also undertaken. Figure D6 shows the annual sunshine data totals, which indicates the same increasing trend over the period of record. The influence of rainfall on evaporation was discussed in Section 3.2.2 with higher rainfall years producing lower evaporation totals, particularly in years when normally higher evaporation months have above average rainfall. In terms of derived evaporation, higher rainfall reduces the level of solar radiation reaching the ground through increased cloud cover and hence reduces the sunshine hours. The reverse will occur during low rainfall years. This is illustrated by the 1972 and 1992 data, which resulted from well below average and well above average rainfall respectively. The mean of the data shown in Figure D6 is 2656 hours, the median 2654 hours and the standard deviation 152 hours. Examination of total sunshine hour totals on a monthly time scale revealed increasing trends in almost every month.

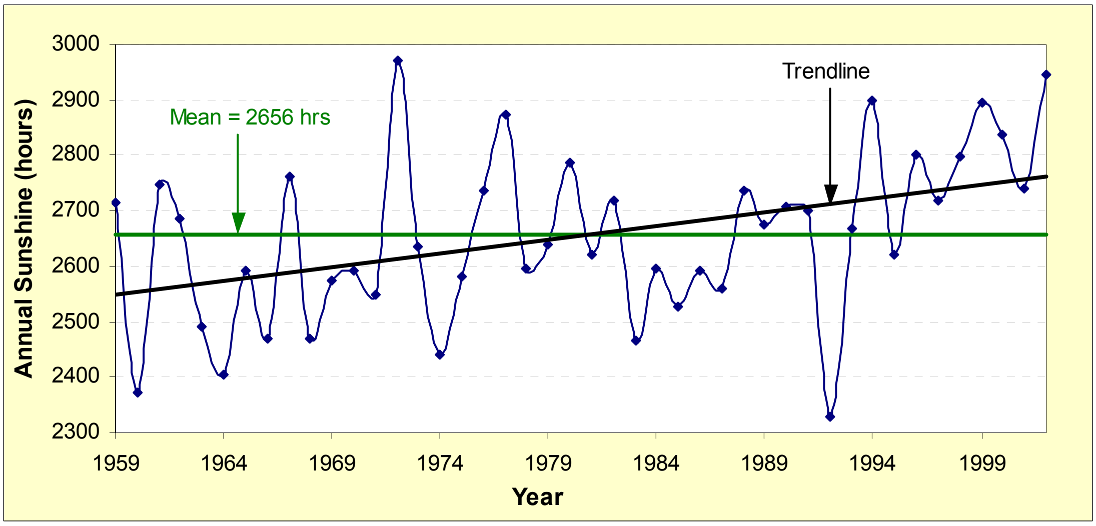


Figure D6 Annual Sunshine Totals and Long Term Trends at Nuriootpa (023321/023373).

The heat of the air exerts a controlling influence on the rate of evaporation, particularly from vegetative surfaces. As such, the water loss via evaporation is greater in warmer weather.

Examination of maximum and minimum temperature data at annual scales does not produce meaningful information because of the cyclic nature of these values over the year and because “monthly totals” are not suitable. Therefore, the temperature data was examined at a monthly scale for any evidence of a trend over the period of record. For the data from many months there was no trend evident. However, a number of months showed significant increasing trends in both maximum and minimum temperatures. The most significant of these were for February and September as shown in Figures D7 and D8, with May and December also showing increasing trends.

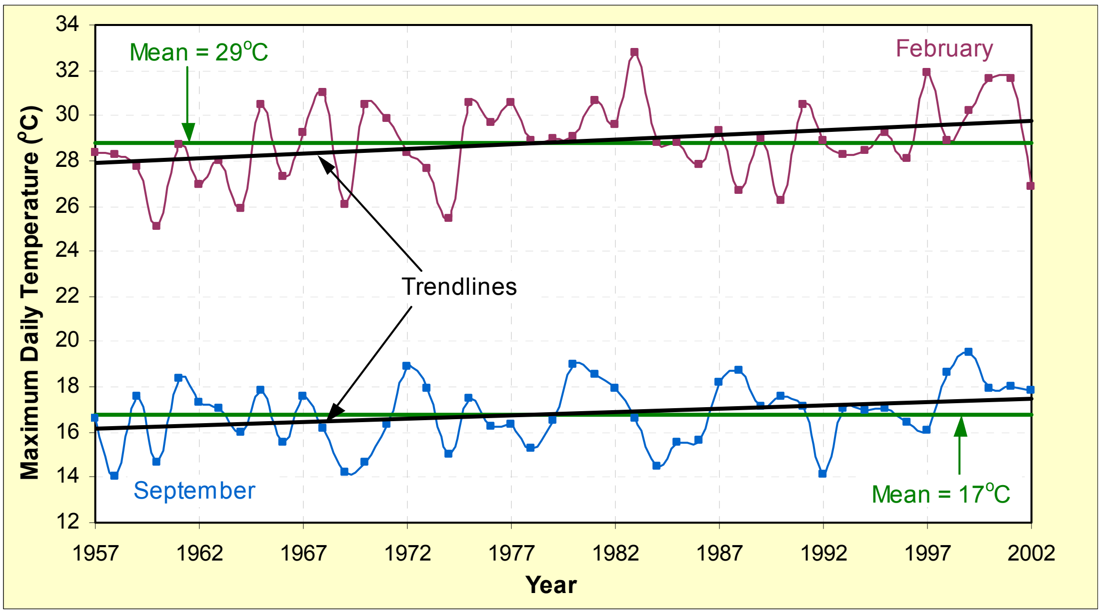


Figure D7 Long Term Trends in February and September Maximum Temperatures at Nuriootpa (023321/023373).

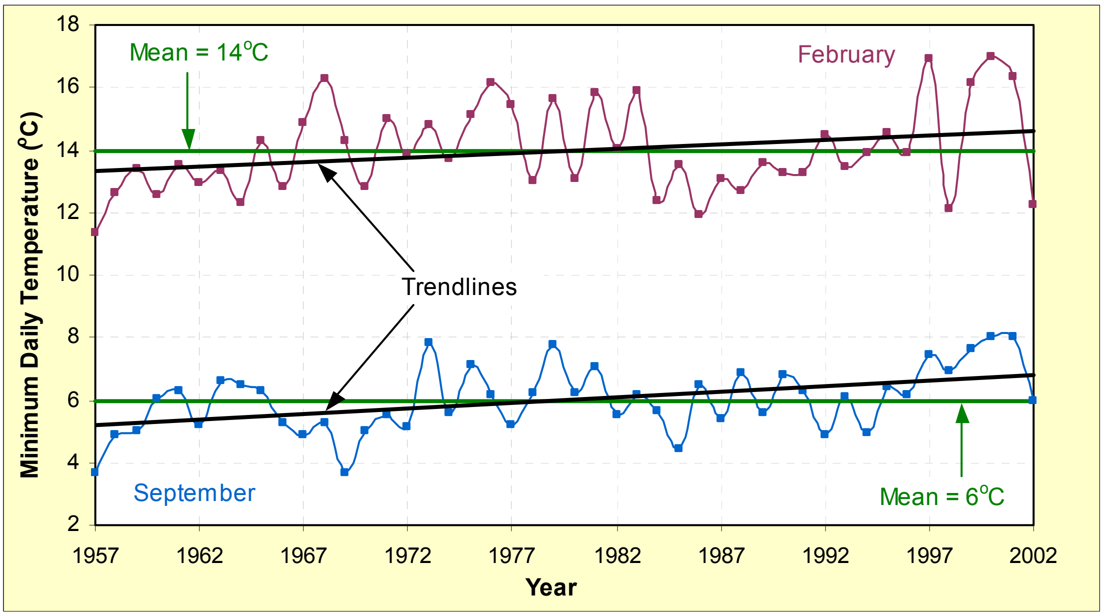


Figure D8 Long Term Trends in February and September Minimum Temperatures at Nuriootpa (023321/023373).

APPENDIX E STREAMFLOW

E.1 Data Availability and Processing

Daily streamflow data in South Australia is principally collected by DWLBC, with a small number of stations operated by the Bureau of Meteorology (BoM) and SA Water. It was identified in Section 3.3.1 that there are few good quality streamflow recording locations within the Upper River Torrens catchment. Although there were some sections of missing data within the available records these were not infilled due to lack of good correlated reference stations.

The primary data processing undertaken was to identify sections of the data for which the quality may be doubtful. The majority of streamflow gauges have inlet pipes that connect the pool behind the measuring weir to a well such that the height of water in the well is equal to the height of water in the weir pool. Therefore, this pipe may become blocked due to silt or debris and requires regular maintenance and back flushing. This will cause periods of the data to be doubtful. Other errors may be due to inoperative recorders, station reconstruction, debris interference on control or one off events such as a major release of water to flush Torrens lake in city due to algae. During model calibration, periods of data that may be doubtful can be excluded or a lower weight given to the accuracy of the predicted values.

As indicated in Section 3.3.1, the control section of a streamflow gauge will be sensitive to varying flow ranges. For each of the streamflow gauges analysed here, the following controls are in place:

- River Torrens @ Mount Pleasant (AW504512) - Stable natural rock bar with minor concrete;
- Sixth Creek @ Castambul (AW504523) - Concrete crump weir;
- Kersbrook Creek @ u/s Millbrook Reservoir (AW504525) - Triangular V weir; and
- River Torrens @ Gumeracha Weir (AW504500) - Broad rectangular weir.

Controls such as a triangular V weir will have a higher sensitivity for low flows and are often used on streams for which an estimate of the base flow is required for environmental flow analysis. Crump weirs are reasonably sensitive at low flows but not as much as the triangular V weir. The natural rock bar at the Mount Pleasant gauging station is less sensitive to low flows because of the flat control. Despite this, the data from this station is generally regarded as being of a high quality across a wide flow range. Broad rectangular weirs are not sensitive to low flows, particular ones such as Gumeracha Weir, which has dimensions of 2.44 metres by 34.4 metres.

E.2 Data Analysis

An analysis of the data from the gauging stations at Mount Pleasant (AW504512), Sixth Creek (AW504523) and Kersbrook Creek (AW504525) was undertaken at annual, monthly and daily time scales. The data from Gumeracha Weir (AW504500) was used in conjunction with data from the Millbrook diversion channel (AW504508) and scour releases to estimate catchment runoff upstream of the weir.

Annual Streamflow

An analysis of the streamflow data for the gauged catchments at Mount Pleasant and Gumeracha Weir was presented in Section 3.3.2. Figures E1 and E2 now show the annual data for the Sixth Creek and Kersbrook Creek gauged catchments respectively. Similar patterns and variability to those observed for the Mount Pleasant catchment can be seen for these sites. For the Sixth Creek catchment a maximum flow of 21553 ML was observed in 1992 and a minimum flow of 2596 ML in 1982. While there are only ten years of flow data for the Kersbrook Creek catchment, the variability is still evident with a maximum flow of 5102 ML in 1996 and a minimum flow of 277 ML in 1994.

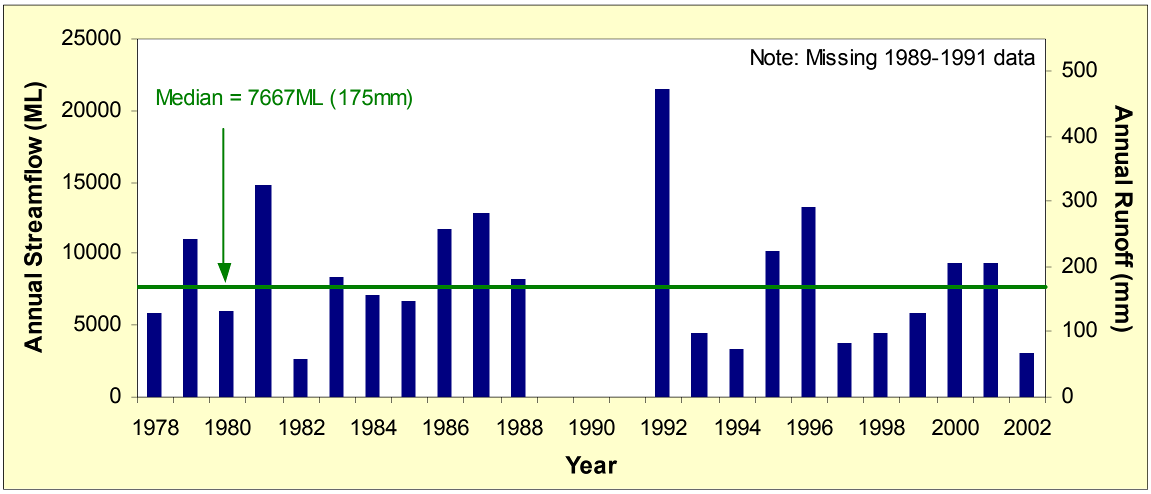


Figure E1 Annual Streamflow from Sixth Creek Gauged Catchment.

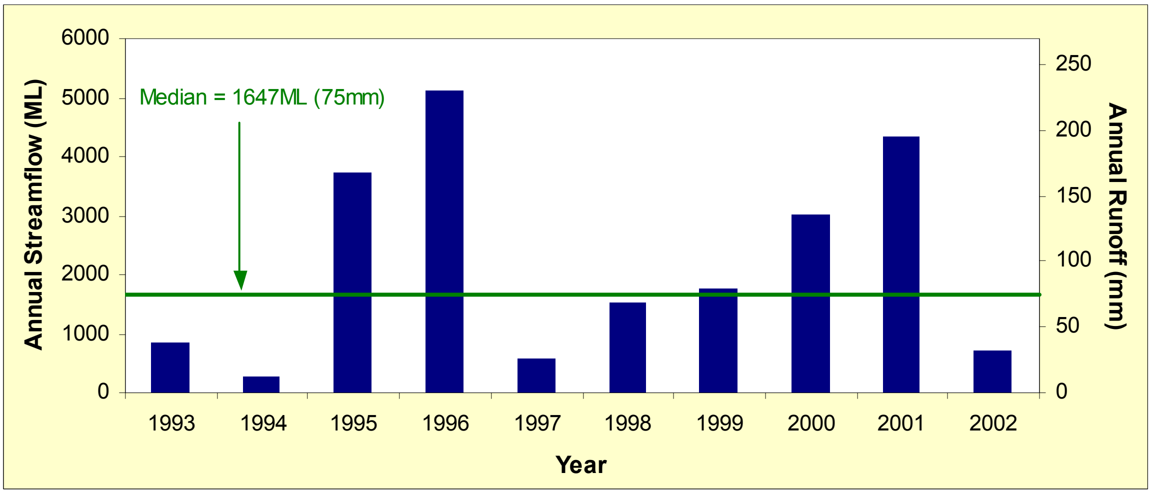


Figure E2 Annual Streamflow from Kersbrook Creek Gauged Catchment.

Monthly Streamflow

An analysis of the mean monthly streamflow and how it relates to mean monthly rainfall was presented in Section 3.3.2 for the Mount Pleasant and Gumeracha Weir catchments. For lower rainfall catchments such as the Mount Pleasant, and Kersbrook Creek shown in Figure E3, 95 percent of the annual streamflow occurs between June and October. For higher rainfall catchments such as Sixth Creek, 85 percent of the annual streamflow occurs between May and November as shown in Figure E4. Because there is higher annual rainfall, particularly in the months of March to May, the catchment will become saturated more quickly and larger runoff events will occur earlier in the year.

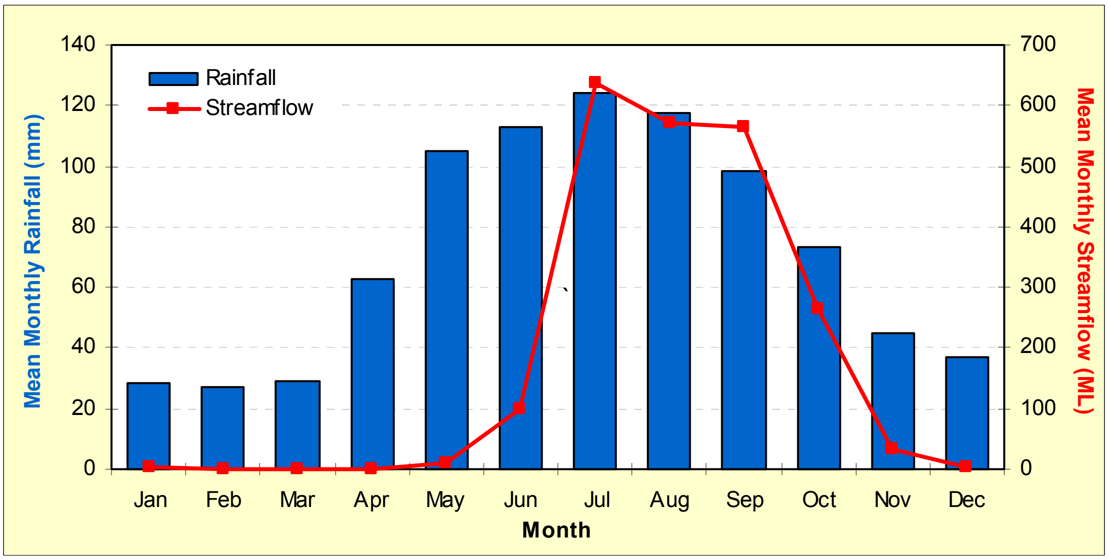


Figure E3 Mean Monthly Streamflow and Rainfall from the Kersbrook Creek Gauged Catchment.

