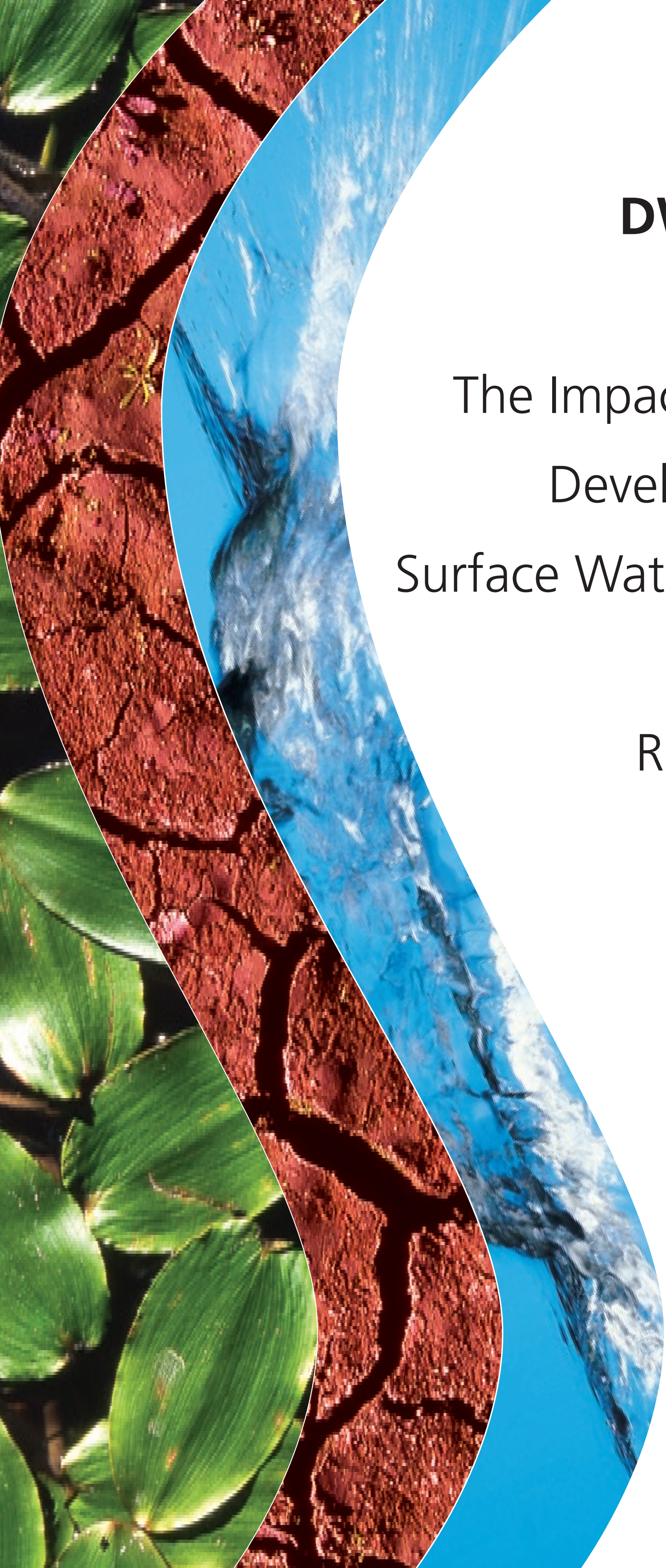

DWLBC REPORT

The Impact of Farm Dam Development on the Surface Water Resources of the South Para River Catchment

2003/19

Government of South Australia
Department of Water, Land and Biodiversity Conservation

The Impact of Farm Dam Development on the Surface Water Resources of the South Para River Catchment

Kim Teoh

Knowledge and Information Division
Department of Water, Land and Biodiversity Conservation

June 2006

Report DWLBC 2003/19

Government of South Australia
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Knowledge and Information Division

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FOREWORD

South Australia's unique and precious natural resources are fundamental to the economic and social wellbeing of the State. It is critical that these resources are managed in a sustainable manner to safeguard them both for current users and for future generations.

The Department of Water, Land and Biodiversity Conservation (DWLBC) strives to ensure that our natural resources are managed so that they are available for all users, including the environment.

In order for us to best manage these natural resources it is imperative that we have a sound knowledge of their condition and how they are likely to respond to management changes. DWLBC scientific and technical staff continues to improve this knowledge through undertaking investigations, technical reviews and resource modelling.

Rob Freeman
CHIEF EXECUTIVE
DEPARTMENT OF WATER, LAND AND BIODIVERSITY CONSERVATION

ACKNOWLEDGEMENTS

The study is funded by the Mt Lofty Ranges Initiative Program with the Department of Water, Land and Biodiversity Conservation (DWLBC) as the lead agency, in partnership with the Northern Adelaide and Barossa Catchment Water Management Board (NABCWMB), now forming part of the Adelaide and Mount Lofty Ranges Natural Resources Management Board, and the South Australian Water Corporation (SA Water).

In particular, the writer wishes to thank Rob Leaney, Bruce Murdoch and Tony Thomson for their assistance in data analysis, David Cresswell for his comments in writing this report and Richard Clark of Richard Clark and Associates for his peer review.