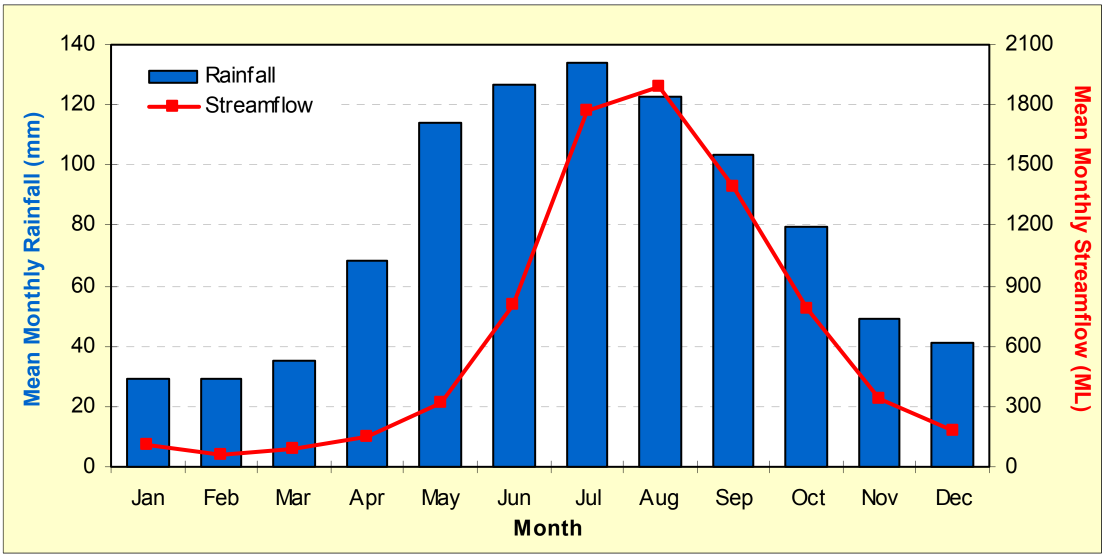


Figure E4 Mean Monthly Streamflow and Rainfall from the Sixth Creek Gauged Catchment.

Daily Streamflow

Statistics of daily streamflow from each gauged catchment was presented in Section 3.3.2, together with the flow frequency curve at the Mount Pleasant gauging station. Figures E5 to E7 present the flow frequency curves at the remaining gauging stations. Although annual and monthly "natural" inflows at Gumeracha Weir were estimated, this was only able to be undertaken at a daily scale during catchment modelling (refer Section 5.1.2 for results). Hence the flow frequency curve shown in Figure E7 includes the effects of the M-A Pipeline discharges. Table E1 presents some characteristics of these curves.

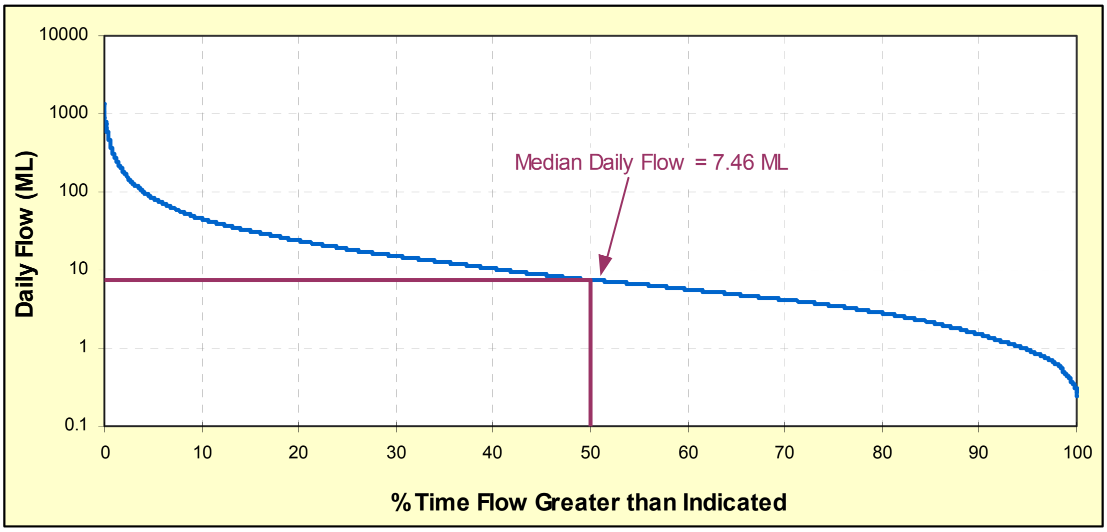


Figure E5 Flow Frequency Curve at the Sixth Creek Gauging Station.

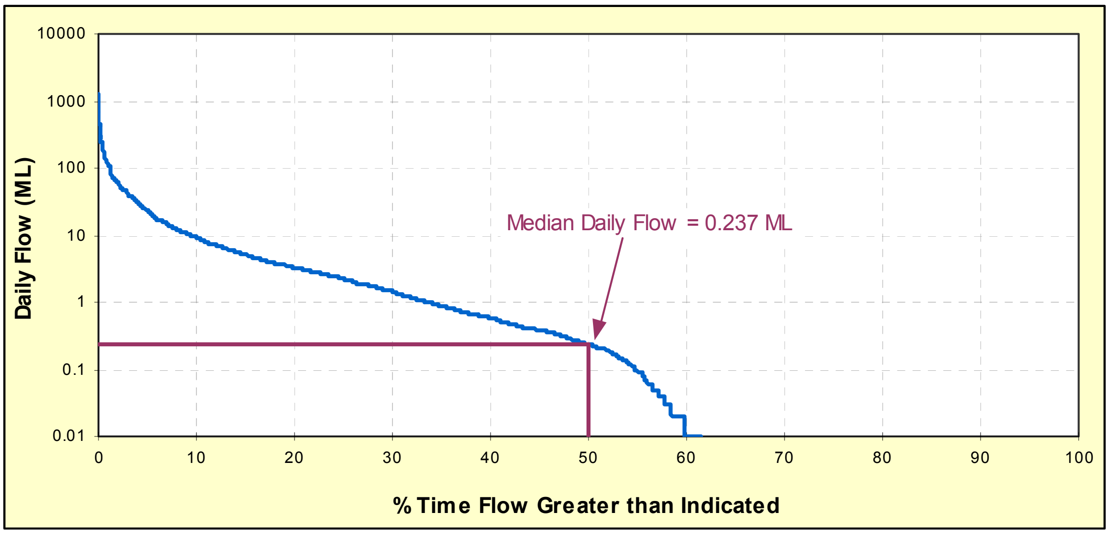


Figure E6 Flow Frequency Curve at the Kersbrook Creek Gauging Station.

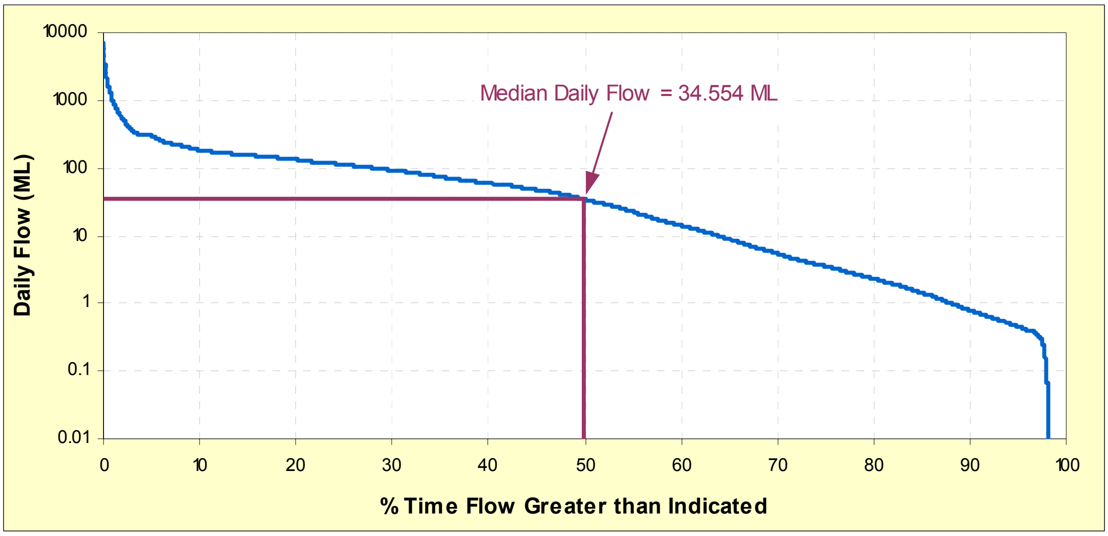


Figure E7 Flow Frequency Curve for the Recorded Inflow into Gumeracha Weir.

Table E1 Exceedance Characteristics of Flow Frequency Curves at the Sixth Creek, Kersbrook Creek and Gumeracha Weir Gauging Stations.

	Sixth Creek		Kersbrook Creek		Gumeracha Weir[1]	
	% Year	No. Days	% Year	No. Days	% Year	No. Days
Ceases to Flow[2]	-	-	38	140	2	7
Flow ≥ 1 ML/day	94	345	34	123	88	321
Flow ≥ 10 ML/day	41	150	9	35	64	233
Flow ≥ 20 ML/day	23	83	5	20	56	205
Flow ≥ 50 ML/day	9	33	2	9	44	160
Flow ≥ 100 ML/day	4	15	1	4	28	102

[1]Values for recorded inflow into Gumeracha Weir, which include M-A pipeline transfers.
[2]Cease to flow is assumed to occur at 0.01 ML/day as flows below this are difficult to measure.

E.3 Rainfall-Runoff Relationships

Annual rainfall-runoff relationships provide a straightforward means of determining how much runoff can be expected from a catchment given a specific level of rainfall. They are often used for comparing the characteristics of different catchments and can also be used for initial runoff estimates from ungauged catchments. The average annual runoff coefficient and the TanH function are two commonly used tools.

The average annual runoff coefficient (R_C) can be defined as:

$$R_C = \frac{\sum_{i=1}^{n} \frac{P_i}{R_i}}{n} \tag{E.1}$$

where:

P_i = annual rainfall in year i (where $i = 1, \cdots, n$);

R_i = annual runoff in year i (where $i = 1, \cdots, n$); and

n = number of years of data.

Section 3.3.3 provided runoff coefficients for the catchment upstream of each gauging station.

The Tanh function is a simple rainfall-runoff relationship and provides an effective site-based relationship that can be used infilling annual or monthly runoff values. It is a standard hyperbolic function defined (Grayson *et al*., 1996) as:

$$Q = (P - L) - F \tanh\left[\frac{(P - L)}{F}\right] \tag{E.2}$$

where:

Q = runoff (mm);

P = rainfall (mm);

L = notional loss (mm); and

F = notional infiltration (mm).

While Equation E.2 can be applied to any data, it should be used only where the average storage of soil water is approximately constant, that is, where the notional loss and infiltration are expected to be similar (Grayson *et al*., 1996). Annual data satisfies this requirement but for monthly data a curve should be fitted to the data from each individual month. Section 3.3.3 presented the TanH rainfall-runoff curve for the Mount Pleasant sub-catchment (AW504512). Figures E8 to E10 show these relationships for the remaining available stations. Although annual runoff volumes close to zero have not been observed for the Sixth Creek sub-catchment (AW504523), it could be estimated that little runoff would occur for an annual rainfall less than 400 mm. Similarly for the Kersbrook Creek (AW504525) sub-catchment and the natural inflow into Gumeracha Weir (AW504500), there would need to be an annual rainfall of approximately 450 mm and 650 mm respectively for runoff to occur.

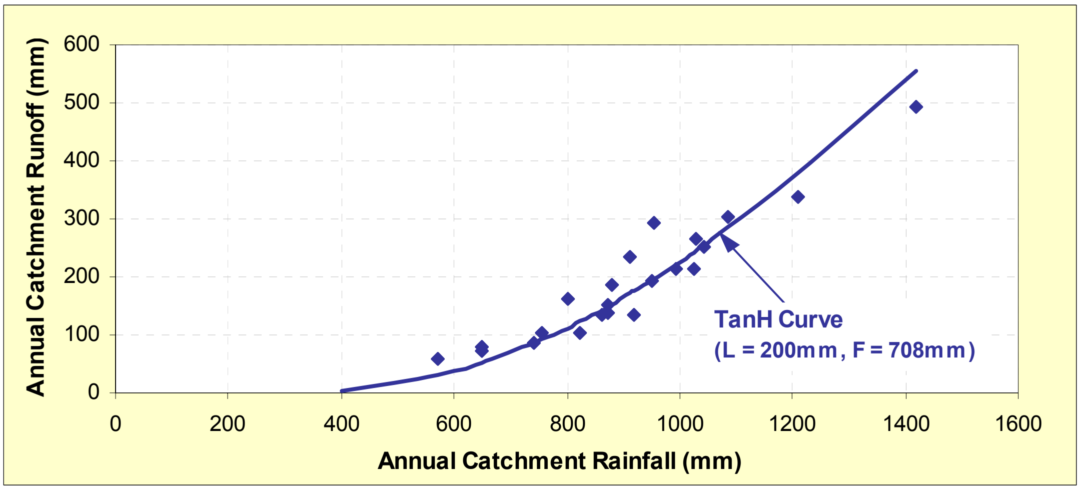


Figure E8 Rainfall-Runoff Curve for the Sixth Creek Gauged Catchment.

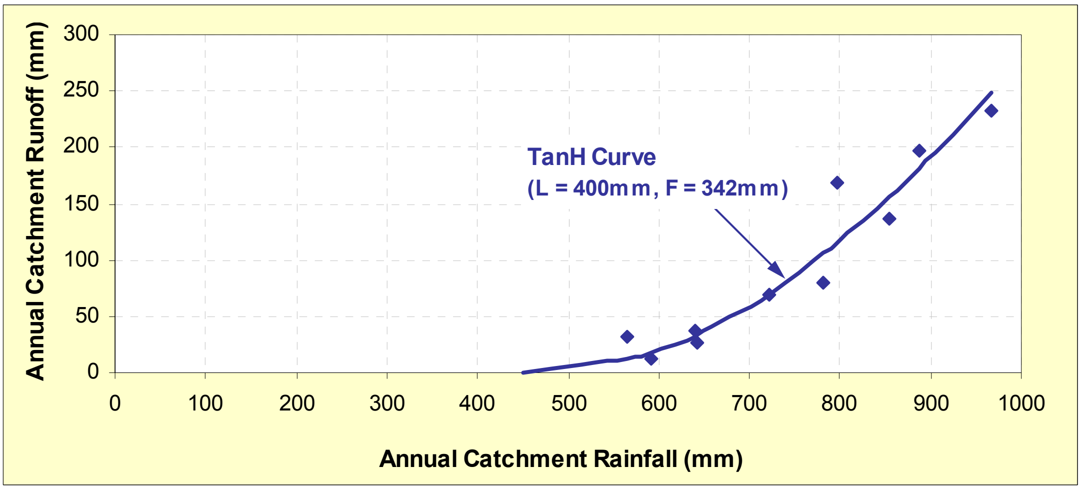


Figure E9 Rainfall-Runoff Curve for the Kersbrook Creek Gauged Catchment.

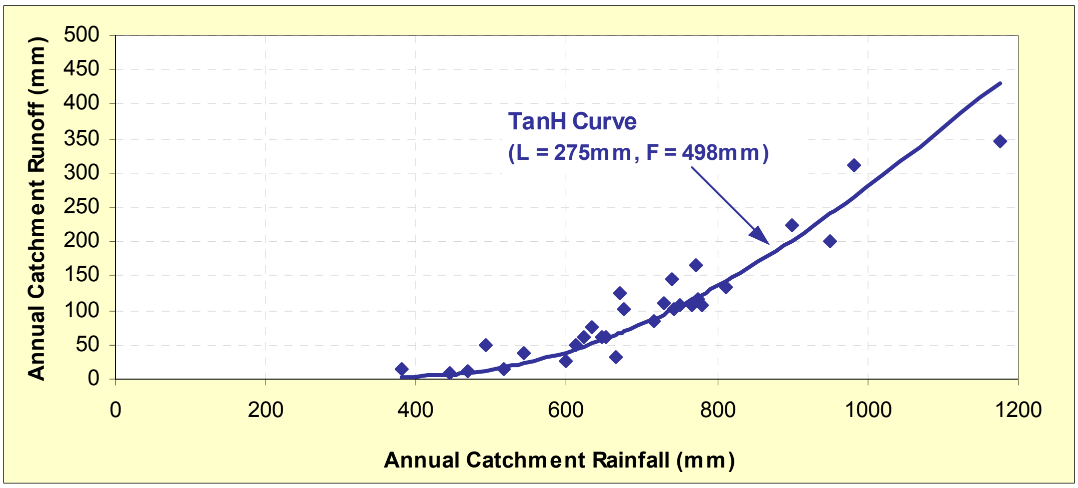


Figure E10 Rainfall-Runoff Curve (Natural Runoff) for Gumeracha Weir Gauged Catchment.

APPENDIX F SURFACE WATER MODELLING

Hydrological computer models that can adequately describe catchment rainfall-runoff processes and incorporate current development levels offer the most flexible means of determining the availability of surface water resources, long term catchment behaviour and the impact that development has had on the natural flow regime.

For this study, long-term rainfall and evaporation data was used to calibrate a conceptual surface water model and then simulate runoff data for the Upper River Torrens catchment. Section 4.1 provided information on the stages required, namely model construction, model calibration and scenario evaluation. This appendix provides additional information on the methodology behind model construction, the water balance models used and results from model calibration.

F.1 Model Construction Methodology

The major sub-catchments defined in Section 2.2 were further sub-divided into minor sub-catchments for modelling as outlined in Section 4.2.1. The minor sub-catchments were based on significant on-stream or *controlling* dams as these delay all upstream catchment runoff from moving downstream until the dam is full and overflows.

Figure F1 shows two minor sub-catchments in the Mount Pleasant sub-catchment (MP5 and MP6). There are a number of points to note:

- Although there are dams upstream of each of the limiting dams, runoff is prevented from leaving the minor sub-catchment until these particular dams overflow.
- To determine which dams are limiting, a dam capacity to upstream catchment area ratio was determined for each dam. The larger this ratio, the longer the dam will take to fill and overflow. This then enabled a meaningful comparison between consecutive dams.
- Because the area to capacity ratio for MP6 is greater than for MP5, MP5 is likely to fill and overflow first. Therefore, in order to ensure that the model behaves as realistically as possible, two minor sub-catchments are required in this area.

These minor sub-catchments are then represented by rural and off-stream dam nodes (diversion equals 1.0) as shown on the right.

Other factors considered were secondary streams, groups of off-stream farm dams from which runoff will overflow into areas without dams, rainfall patterns and land use information such as large areas of forestry. It was preferable to have major stream reaches defined as minor sub-catchments as this allowed a straightforward evaluation of localised streamflow volumes and development impacts. Major rural towns were also defined separately.

Figure F1 Model Construction: Representation of Minor Sub-Catchments and Farm Dams.

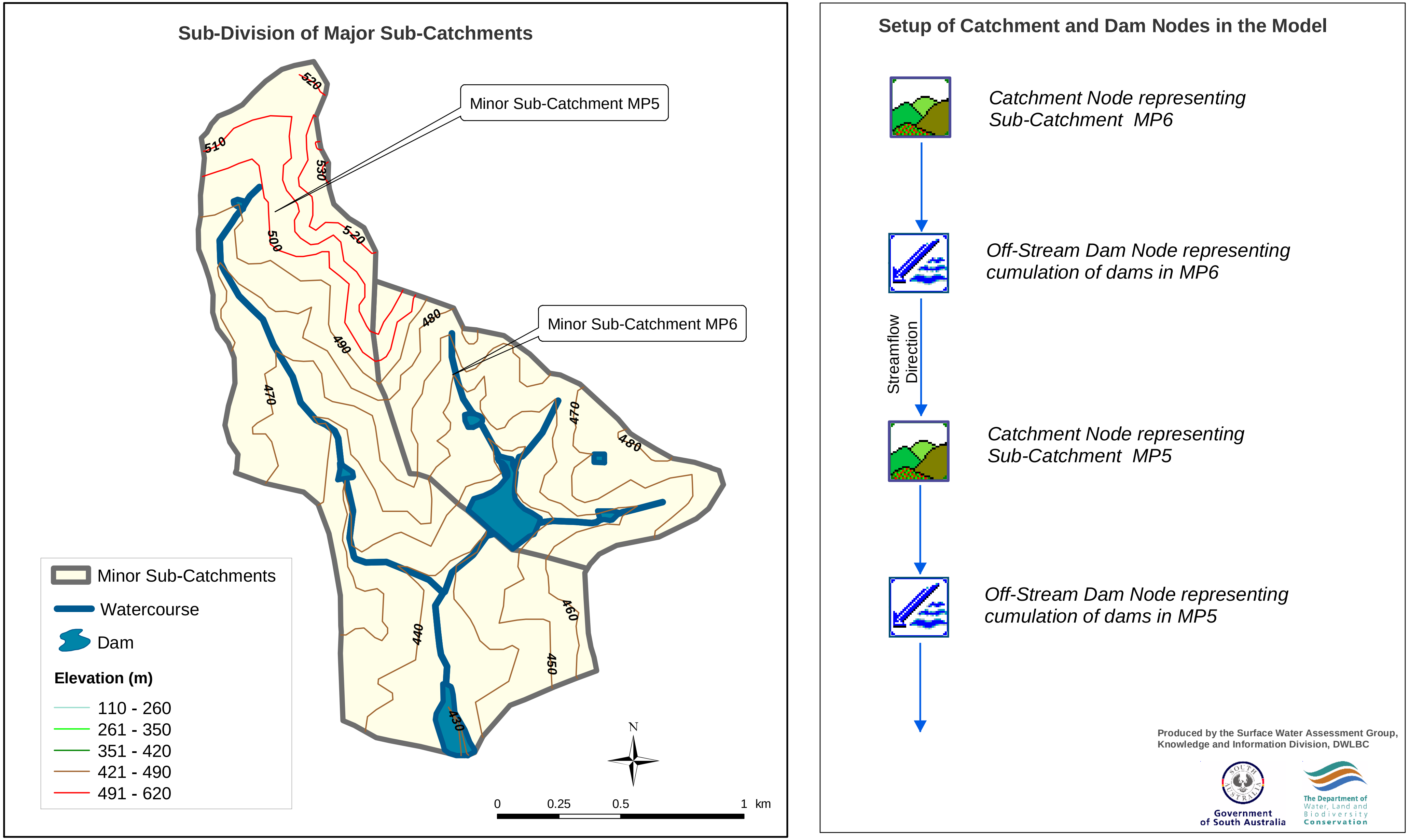
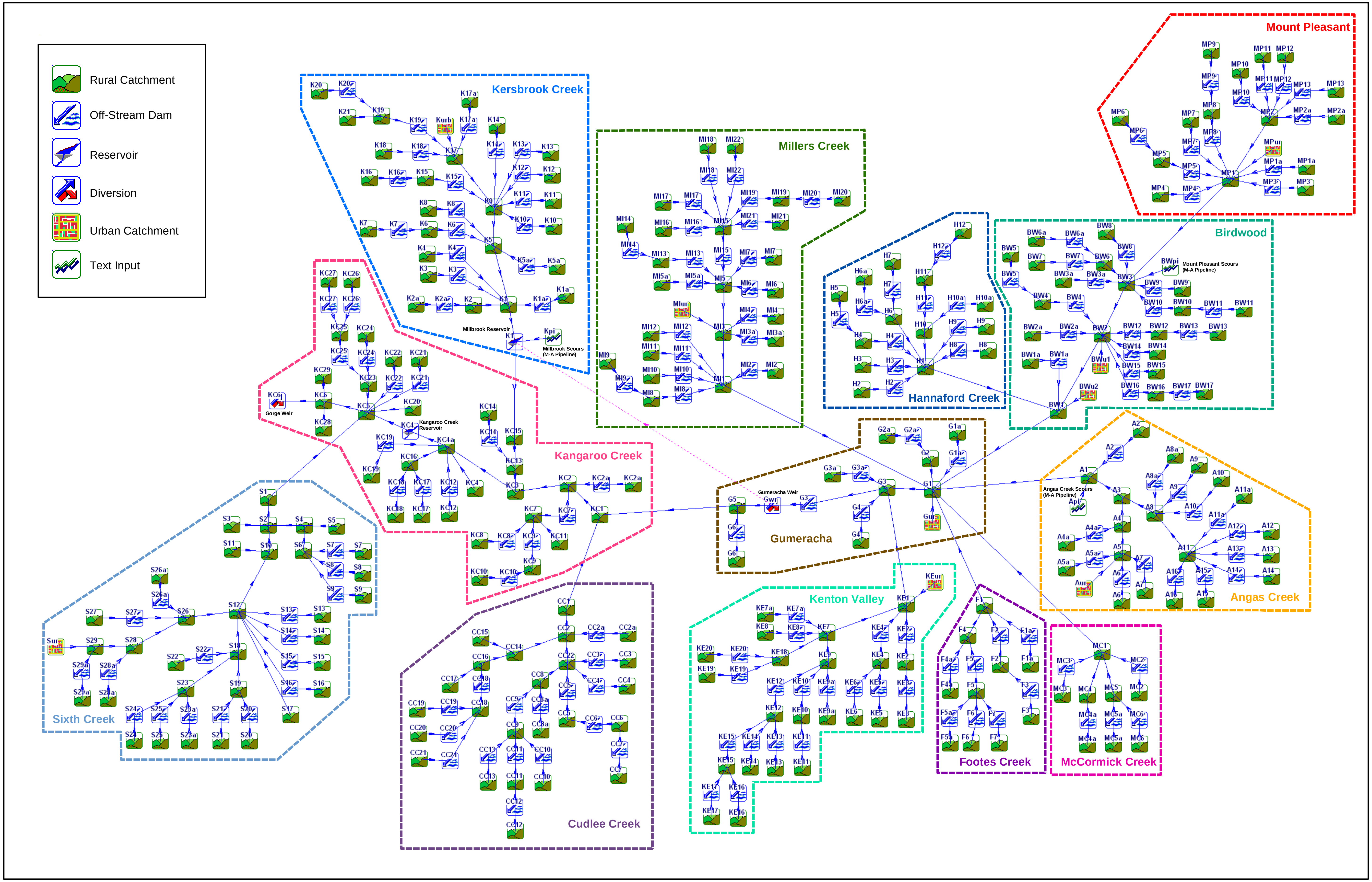


Figure F2 Model Layout.



Sub-Catchment Node Details

This section provides the details for each of the nodes within each sub-catchment within the model. There are a number of points to note.

1. The rainfall column provides the rainfall station and factor used for each node, where: B - Birdwood (023705), G - Gumeracha (023719), CC - Cudlee Creek (023731), MP - Mount Pleasant (023737), U - Uraidla (023750), A - Ashton (023803).
2. Three nodes were used to represent each of the three Mannum-Adelaide Pipeline Transfer Scours, namely Bwpi (Mount Pleasant Scours in Birdwood sub-catchment), Api (Angas Creek Scours in Angas Creek Sub-Catchment) and Kpi (Millbrook Scours in Kersbrook Creek sub-catchment).

Table F1a Mount Pleasant Sub-Catchment and Farm Dam Node Details.

ID	Rural Area (km^2)	No. of Dams	Dam Volume (ML)	Dam Surface Area (m^2)	Dam Diversion	Dam Density (ML/km^2)	F_1	Rainfall
MP1	0.783	-	-	-	-	-	-	MP
MP1a	6.352	24	37.4	29160.6	0.40	5.9	1647.2	MP
MP2	0.501	-	-	-	-	-	-	0.95MP
MP2a	4.511	30	71.4	58631.2	0.50	15.8	1983.1	0.95MP
MP3	1.752	6	20.1	12706.5	0.20	11.5	1173.1	MP
MP4	0.333	1	48.4	28503.0	1.00	145.4	1312.3	MP
MP5	1.505	3	45.8	22736.4	1.00	30.4	1094.4	1.05MP
MP6	0.685	4	146.6	54976.8	1.00	214.2	1050.8	1.05MP
MP7	1.340	10	69.1	48852.5	1.00	51.6	1696.6	1.05MP
MP8	1.845	8	31.5	18332.6	0.10	17.1	1187.2	1.05MP
MP9	0.760	4	85.5	47528.5	1.00	112.5	1393.9	1.05MP
MP10	1.032	6	33.1	19618.5	1.00	32.1	1220.0	MP
MP11	1.112	6	46.0	23800.4	1.00	41.4	1141.2	MP
MP12	1.762	2	209.0	88413.0	0.55	118.6	1275.4	MP
MP13	1.141	6	78.3	35272.3	0.60	68.6	1108.9	0.95MP
Totals	25.414	110	922.3	488532.4	0.54	36.29		MP

Table F1b Mount Pleasant Sub-Catchment Urban Node Details.

ID	Total Area (km^2)	No. Houses	Roof Area (m^2)	Connection	Pavement (m^2)	Connection	Rainfall
MPUr	0.695	293	200	0.5	200	0.5	MP

Table F2a Birdwood Sub-Catchment and Farm Dam Node Details.

ID	Rural Area (km^2)	No. of Dams	Dam Volume (ML)	Dam Surface Area (m^2)	Dam Diversion	Dam Density (ML/km^2)	F_1	Rainfall
BW1	1.521	-	-	-	-	-	-	B
BW1a	2.107	4	8.5	6178.2	0.10	4.0	1128.5	B
BW2	0.550	-	-	-	-	-	-	B
BW2a	4.806	18	43.7	30794.7	0.20	9.1	1536.9	B
BW3	0.392	-	-	-	-	-	-	0.95B
BW3a	3.524	15	23.2	18084.3	0.50	6.6	1494.6	0.95B
BW4	3.641	13	29.9	20267.6	0.40	8.2	1369.5	B
BW5	0.262	4	44.4	21790.6	1.00	169.7	1074.0	B
BW6	0.473	-	-	-	-	-	-	0.95B
BW6a	4.256	24	52.9	37080.3	0.80	12.4	1590.8	0.95B
BW7	1.313	13	72.5	43905.6	1.00	55.2	1467.6	0.95B
BW8	3.495	14	34.9	22881.2	0.25	10.0	1366.6	0.95B
BW9	5.543	13	34.1	25154.2	0.05	6.2	1528.4	0.90B
BW10	2.332	12	40.9	25871.0	1.00	17.5	1363.1	0.95B
BW11	0.697	6	19.8	11894.1	1.00	28.4	1112.1	0.90B
BW12	2.040	13	41.4	28003.3	1.00	20.3	1459.6	0.95B
BW13	3.074	18	366.0	161784.6	1.00	119.1	1496.5	0.95B
BW14	1.096	10	93.8	48200.6	1.00	85.6	1312.7	0.90B
BW15	1.606	9	192.7	88909.2	1.00	120.0	1367.9	B
BW16	4.312	30	59.3	42960.7	1.00	13.7	1685.2	B
BW17	3.203	18	52.5	34855.5	1.00	16.4	1504.2	0.95B
Totals	50.240	234	1210.5	668615.8	0.57	24.1		0.96B

Table F2b Birdwood Sub-Catchment Urban Node Details.

ID	Total Area (km^2)	No. Houses	Roof Area (m^2)	Connection	Pavement (m^2)	Connection	Rainfall
BWU1	0.140	82	200	0.5	200	0.5	B
BWU2	0.512	229	200	0.5	200	0.5	B

Table F3 Hannaford Creek Sub-Catchment and Farm Dam Node Details.

ID	Rural Area (km^2)	No. of Dams	Dam Volume (ML)	Dam Surface Area (m^2)	Dam Diversion	Dam Density (ML/km^2)	F_1	Rainfall
H1	1.553	1	0.3	326.8	-	0.2	-	1.05B
H2	0.354	4	5.3	4231.5	0.60	14.9	1131.9	1.05B
H3	0.741	9	13.6	10707.8	0.93	18.3	1354.4	1.05B
H4	0.718	2	2.9	2322.4	1.00	4.1	990.6	1.05B
H5	0.106	2	3.7	2645.8	1.00	34.9	941.0	1.05B
H6	0.187	-	-	-	-	-	-	1.05B
H6a	1.680	7	10.5	8187.2	0.05	6.3	1266.0	1.05B
H7	1.673	13	29.4	20152.5	1.00	17.6	1379.5	1.05B
H8	0.140	2	6.6	4455.0	1.00	47.3	992.5	1.05B
H9	0.889	3	25.8	13297.6	0.21	29.0	1008.6	1.05B
H10	0.419	-	-	-	-	-	-	1.05B
H10a	3.771	8	15.4	11129.4	0.10	4.1	1271.3	1.05B
H11	2.342	11	73.0	43966.7	1.00	31.2	1461.0	1.05B
H12	0.477	7	73.5	38044.0	1.00	154.1	1257.3	1.05B
Totals	15.050	69	260.0	159466.5	0.47	17.2		1.05B

Table F4a Angas Creek Sub-Catchment and Farm Dam Node Details.

ID	Rural Area (km^2)	No. of Dams	Dam Volume (ML)	Dam Surface Area (m^2)	Dam Diversion	Dam Density (ML/km^2)	F_1	Rainfall
A1	0.814	1	1.6	1225.0	-	1.9	-	1.05B
A2	0.078	2	5.0	3093.4	1.00	64.7	860.5	1.05B
A3	1.406	1	1.6	1225.3	-	1.1	-	1.05B
A4	0.323	-	-	-	-	-	-	B
A4a	2.905	12	20.3	15493.9	0.10	7.0	1422.8	B
A5	0.570	-	-	-	-	-	-	B
A5a	5.296	38	71.0	51159.7	0.30	13.4	1738.8	B
A6	1.128	8	34.1	20304.4	1.00	30.3	1234.0	B
A7	1.766	13	58.9	32891.9	1.00	33.4	1296.3	0.95B
A8	0.221	-	-	-	-	-	-	B
A8a	2.759	14	26.5	19836.5	0.30	9.6	1474.4	B
A9	0.633	4	21.5	11720.8	1.00	34.0	1028.1	B
A10	0.551	6	27.6	15859.8	1.00	50.1	1139.0	B
A11	0.206	-	-	-	-	-	-	B
A11a	1.853	13	26.8	19073.0	0.20	14.5	1404.7	B
A12	0.203	8	23.8	14429.6	0.42	117.0	1167.4	0.95B
A13	1.291	1	63.2	23076.4	0.64	48.9	860.5	0.95B
A14	1.886	8	23.5	15559.9	0.24	12.4	1273.4	0.95B
A15	2.654	24	57.8	42618.4	0.88	21.8	1704.5	0.95B
A16	0.504	4	29.8	16861.8	1.00	59.0	1141.4	0.95B
Totals	27.045	157	492.8	304430.0	0.42	18.22		0.99B

Table F4b Angas Creek Sub-Catchment Urban Node Details.

ID	Total Area (km^2)	No. Houses	Roof Area (m^2)	Connection	Pavement (m^2)	Connection	Rainfall
Aur	0.202	110	200	0.5	200	0.5	B

Table F5a Gumeracha Sub-Catchment and Farm Dam Node Details.

ID	Rural Area (km^2)	No. of Dams	Dam Volume (ML)	Dam Surface Area (m^2)	Dam Diversion	Dam Density (ML/km^2)	F_1	Rainfall
G1	0.417	-	-	-	-	-	-	0.91G
G1a	6.738	16	25.2	19243.0	0.30	3.7	1487.0	0.91G
G2	2.621	-	-	-	-	-	-	0.90G
G2a	1.632	24	58.7	39915.5	1.00	35.9	1578.0	0.90G
G3	0.214	1	200.0	80000.0	1.00	-	-	G
G3a	4.783	6	10.3	7652.4	0.05	2.2	1203.6	G
G4	2.907	7	23.7	14709.4	1.00	8.1	1195.6	0.95G
G5	4.192	-	-	-	-	-	-	1.05G
G6	4.596	12	38.4	24922.8	0.60	8.4	1378.6	1.03G
Totals	28.101	65	156.2	106443.1	0.34	5.56		0.97G

*Note: Dam node G3 is Gumeracha Weir. This is not counted as a dam in the number, volume, surface area, diversion and density totals above.

Table F5b Gumeracha Sub-Catchment Urban Node Details.

ID	Total Area (km^2)	No. Houses	Roof Area (m^2)	Connection	Pavement (m^2)	Connection	Rainfall
Gur	0.252	133	200	0.5	200	0.5	0.97G

Table F6 Footes Creek Sub-Catchment and Farm Dam Node Details.

ID	Rural Area (km^2)	No. of Dams	Dam Volume (ML)	Dam Surface Area (m^2)	Dam Diversion	Dam Density (ML/km^2)	F_1	Rainfall
F1	0.100	-	-	-	-	-	-	1.1B
F1a	1.217	4	17.9	11067.1	0.30	14.7	1120.1	1.1B
F2	2.488	6	117.4	64133.0	1.00	47.2	1462.1	1.1B
F3	0.125	2	19.2	9599.1	1.00	153.6	922.3	1.1B
F4	0.807	-	-	-	-	-	-	1.1B
F4a	1.088	4	18.6	11295.7	0.30	17.1	1112.8	1.1B
F5	0.835	1	61.6	22613.9	1.00	73.7	860.5	1.1B
F5a	0.197	6	15.5	10656.1	1.00	78.6	1210.3	1.1B
F6	1.036	5	14.8	9912.3	1.00	14.3	1169.7	1.1B
F7	1.561	4	31.9	15243.6	0.45	20.4	976.9	1.1B
Totals	9.455	32	296.8	154520.8	0.64	31.4		1.1B

Table F7 McCormick Creek Sub-Catchment and Farm Dam Node Details.

ID	Rural Area (km^2)	No. of Dams	Dam Volume (ML)	Dam Surface Area (m^2)	Dam Diversion	Dam Density (ML/km^2)	F_1	Rainfall
MC1	1.826	-	-	-	-	-	-	1.05B
MC2	1.159	5	50.7	33794.9	1.00	43.7	1501.2	1.05B
MC3	0.435	2	14.0	8055.6	1.00	32.3	990.3	1.05B
MC4	0.300	-	-	-	-	-	-	1.05B
MC4a	3.849	19	35.7	25371.3	0.35	9.3	1488.3	1.05B
MC5	0.740	-	-	-	-	-	-	1.05B
MC5a	0.739	8	10.0	8078.8	1.00	13.5	1300.7	1.05B
MC6	0.263	3	23.2	11535.8	1.00	88.0	952.8	1.05B
Totals	9.313	37	133.5	86836.4	0.42	14.3		1.05B

Table F8a Millers Creek Sub-Catchment and Farm Dam Node Details.

ID	Rural Area (km^2)	No. of Dams	Dam Volume (ML)	Dam Surface Area (m^2)	Dam Diversion	Dam Density (ML/km^2)	F_1	Rainfall
MI1	1.866	-	-	-	-	-	-	1.05B
MI2	1.511	7	33.2	17891.9	0.86	22.0	1111.6	1.05B
MI3	0.548	-	-	-	-	-	-	1.05B
MI3a	0.152	3	3.7	2949.5	1.00	24.0	1054.3	1.05B
MI4	1.093	11	42.7	27027.2	1.00	39.1	1374.2	1.05B
MI5	0.361	-	-	-	-	-	-	1.05B
MI5a	3.531	10	18.1	13646.5	0.10	5.1	1371.9	1.05B
MI6	1.624	11	29.0	19478.4	0.65	17.8	1348.0	1.05B
MI7	1.331	8	67.2	30444.1	0.82	50.5	1081.1	1.05B
MI8	0.767	5	7.9	6160.3	0.50	10.3	1195.5	1.05B
MI9	0.075	1	17.5	5778.0	1.00	233.2	595.3	1.05B
MI10	0.507	3	31.9	16075.0	0.86	62.9	1031.9	1.05B
MI11	0.744	1	6.1	3632.3	0.73	8.3	860.5	1.05B
MI12	2.143	13	32.9	22432.6	0.45	15.4	1402.5	1.05B
MI13	0.971	1	3.2	2149.7	0.77	3.3	860.4	1.05B
MI14	0.490	2	26.1	14081.8	1.00	53.2	1059.2	1.05B
MI15	1.406	5	5.8	4787.9	0.94	4.1	1184.4	1.05B
MI16	0.471	6	28.8	15122.4	1.00	61.0	1052.4	1.05B
MI17	0.901	14	15.7	13021.6	1.00	17.5	1462.3	1.05B
MI18	0.328	6	10.9	7850.1	1.00	33.2	1179.0	1.05B
MI19	1.221	16	22.5	17227.4	1.00	18.4	1459.4	1.05B
MI20	0.253	3	14.9	8027.1	1.00	58.7	943.8	1.05B
MI21	0.388	2	3.2	2469.1	1.00	8.1	991.8	1.05B
MI22	0.098	1	61.0	25319.0	1.00	620.4	970.0	1.05B
Totals	22.780	129	482.1	275572.0	0.60	21.2		1.05B

Table F8b Millers Creek Sub-Catchment Urban Node Details.

ID	Total Area (km^2)	No. Houses	Roof Area (m^2)	Connection	Pavement (m^2)	Connection	Rainfall
MIur	0.052	52	200	0.5	200	0.5	1.05B

Table F9a Kenton Valley Sub-Catchment and Farm Dam Node Details.

ID	Rural Area (km^2)	No. of Dams	Dam Volume (ML)	Dam Surface Area (m^2)	Dam Diversion	Dam Density (ML/km^2)	F_1	Rainfall
KE1	1.211	-	-	-	-	-	-	0.94G
KE2	0.835	1	4.1	2618.3	1.00	4.9	860.6	0.94G
KE3	0.206	2	6.5	4197.3	1.00	31.6	950.6	0.94G
KE4	0.919	3	5.2	3936.0	0.55	5.6	1067.5	0.94G
KE5	0.298	5	13.1	9081.1	1.00	44.0	1177.1	0.94G
KE6	0.350	6	18.9	12258.4	1.00	53.9	1191.7	0.94G
KE7	1.261	-	-	-	-	-	-	0.94G
KE7a	0.491	6	7.2	5805.2	0.70	14.6	1219.0	0.97G
KE8	0.866	8	32.0	14775.8	0.30	36.0	964.3	0.97G
KE9	1.838	-	-	-	-	-	-	0.97G
KE9a	0.133	7	8.6	6890.5	1.00	64.2	1254.9	0.97G
KE10	0.515	4	9.8	6677.9	1.00	19.0	1093.5	0.94G
KE11	0.103	1	7.9	4413.8	1.00	76.0	860.5	0.94G
KE12	0.203	1	0.9	780.3	1.00	4.4	860.5	G
KE13	0.429	6	27.1	15700.5	1.00	63.1	1145.6	0.97G
KE14	0.318	4	27.6	16944.2	1.00	86.7	1219.6	G
KE15	0.605	7	17.8	11954.9	0.70	29.5	1216.8	G
KE16	0.253	4	17.3	10641.6	1.00	68.3	1110.8	G
KE17	0.072	2	8.6	5481.5	1.00	120.1	993.0	G
KE18	0.356	-	-	-	-	-	-	G
KE19	0.122	4	6.2	4792.8	1.00	51.3	1120.9	G
KE20	1.175	9	10.8	8863.4	1.00	9.2	1340.1	G
Totals	12.558	80	228.6	145813.5	0.52	18.2		0.96G

Table F9b Kenton Valley Sub-Catchment Urban Node Details.

ID	Total Area (km^2)	No. Houses	Roof Area (m^2)	Connection	Pavement (m^2)	Connection	Rainfall
KEur	0.275	171	200	0.5	200	0.5	0.94G

Table F10 Cudlee Creek Sub-Catchment and Farm Dam Node Details.

ID	Rural Area (km^2)	No. of Dams	Dam Volume (ML)	Dam Surface Area (m^2)	Dam Diversion	Dam Density (ML/km^2)	F_1	Rainfall
CC1	0.777	1	1.7	1293.4	-	-	-	1.03CC
CC2	1.030	1	1.6	1225.2	-	-	-	1.03CC
CC2a	0.579	3	4.8	3715.7	0.95	8.3	1067.0	1.03CC
CC3	0.628	1	1.0	878.1	0.25	1.6	860.4	1.03CC
CC4	1.515	3	5.0	3870.2	1.00	3.3	1079.0	0.97CC
CC5	1.703	17	33.0	22706.1	1.00	19.4	1417.6	0.97CC
CC6	0.597	8	18.5	12420.8	1.00	30.9	1228.4	0.97CC
CC7	0.115	3	6.6	4318.5	1.00	56.9	972.1	0.97CC
CC8	0.475	-	-	-	-	-	-	1.03CC
CC8a	0.220	1	1.3	1087.7	1.00	6.1	860.7	1.03CC
CC9	1.514	1	6.8	3938.8	1.00	4.5	860.5	1.03CC
CC10	1.338	11	46.3	28830.1	1.00	34.6	1375.3	1.03CC
CC11	0.563	7	10.9	8220.2	1.00	19.3	1239.8	CC
CC12	0.061	1	4.0	2571.4	1.00	64.9	860.5	CC
CC13	0.331	4	19.0	11310.6	1.00	57.3	1096.0	CC
CC14	2.871	5	6.1	4860.0	-	-	-	1.05CC
CC15	1.914	-	-	-	-	-	-	1.06CC
CC16	0.163	-	-	-	-	-	-	1.06CC
CC17	1.157	-	-	-	-	-	-	1.06CC
CC18	1.218	5	18.7	11584.2	0.87	15.4	1134.7	1.06CC
CC19	0.222	2	20.0	11369.0	1.00	90.2	1056.2	1.05CC
CC20	0.170	2	10.3	6021.4	1.00	60.6	948.0	1.05CC
CC21	0.161	1	6.3	3693.2	1.00	39.1	860.5	1.05CC
CC22	0.788	1	1.6	1225.1	-	-	-	1.02CC
Totals	20.109	78	223.2	145139.5	0.51	11.1		1.03CC

Table F11 Kangaroo Creek Sub-Catchment and Farm Dam Node Details.

ID	Rural Area (km^2)	No. of Dams	Dam Volume (ML)	Dam Surface Area (m^2)	Dam Diversion	Dam Density (ML/km^2)	F_1	Rainfall
KC1	1.069	1	1.6	1225.1	-	-	-	1.08G
KC2	1.221	-	-	-	-	-	-	1.06G
KC2a	0.231	7	26.7	16180.9	1.00	115.9	1193.6	1.07G
KC3	1.568	-	-	-	-	-	-	1.02G
KC4	7.318	1	19030.0	1040000.0	1.00	-	-	1.03G
KC5	1.790	-	-	-	-	-	-	0.97G
KC6	1.729	1	24.2	17000.0	1.00	-	-	0.90G
KC7	0.807	4	7.5	5239.3	0.68	9.3	1062.8	1.10G
KC8	0.650	3	2.5	2118.2	0.60	3.8	1036.7	1.10G
KC9	0.455	2	4.8	3369.6	0.86	10.6	964.8	1.10G
KC10	1.439	3	7.0	4788.0	1.00	4.6	1059.8	1.10G
KC11	1.217	-	-	-	-	-	-	1.10G
KC12	1.127	7	30.3	17768.7	0.80	26.9	1187.7	1.07G
KC13	0.099	-	-	-	-	-	-	1.03G
KC14	0.358	1	1.2	988.7	0.07	3.3	860.7	1.02G
KC15	0.439	-	-	-	-	-	-	1.03G
KC16	0.976	-	-	-	-	-	-	1.07G
KC17	1.298	1	8.0	4467.9	1.00	6.1	860.5	1.10G
KC18	0.581	4	12.5	8078.3	1.00	21.6	1088.0	1.07G
KC19	4.718	1	1.7	1318.8	0.03	0.4	860.4	1.10G
KC20	0.835	-	-	-	-	-	-	0.98G
KC21	0.417	2	2.3	1885.0	0.05	5.5	982.3	0.99G
KC22	0.398	4	3.0	2190.9	0.05	7.6	911.1	0.97G
KC23	0.257	-	-	-	-	-	-	0.95G
KC24	0.176	2	1.7	1525.5	1.00	9.7	993.0	0.95G
KC25	2.311	9	26.0	16983.7	1.00	11.3	1280.1	0.93G
KC26	1.219	5	114.4	40797.0	1.00	93.8	949.5	0.98G
KC27	0.498	7	11.5	8743.4	1.00	23.0	1263.6	0.93G
KC28	2.667	-	-	-	-	-	-	0.93G
KC29	0.731	-	-	-	-	-	-	0.89G
Totals	38.599	63	262.3	154669.2	0.26	6.79		1.03G

*Note: Dam node KC4 is Kangaroo Creek Reservoir, Dam node KC6 is Gorge Weir. These are not counted as dams in the number, volume, surface area, diversion and density totals above.

Table F12a Kersbrook Creek Sub-Catchment and Farm Dam Node Details.

ID	Rural Area (km^2)	No. of Dams	Dam Volume (ML)	Dam Surface Area (m^2)	Dam Diversion	Dam Density (ML/km^2)	F_1	Rainfall
K1	5.018	1	16500.0	1710000.0	1.00	-	-	CC
K1a	5.915	15	43.7	28883.0	0.15	7.4	1443.4	CC
K2	1.266	-	-	-	-	-	-	0.94CC
K2a	0.518	10	34.7	21526.1	1.00	67.1	1289.6	0.94CC
K3	0.671	12	17.7	13916.0	1.00	26.3	1426.7	0.94CC
K4	0.711	5	14.7	9598.3	0.73	20.7	1138.1	0.95CC
K5	0.205	-	-	-	-	-	-	0.95CC
K5a	2.408	10	37.2	23207.9	0.25	15.5	1315.8	0.95CC
K6	1.383	12	57.3	28691.7	1.00	41.4	1156.1	0.94CC
K7	1.645	3	68.2	26068.1	1.00	41.4	915.1	0.91CC
K8	1.589	13	57.9	31083.5	0.83	36.4	1242.4	0.93CC
K9	1.105	-	-	-	-	-	-	0.94CC
K10	0.402	5	44.4	20824.1	1.00	110.3	1027.3	0.93CC
K11	1.866	13	51.9	32270.5	0.45	27.8	1406.9	0.93CC
K12	0.193	2	50.9	19285.8	1.00	264.3	853.3	0.92CC
K13	0.563	8	37.7	25083.9	0.95	67.0	1408.5	0.92CC
K14	1.089	12	49.5	30389.1	0.97	45.4	1375.8	0.91CC
K15	2.096	12	65.9	46255.8	0.71	31.3	1673.9	0.91CC
K16	0.874	1	0.6	599.6	0.74	0.7	860.8	0.91CC
K17	0.890	-	-	-	-	-	-	0.90CC
K17a	0.555	4	11.8	7958.1	1.00	21.2	1125.3	0.90CC
K18	0.424	7	25.8	16648.1	0.91	60.9	1263.1	0.90CC
K19	1.427	13	66.4	46540.2	0.98	46.5	1667.0	0.90CC
K20	0.597	2	3.3	2458.4	0.70	5.5	957.3	0.88CC
K21	3.002	-	-	-	-	-	-	0.88CC
Totals	36.411	159	739.1	431288.1	0.42	20.3		0.94CC

*Note: Dam node K1 is Millbrook Reservoir. This is not counted as a dam in the number, volume, surface area, diversion and density totals above.

Table F12b Kersbrook Creek Sub-Catchment Urban Node Details.

ID	Total Area (km^2)	No. Houses	Roof Area (m^2)	Connection	Pavement (m^2)	Connection	Rainfall
Kur	0.345	152	200	0.5	200	0.5	0.90CC

Table F13a Sixth Creek Sub-Catchment and Farm Dam Node Details.

ID	Rural Area (km^2)	No. of Dams	Dam Volume (ML)	Dam Surface Area (m^2)	Dam Diversion	Dam Density (ML/km^2)	F_1	Rainfall
S1	0.499	-	-	-	-	-	-	0.90CC
S2	1.368	-	-	-	-	-	-	0.90CC
S3	1.980	-	-	-	-	-	-	0.95CC
S4	0.897	-	-	-	-	-	-	0.97CC
S5	1.751	-	-	-	-	-	-	CC
S6	2.415	-	-	-	-	-	-	CC
S7	0.636	5	15.7	10225.0	1.00	24.7	1151.1	1.09CC
S8	1.029	13	27.8	19582.5	0.50	27.0	1402.3	1.09CC
S9	0.768	2	5.9	3949.7	0.55	7.7	964.3	1.08CC
S10	5.234	-	-	-	-	-	-	1.03CC
S11	1.168	-	-	-	-	-	-	1.03CC
S12	4.769	-	-	-	-	-	-	1.06CC
S13	0.688	4	11.6	7969.5	0.33	16.8	1143.4	1.09CC
S14	0.775	2	5.8	4003.1	0.04	7.5	986.5	1.09CC
S15	0.446	1	0.7	678.8	0.50	1.7	860.2	0.90A
S16	1.316	5	4.9	4187.2	0.65	3.7	1189.3	0.90A
S17	0.595	-	-	-	-	-	-	0.90A
S18	0.424	-	-	-	-	-	-	0.90A
S19	0.560	-	-	-	-	-	-	0.90A
S20	0.731	4	13.4	8571.7	1.00	18.3	1096.7	0.92A
S21	0.964	4	41.5	11950.3	1.00	43.0	621.9	0.92A
S22	1.252	3	11.8	7241.9	0.05	9.5	1019.9	0.92A
S23	1.732	-	-	-	-	-	-	0.92A
S23a	0.353	8	14.8	11018.5	1.00	42.0	1298.0	0.94A
S24	0.990	3	28.7	13632.5	0.53	29.0	949.2	0.97A
S25	0.876	7	20.6	13833.0	0.46	23.6	1252.7	0.95A
S26	2.141	-	-	-	-	-	-	0.87A
S26a	0.623	12	21.8	15904.8	1.00	35.0	1378.0	0.87A
S27	1.419	11	9.3	7683.0	0.21	6.6	1304.9	0.90A
S28	2.191	-	-	-	-	-	-	0.95A
S28a	0.366	9	10.5	8487.9	1.00	28.7	1313.6	0.95A
S29	2.312	-	-	-	-	-	-	A
S29a	0.754	10	28.5	19034.9	0.80	37.8	1336.1	A
Totals	44.022	103	273.4	167954.4	0.18	6.2		1.08CC or 0.87A

*Note: Dam node K1 is Millbrook Reservoir. This is not counted as a dam in the number, volume, surface area, diversion and density totals above.

Table F13b Sixth Creek Sub-Catchment Urban Node Details.

ID	Total Area (km^2)	No. Houses	Roof Area (m^2)	Connection	Pavement (m^2)	Connection	Rainfall
Sur	0.199	94	200	0.5	200	0.5	A

F.2 Water Balance Models

Rural Areas

A modified Australian Water Balance Model (AWBM) (Heneker, 2002) was chosen as the water balance model to transform rainfall into runoff for rural sub-catchments. This is shown in Figure F3 with parameters defined in Table F14. The AWBM is a saturation overland flow model developed by Boughton (1993, 2000). Surface runoff occurs after the soil becomes saturated from below, unlike overland (Hortonian) flow that occurs when the rainfall intensity exceeds the infiltration capacity of the soil. It incorporates an explicit water balance model which uses recorded rainfall and estimates of evapotranspiration to simulate losses and runoff from a catchment area.

The AWBM allows for spatial variability of the catchment by using three surface stores. The different storage capacities (C1-C3) represent partial areas of the catchment (A1-A3), allowing the simulation of partial area runoff. The initial loss from each partial area is therefore dependent on the storage available in each of the surface stores at the commencement of the rainfall event, and any evapotranspiration that occurs during the event. An evaporation multiplier (Em) was used to convert the pan/potential evaporation to evapotranspiration. When each of the surface stores is full, any overflow is partitioned into rainfall excess and baseflow recharge using a baseflow index (BFI). Baseflow then occurs at a rate proportional to the level in the lower store. This modified AWBM differs from the original AWBM as it incorporates daily evaporation data and a linear surface routing store derived from first principles. The linear store was incorporated to simulate routing of the surface runoff, which is required on some catchments when there is a delay between the time of the rainfall occurrence and the appearance of this runoff as streamflow.

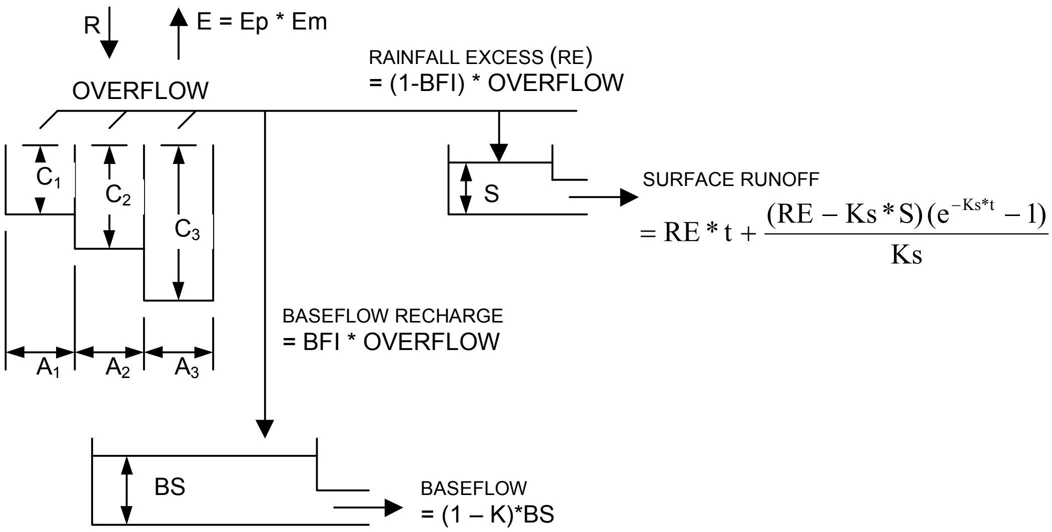


Figure F3 Modified AWBM.

Table F14 Description of Modified AWBM Parameters

Parameter Description	Symbol	Units
Rainfall	P	mm
Capacity of surface stores 1 to 3	C1-C3	mm
Partial area of stores 1 to 3	A1-A3	-
Evaporation multiplier	Em	-
Actual evaporation	E	mm
Baseflow infiltration index	BFI	-
Surface routing store coefficient	Ks	-
Sub-surface routing store coefficient	K	-
Current water level in sub-surface store	BS	mm
Current water level in surface routing store	S	mm
Rainfall excess	RE	mm

Urban Areas

An *initial loss-continuing loss* model is one of the most commonly used loss models in Australia for urban areas and was used to model the rainfall-runoff relationship in urban areas for this study. Shown in Figure F4, the initial loss is the loss that occurs prior to the commencement of surface runoff. The model assumes that no runoff occurs until a given loss volume has been reached and the continuing loss is assumed to be a constant average rate of loss throughout the remainder of the event. For this study, an initial loss of 2 mm/day and a continuing loss of 1 mm/day was used.

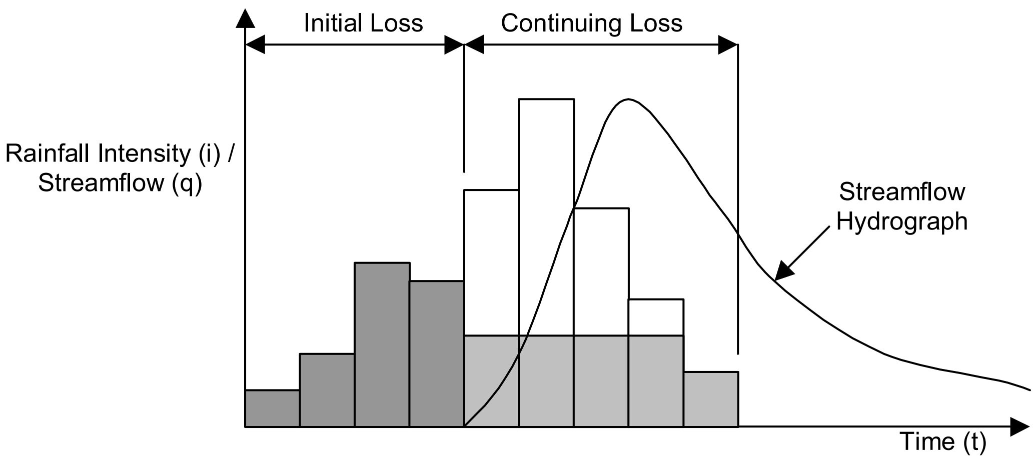


Figure F4 Initial Loss - Continuing Loss Model

F.3 Model Calibration Technique

Calibration of the catchment model with modified AWBM rainfall-runoff model was carried out using the SCE search method (Duan *et al*., 1992; Kuczera, 1997) in the NLFIT program (Kuczera, 1994). This section provides more information on these and the error model used.

SCE Search Method

The SCE search method is a global optimisation procedure that conducts multiple concurrent searches within a multi-dimensional parameter space. This parameter space is defined by the maximum and minimum values of the parameters in the model. Each search is based on a complex (or set) of parameters, which are initially randomly selected from the parameter space. At each iteration, a simplex is randomly selected from each complex and allowed to evolve in a downhill direction using a probabilistic variant of the simplex search method (Press *et al*., 1992), which conducts a local downhill search. The main strength of this algorithm comes form the periodic shuffling and reforming of the complexes that allows global sharing of information about the objective function.

NLFIT Objective Function and Error Model

NLFIT is a Bayesian non-linear regression program to which specific model algorithms or executable programs can be added and subsequently calibrated. The WaterCress program was linked to NLFIT, with the option to calibrate up to four responses, namely daily, monthly and yearly flow values, as well as the daily flow frequency curve.

The *least squares error model* is widely used to describe errors in conceptual rainfall-runoff models. A consequence of this error model is that model parameters are calibrated by searching for the parameters that minimise the sum-of-squares of the residuals (Kuczera, 1994; Sumner *et al*., 1997), which defines the objective function. The residuals are the difference between the observed and predicted (or modelled) data.

Although up to four responses can be calibrated simultaneously, for two of these responses (daily and monthly runoff values) the relationship between the observed and predicted data is defined as:

$$Q_i^d = \hat{Q}_i^d + \varepsilon_i^d \qquad i = 1, \cdots, n \qquad \text{(F.1a)}$$

$$Q_j^m = \hat{Q}_j^m + \varepsilon_j^m \qquad j = 1, \cdots, m \qquad \text{(F.1b)}$$

where :

Q_i^d = observed daily runoff on day *i*;

$\hat{Q}_i^d$ = predicted daily runoff on day *i*;

ε_i^d = residual or random error in daily runoff on day *i*;

n = number of observations in the daily runoff response;

Q_j^m = observed monthly runoff in month *j*;

$\hat{Q}_j^m$ = predicted monthly runoff in month *j*;

ε_j^m = residual or random error in monthly runoff of month *j*; and

m = number of observations in the monthly runoff response.

The residuals are estimates of ε (Kuczera, 1994). The least squares model assumes that the expected value of ε is zero, the variance of ε is constant and that the residuals are statistically independent.

In order to simultaneously calibrate the daily and monthly runoff values, the error model is generalised within NLFIT using a generalised least squares approach. In the context of this application the generalised least squares is implemented by dividing for each response, the sum of the squares of the residuals by an estimate of the residual variance, thereby standardising or non-dimensionalising the residuals. It is then meaningful to add these standardised sum-of-squares terms together to form a joint objective function.

Correlation Statistics

Correlation statistics are used to determine how well a model is able to reproduce the observed data. Two common statistics for this assessment are the coefficient of determination (R^2) and the coefficient of efficiency (E).

The coefficient of determination is the square of the Pearson's product moment correlation coefficient and describes the proportion of the total variance in the observed data that can be explained by the model. R^2 describes a relationship between the observed and predicted (modelled data) and is defined (Legates and McCabe, 1999) as:

$$R^2 = \left\{ \frac{\sum_{i=1}^{N}\left(O_i - \overline{O}\right)\left(P_i - \overline{P}\right)}{\left[\sum_{i=1}^{N}\left(O_i - \overline{O}\right)^2\right]^{0.5}\left[\sum_{i=1}^{N}\left(P_i - \overline{P}\right)^2\right]^{0.5}} \right\}^2 \tag{F.2}$$

where:

O_i = *i*th observed data point;

$\overline{O}$ = mean of the observed data;

P_i = *i*th predicted data point; and

$\overline{P}$ = mean of the predicted data.

The value of R^2 ranges from 0.0 to 1.0 with values close to 1.0 indicating better correlation.

While a high value of R^2 only indicates high correlation it does not necessarily mean that the predicted values are equal to the observed values. For this reason the coefficient of efficiency is often considered a better comparison tool because it is sensitive to differences in the observed and predicted means and variances. This is defined (Legates and McCabe, 1999) as:

$$E = 1.0 - \frac{\sum_{i=1}^{N}\left(O_i - P_i\right)^2}{\sum_{i=1}^{N}\left(O_i - \overline{O}\right)^2} \tag{F.3}$$

E ranges from minus infinity to 1.0, with values close to 1.0 again indicating a good approximation of the observed data by the model. A value of E less than zero indicates that $\overline{O}$ is a better predictor than P_i (Legates and McCabe, 1999).

F.4 Model Parameters

Calibration of the hydrological model produced five modified AWBM parameter sets for the four gauged catchments: Set 1 (Mount Pleasant), Set 2 (Gumeracha Weir), Set 10 (Sixth Creek) and Set 11 (Kersbrook Creek). An additional parameter set (Set 3) was used to route the Mannum-Adelaide pipeline discharges from Mount Pleasant and Angas Creek to Gumeracha and simulate transmission losses. Therefore, this was not required when “natural” flow was simulated during the model scenario evaluation stage.

The area downstream of Gumeracha Weir, not including Sixth Creek and Kersbrook Creek, was not gauged and therefore parameter sets were determined from adjacent catchments. The parameter sets used for each major sub-catchment are as follows:

Set 1: Mount Pleasant;

Set 2: Birdwood, Hannaford Creek, Angas Creek, Gumeracha, McCormick Creek, Footes Creek, Kenton Valley and Millers Creek;

Set 6: Cudlee Creek;

Set 8: Kangaroo Creek;

Set 10: Sixth Creek; and

Set 11: Kersbrook Creek.

Set 6 for Cudlee Creek was based on Set 10 for Sixth Creek, and Set 8 for Kangaroo Creek on Set 2 from Gumeracha Weir. Table F15 presents the values for each set.

Table F15 Model Parameters

Parameter	Set 1	Set 2	Set 3	Set 6	Set 8	Set 10	Set 11
C_1	18.0	16.4	20.0	20.0	20.0	17.0	5.0
C_2	241.2	0.0	182.2	235.0	235.0	235.0	223.9
C_3	295.0	0.0	371.3	435.0	435.0	435.0	347.3
A_1	0.125	0.25	0.07	0.14	0.12	0.14	0.11
A_2	0.220	-	0.47	0.12	0.14	0.12	0.15
A_3	0.655	-	0.46	0.74	0.74	0.74	0.74
Em	0.830	-	0.90	0.90	0.90	0.90	0.90
BFI	0.085	-	0.17	0.39	0.30	0.39	0.31
K	0.955	-	0.985	0.989	0.985	0.989	0.80
Ks	2.400	1.663	1.426	1.586	1.500	1.586	2.50

F.5 *Model Calibration Results*

The WaterCress model with modified AWBM rainfall-runoff model was calibrated using the daily rainfall and evaporation data (Sections 3.1 and 3.2) to the streamflow data (Section 3.3) available for the sub-catchments upstream of the four gauging stations as follows:

1. River Torrens @ Mount Pleasant (AW504512);
2. Sixth Creek @ Castambul (AW504523);
3. Kersbrook Creek @ u/s Millbrook Reservoir (AW504525); and
4. River Torrens @ Gumeracha Weir (AW504500).

As in Section 4.3, the analysis in the following sections refers to these as the Mount Pleasant, Sixth Creek, Kersbrook Creek and Gumeracha Weir sub-catchments respectively.

The appropriateness of the calibrated parameters was assessed by comparing the values predicted by the model with observed data at annual, monthly and daily time-scales and by comparing daily flow frequency curves. In Section 4.3.2 an analysis was provided for the Mount Pleasant sub-catchment (AW504512), where the results showed a successful calibration of model parameters. Results are presented here for the remaining sub-catchments.

Figures F5 to F7 show the observed and modelled streamflow data for the respective sub-catchments over varying calibration periods, together with the correlation (R^2) between the daily values for each year. At each location a reasonable representation of the annual streamflow values were obtained. As for the Mount Pleasant sub-catchment, better daily correlations were obtained in average and above average rainfall and hence flow years. Correlations for the Gumeracha Weir sub-catchment were good for all years.

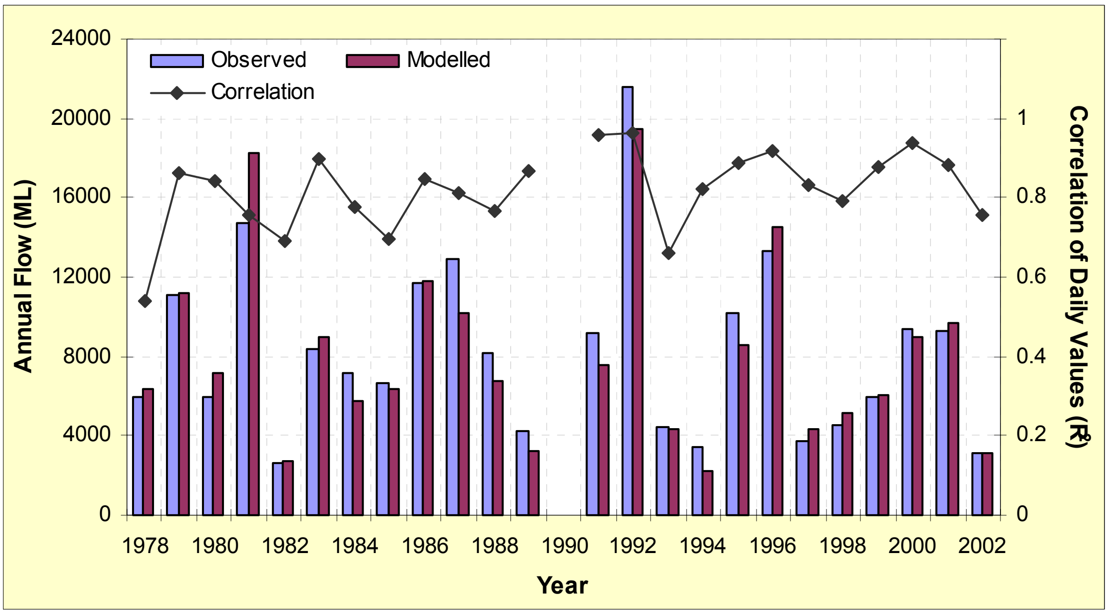


Figure F5 Observed and Modelled Annual Streamflow Data for the Sixth Creek Gauged Catchment (AW504523).

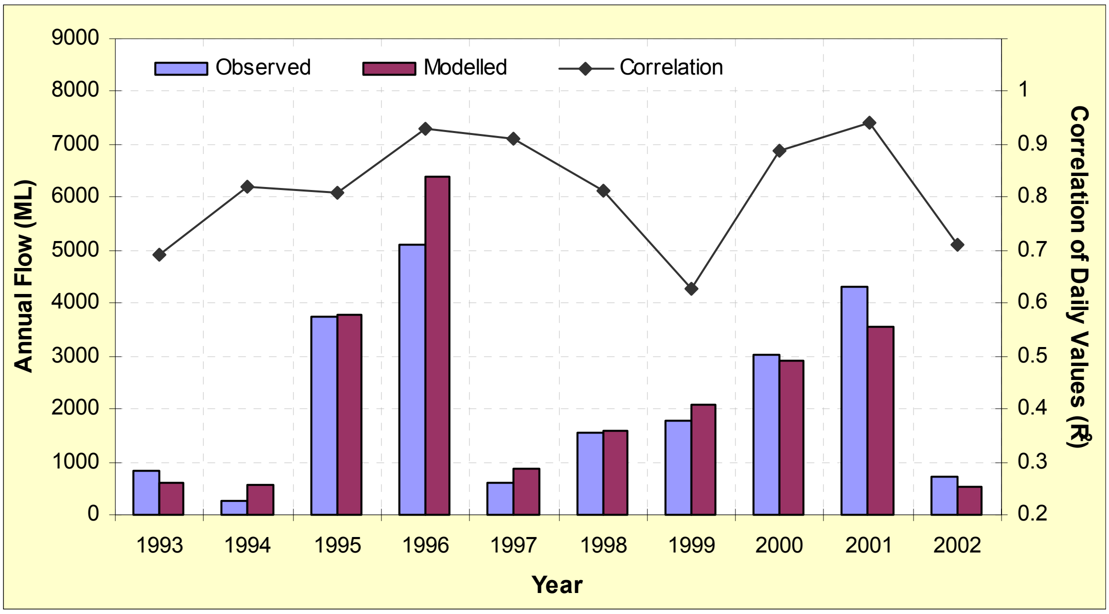


Figure F6 Observed and Modelled Annual Streamflow Data for the Kersbrook Creek Gauged Catchment (AW504525).

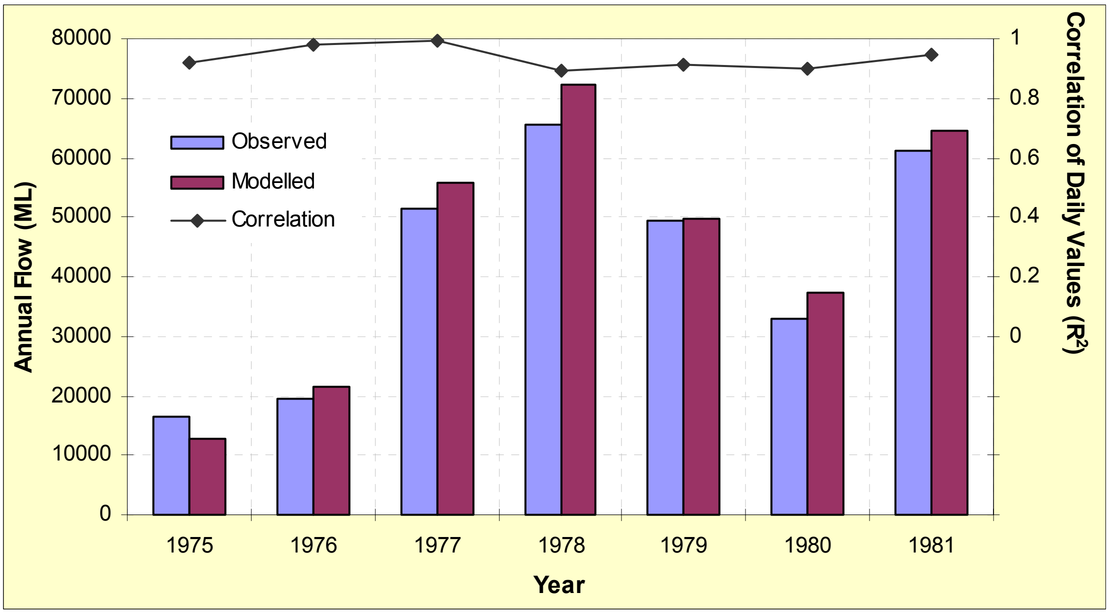


Figure F7 Observed and Modelled Annual Streamflow Data for the Gumeracha Weir Gauged Catchment (AW504500).

Figures F8 to F10 show the observed and modelled mean monthly streamflow values for the respective sub-catchments. A generally good representation is obtained for each sub-catchment. A good correlation (R^2) between the monthly values is also obtained for most months. Less satisfactory correlations were obtained for March and April, in addition to December for Kersbrook Creek. This was explained in Section 4.3.2.

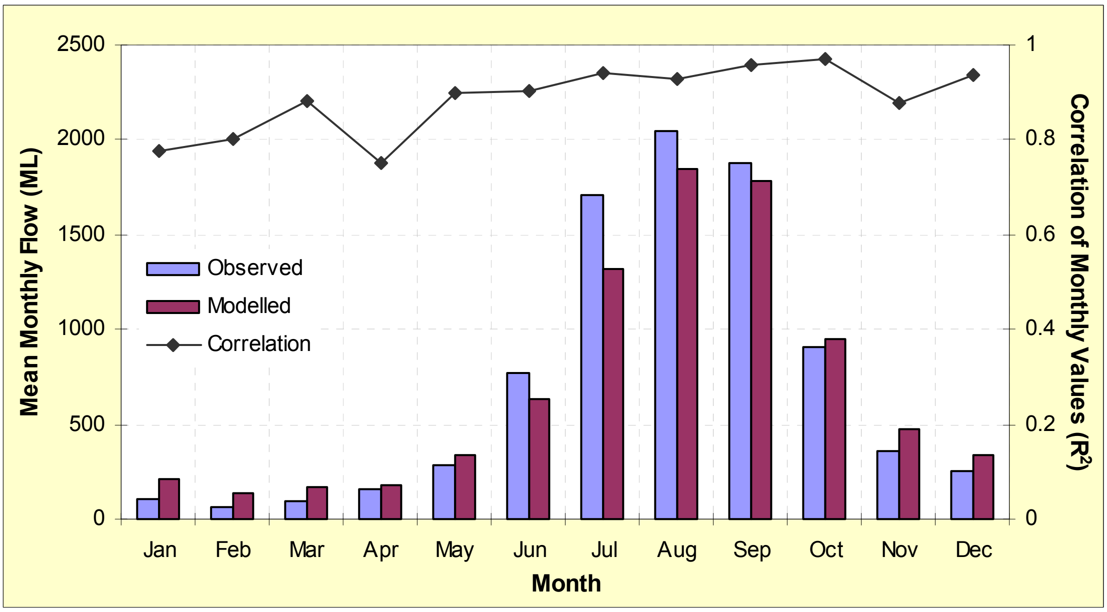


Figure F8 Observed and Modelled Monthly Streamflow Data for the Sixth Creek Gauged Catchment (AW504523).

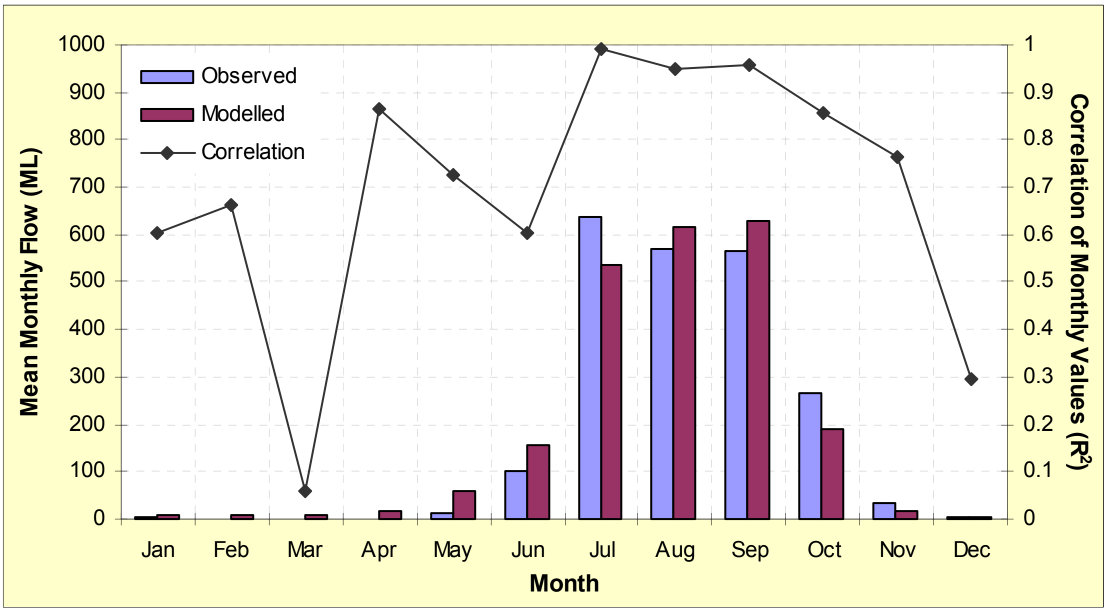


Figure F9 Observed and Modelled Monthly Streamflow Data for the Kersbrook Creek Gauged Catchment (AW504525).

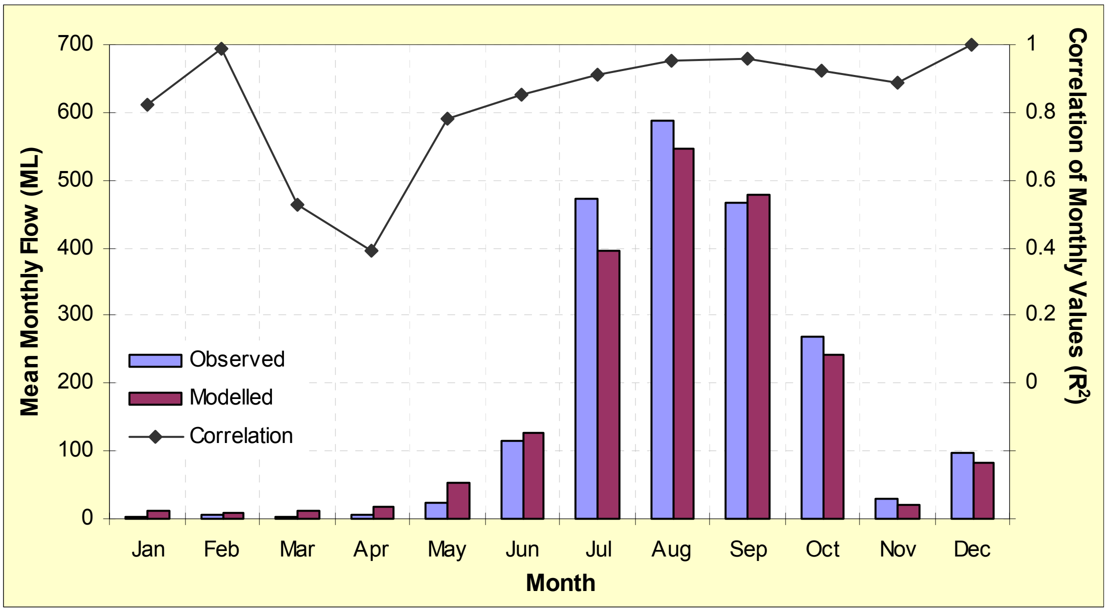


Figure F10 Observed and Modelled Monthly Streamflow Data for the Gumeracha Weir Gauged Catchment (AW504500).

Figures F11 to F13 show the flow frequency curves for each sub-catchment. There are a number of points to note:

- The curve for the Sixth Creek gauging station is generally well reproduced with only the calibration of lower flows being less accurate. The control section for this gauging station is a concrete crump weir (refer Appendix E.1), which is less sensitive at low flow levels;
- The curve for the Kersbrook Creek gauging station is not well reproduced below a flow of approximately 2 ML/day. Calibration at this gauging station was difficult and the representation of this flow frequency curve was a compromise between (a) a good representation to 0.3 ML/day but an extended tail and cease to flow for only 10% of the year as opposed to 60% and (b) a severely underestimated period between 5 ML/day and 0.01 ML/day but a cease to flow for 60% of the year. It is thought that there may be a large amount of transmission losses, which reduce the low flow events such that the creek only flows for 60% of the year. However, the model was unable to capture this.
- The shape of the curve for Gumeracha Weir is different to the other curves, mainly because of the M-A pipeline transfers. These transfers made calibration more difficult. In addition, because Gumeracha Weir is a broad rectangular structure (dimensions 2.44m by 34.4m), it would be very insensitive at low flows, particularly below 1 ML/day and possibly up to 10 ML/day.

Figures F14 to F17 show annual, monthly and daily streamflow traces at each of the gauging stations. In each case, the model was able to provide a reasonable replication of the observed data.

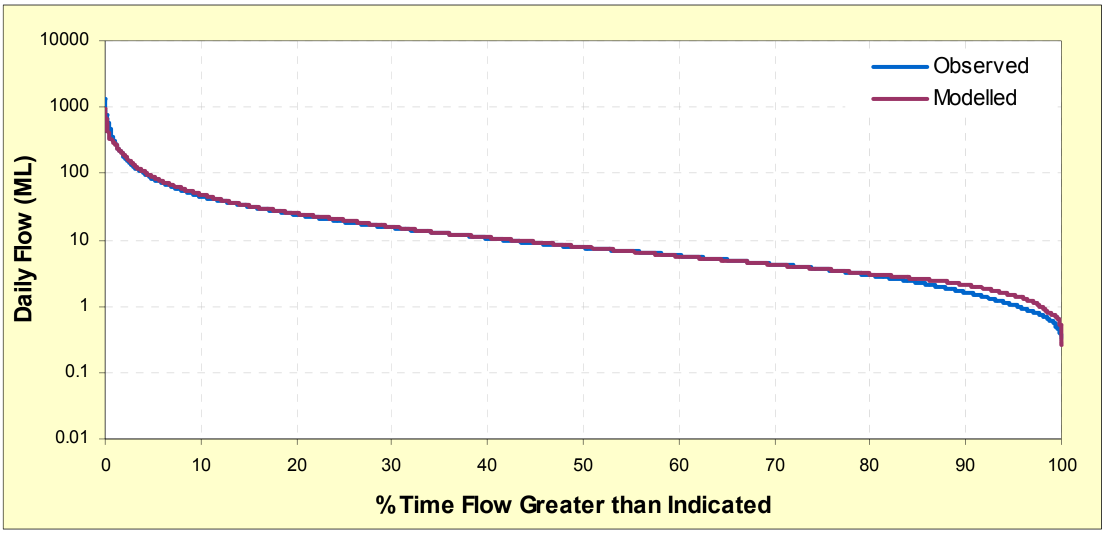


Figure F11 Observed and Modelled Flow Frequency Curve for Sixth Creek (AW504523).

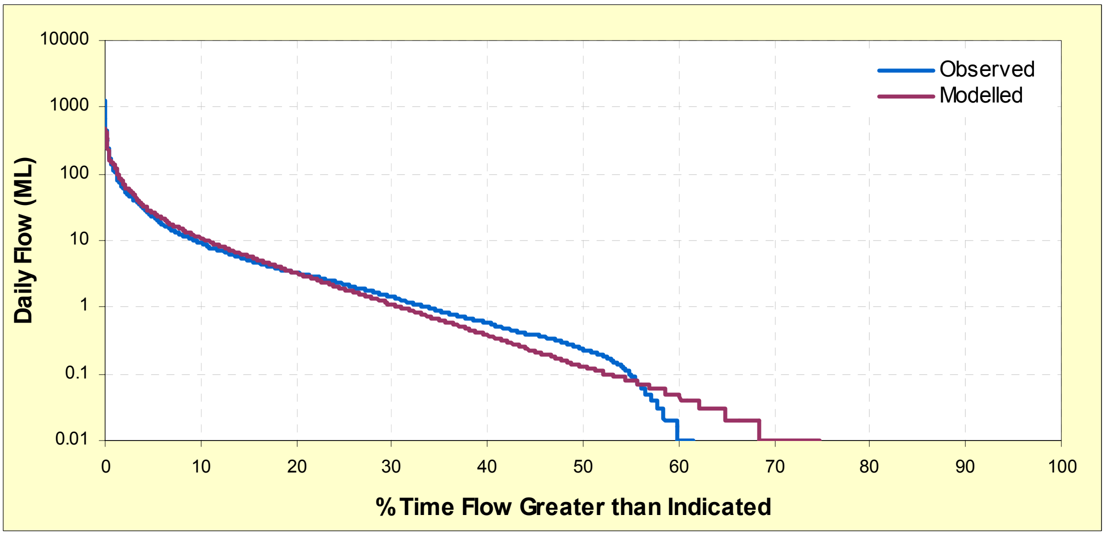


Figure F12 Observed and Modelled Flow Frequency Curve for Kersbrook Creek (AW504525).

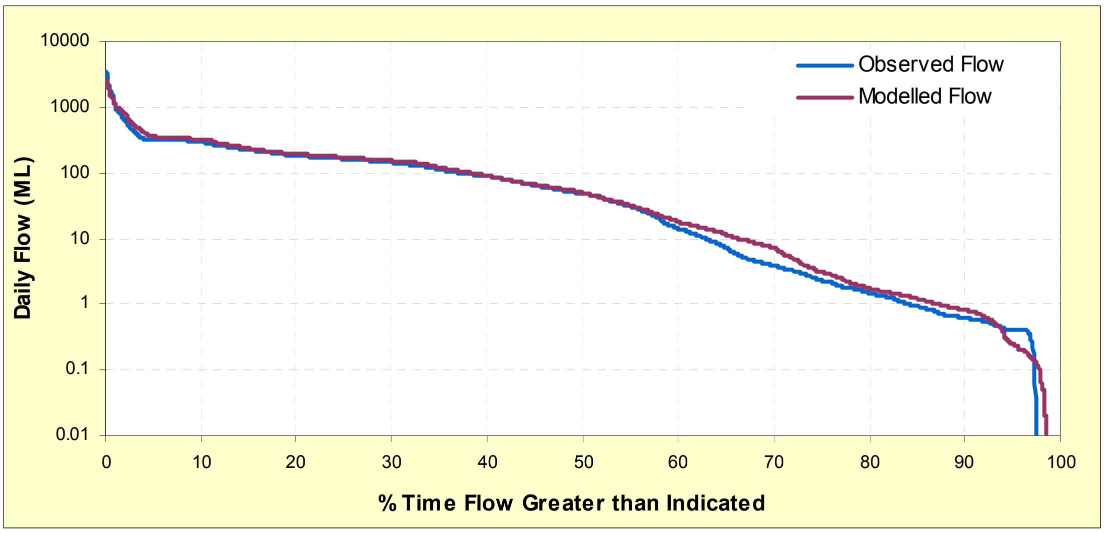
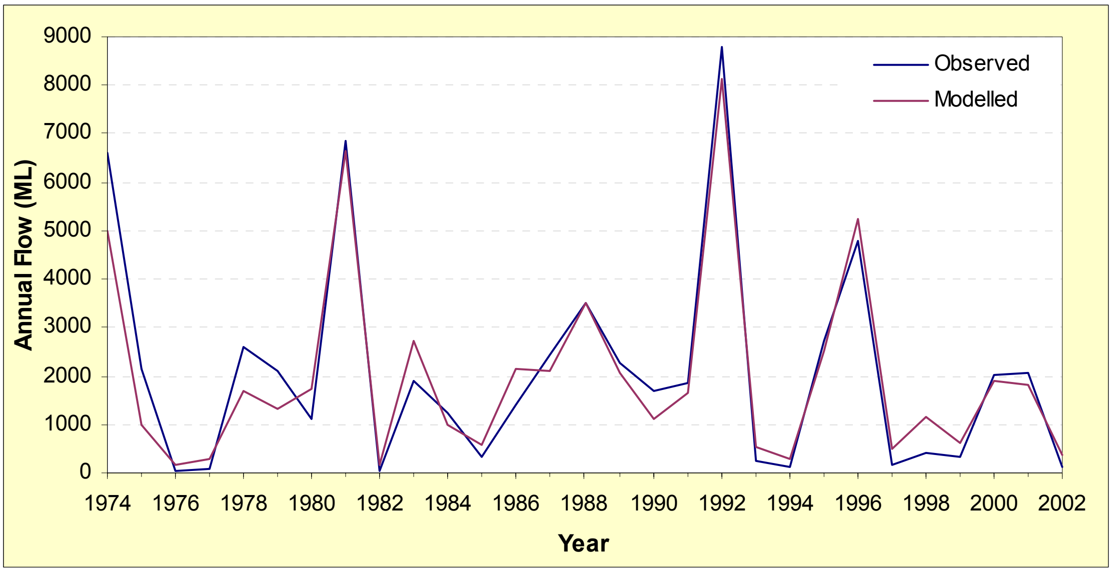
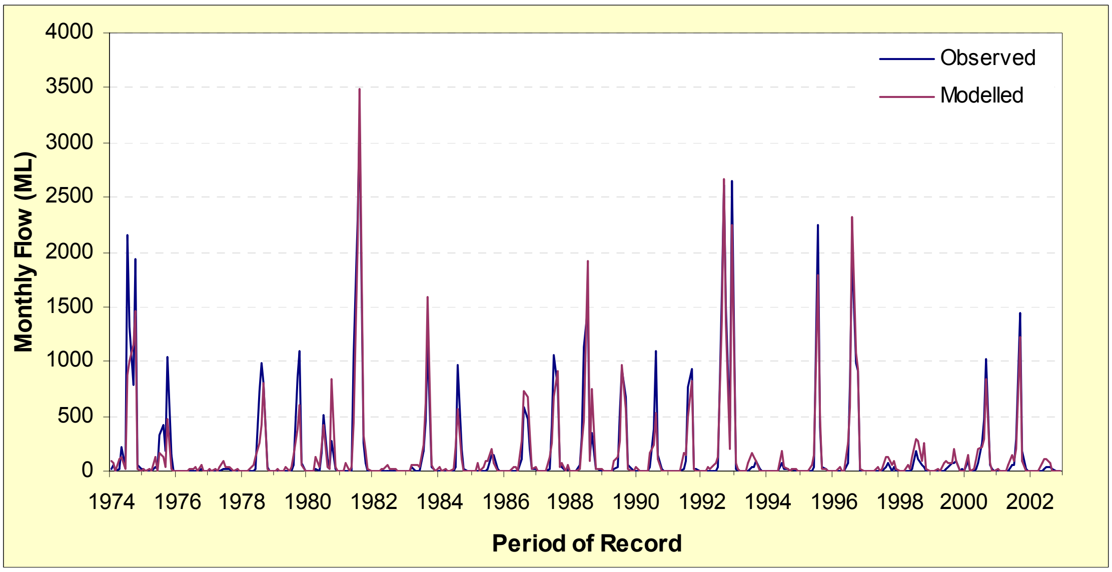


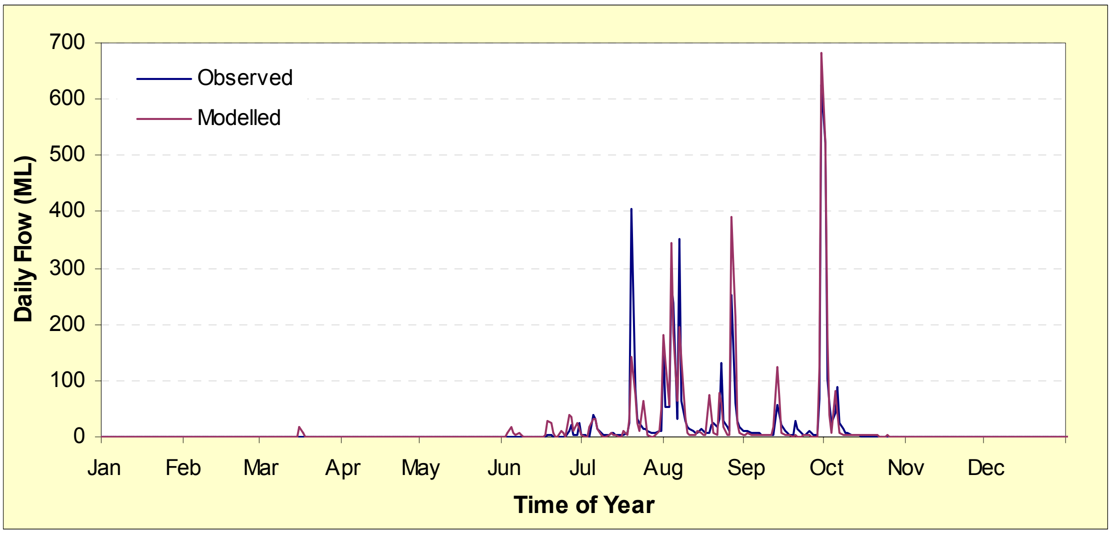
Figure F13 Observed and Modelled Flow Frequency Curve for Gumeracha Weir (AW504500).



(a)

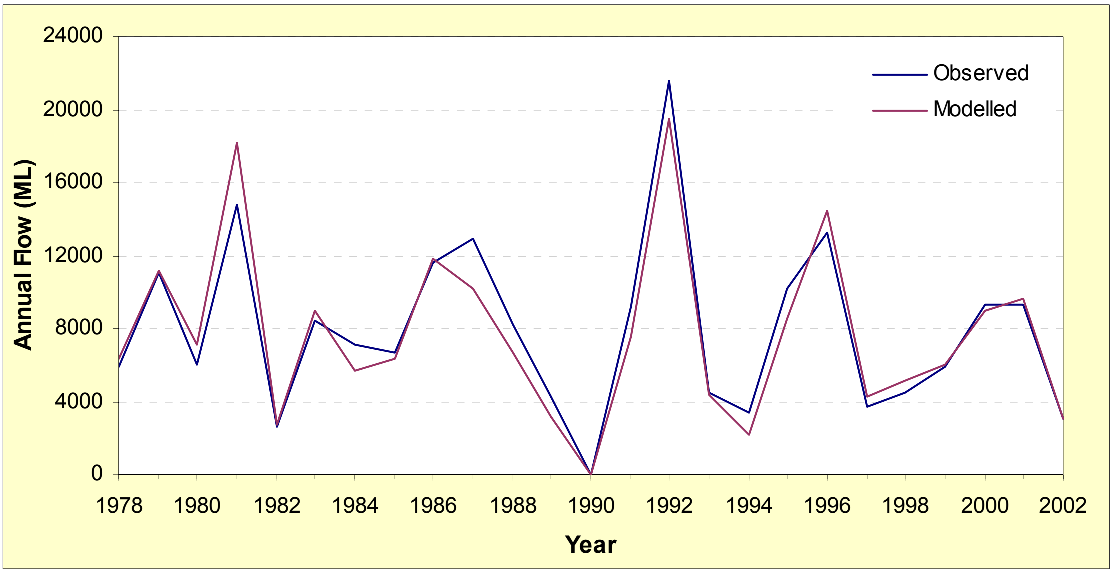


(b)

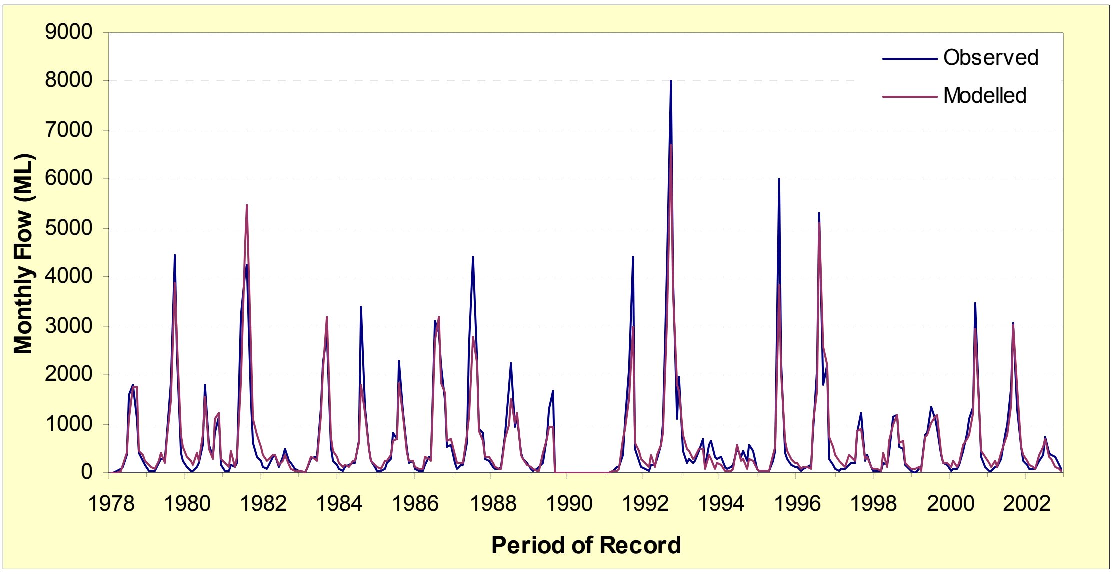


(c)

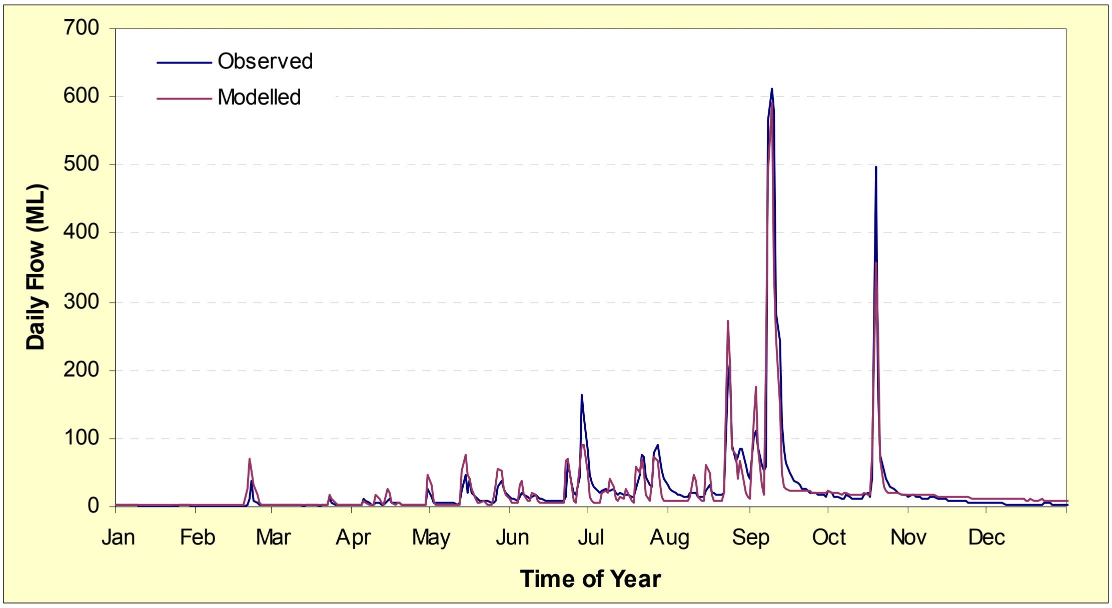
Figure F14 Annual, Monthly and Daily (1996) Flow at Mount Pleasant (AW504512).



(a)

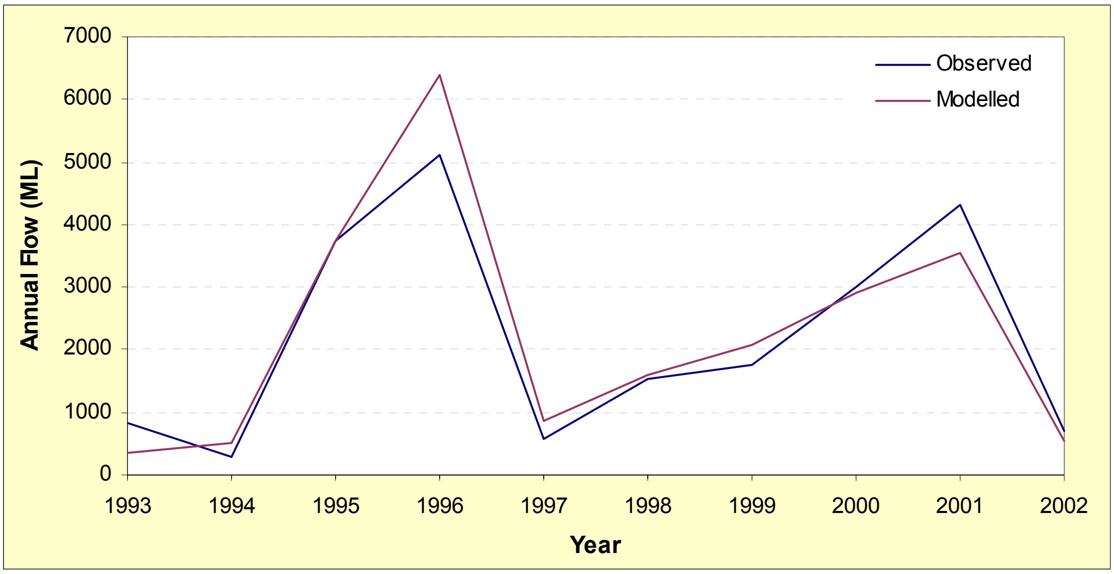


(b)

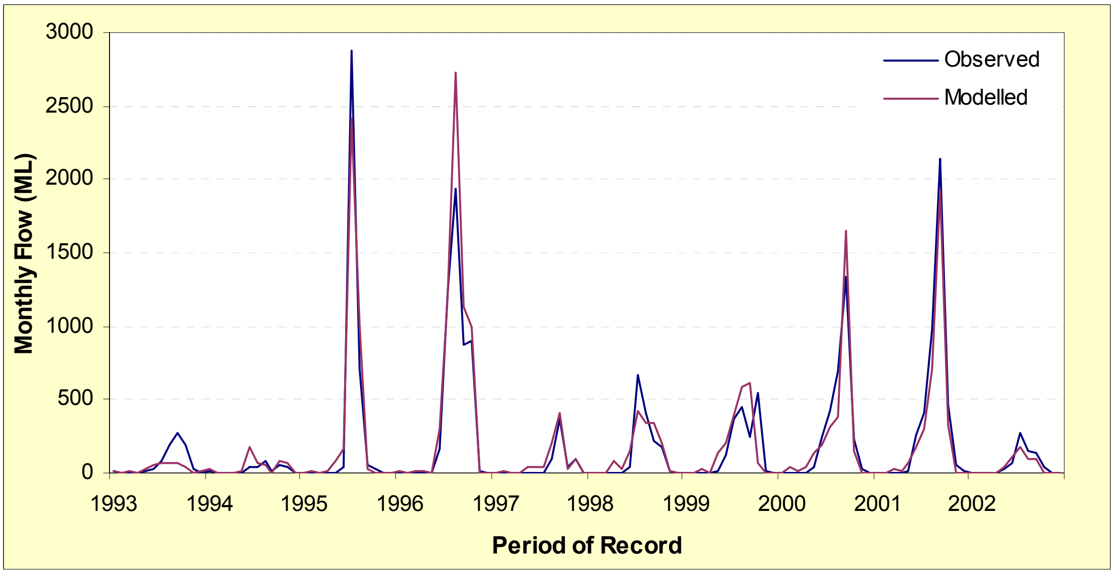


(c)

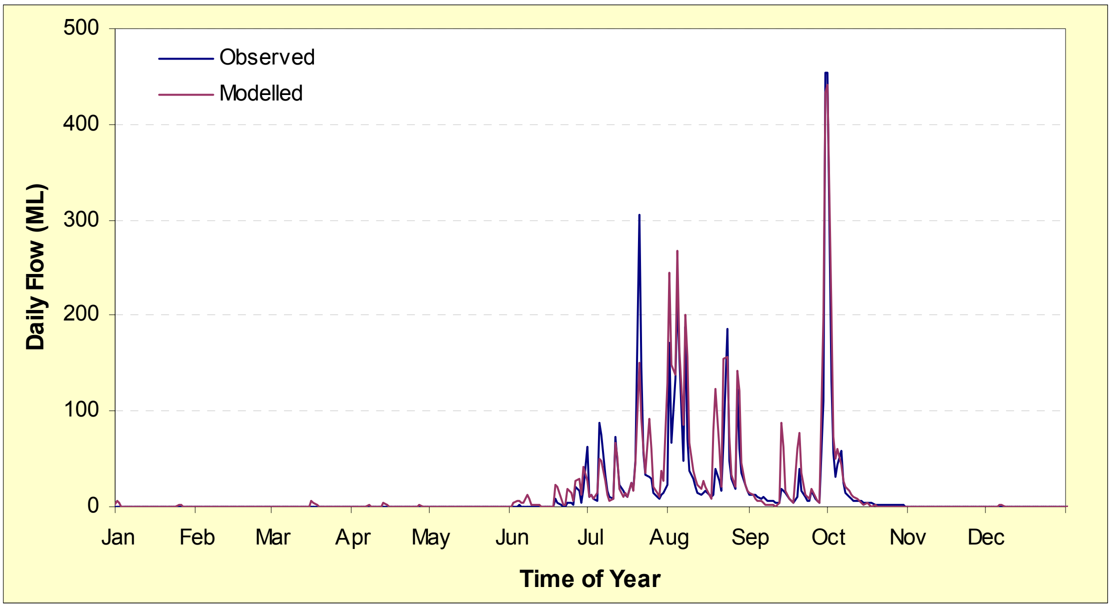
Figure F15 Annual, Monthly and Daily (2000) Flow at Sixth Creek (AW504523).



(a)



(b)



(c)

Figure F16 Annual, Monthly and Daily (1996) Flow at Kersbrook Creek (AW504525).

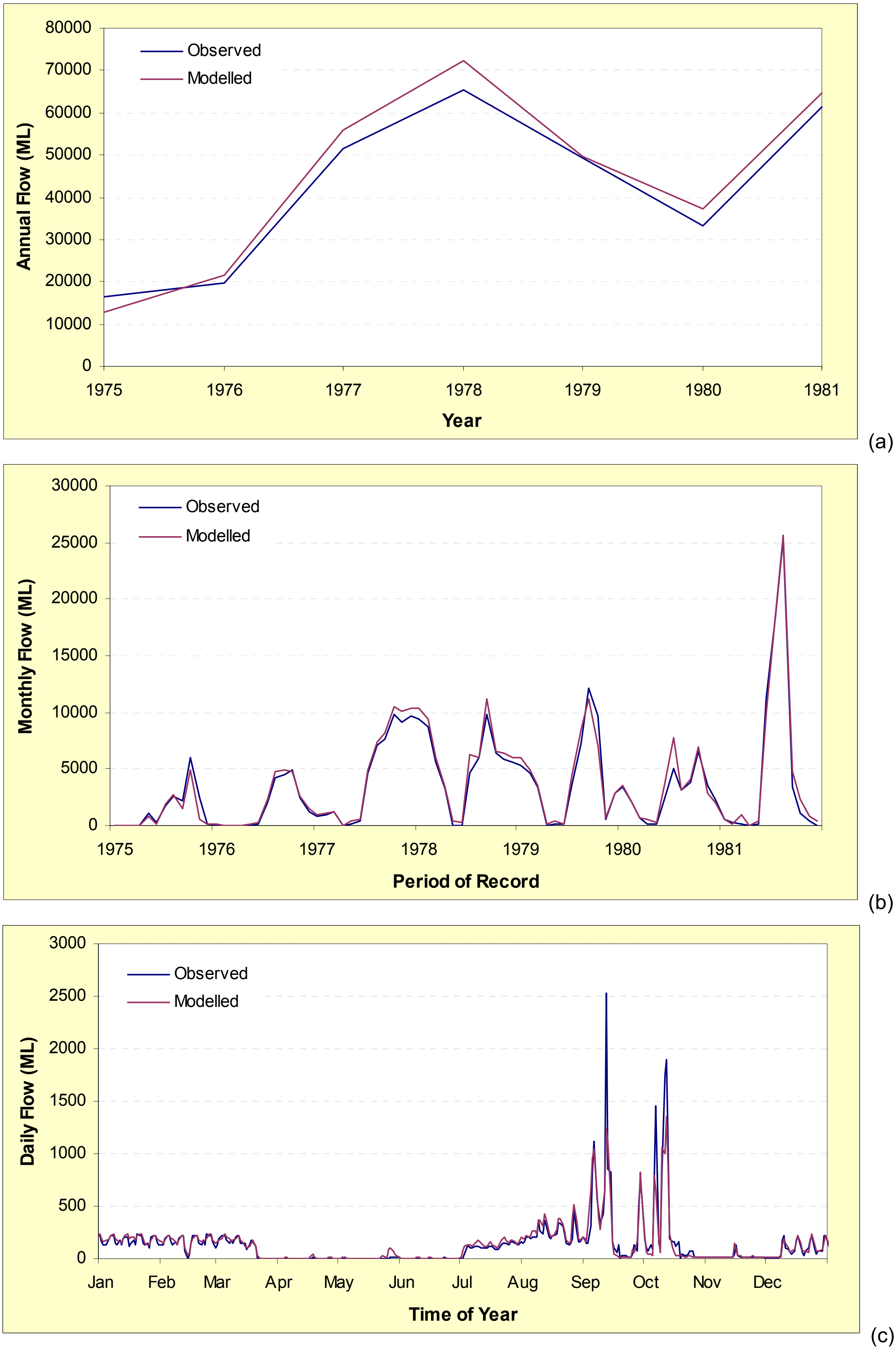


Figure F17 Annual, Monthly and Daily (1979) Flow at Gumeracha Weir (AW504500).