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EXECUTIVE SUMMARY

This report describes a hydrological study of the impact of the reservoirs and the current and possible future farm dam developments on the South Para River catchment flows.

The Department of Land, Water and Biodiversity Conservation, under the Mt Lofty Ranges Initiative Program, undertook this study in conjunction with the Northern Adelaide and Barossa Catchment Water Management Board (now the Adelaide Mount Lofty Ranges Natural Resources Management Board) and the South Australian Water Corporation.

The South Para River is an important water resource catchment. It provides the major source of surface water for the Northern Metropolitan Adelaide and the Barossa Valley water supply system, the irrigation of crops and stock and domestic water use.

1999 farm dam data (current) shows the South Para catchment has 979 farm dams with an aggregated storage of 3000 ML. 868 dams are less than 5 ML capacity and 21 dams are larger than 20 ML. They each constitute about a third of the aggregated volume. In contrast, the capacity of the Warren, South Para and Barossa reservoirs is 54 600 ML.

Recent increased demand for irrigation water due to the expansion of viticulture in the Barossa Valley has caused an expansion in the number and size of farm dams. This has the potential to exacerbate environmental stresses within the catchment and further reduce the inflows into the reservoirs.

The study has involved the steps:

1. Sourcing, processing and validating the available data sets.
2. Constructing a hydrological model and performing a model calibration based on current (1999 data) farm dam data and an assumed water use from the dams of 30% of their storage capacity.
3. Modelling to obtain results for five farm dam development scenarios.

For the purposes of the study the catchment has been divided into three approximately equal areas. The Upper and Middle catchments include all subcatchments feeding into the Warren reservoir and to the Barossa weir, respectively. The Middle catchment includes the catchment containing the Barossa reservoir. The downstream limit of the Lower catchment has been taken at the gauging station situated 2.6 km SE of Gawler (SE of Gawler Station). The modelling focussed on estimating catchment flows and did not specifically address the processes or operations of the reservoirs.

Modelling over the period 1884–1998 shows that the total average and median year pre-development flows for the three catchments (i.e. assuming no losses or diversions via farm dams or reservoirs) would have been 35 359 ML/a and 32 200 ML/a, respectively. In a median year the Lower catchment contributes about 4200 ML/a and the balance is approximately equally split between the Upper and Middle catchments. The average flows during the three-year driest and wettest periods would have been 13 680 ML/a and 62 990 ML/a.

The Consultants Sinclair Knight Merz (SKM, 2001) estimated the average flow to be 42 805 ML/a or about 7 446 ML greater than estimated in this study. There appears good evidence to suggest that SKM may have overestimated the flow in the Lower catchment by 4000 ML/a (probably due to double accounting for spills at the Barossa weir).

Modelling shows that the current level of farm dam development has reduced the predevelopment median flow for the whole catchment by about 7%. At the subcatchment level, the reduction depends on the density of dam development, but, other things being equal, is proportionately greater for the lower rainfall areas (and, of course, is greatest immediately downstream of any storage). The reservoirs have a much greater effect on flows. Under current reservoir and farm dam conditions, the flows from the catchment outlet at the SE of Gawler Station in a median year have been reduced by 90% from their original level.

At the Barossa weir, from 1967–96, water data shows that on average about 21 671 ML/a was diverted from the Middle and Upper catchments for water supply. The volume includes 4233 ML/a supplemented from the River Murray. The estimated average catchment pre-development inflow for the Middle and Upper catchment was 30 200 ML/a, ~2130 ML/a would have been intercepted via farm dams and 3529 ML/a spilled via the weir. By difference, the unaccounted losses from the three reservoirs must have been about 7103 ML/a. This is equivalent to about 1100 mm/a of evaporation loss from the combined surface areas of the reservoirs at full supply, but may reflect other unaccounted losses or data inaccuracies. Thus about 88% of the upstream catchment flow has been intercepted. Since the spills over the Barossa weir only now occur on average about once every five years, the median flow just downstream of the weir is zero.

As a result, the water dependent ecosystems below the Barossa Diversion Weir have become significantly ecologically stressed (Philpott et al., 1999).

The results show that large dams have better efficiency than smaller dams when measured in terms of the percentage that the water use (i.e. supply from the dam) comprises of the total reduction in flow caused by the dam. For the reservoirs the efficiency is 75% while for the farm dams it is only about 35%. It is likely that many of the smaller, shallower farm dams (particularly those used for stock watering only) have supply efficiencies of only a few percent. These low efficiencies imply that the use of groundwater may be a far more efficient means for supplying water in many situations

The sensitivity of the level of use taken from farm dams was investigated. If the annual usage rose from the assumed level of 30% of the dam capacities to 70% (say as a response to limits being placed on further dam capacity increases) the reduction due to farm dams only increased by about 50%.

The annual rainfall to runoff relationship is non-linear and can be fitted using a (Tanh type) curve with a threshold for runoff commencement at about 400–450 mm/a. The predevelopment runoff coefficients were estimated to be 16% for both the Upper and Middle catchments and only 8% for the Lower catchment.

Since the farm dam development guidelines provided in the Northern Adelaide and Barossa Catchment Water Management Plan (NABCWMP) 2001–2006 assume a blanket runoff coefficient of 10% across the whole catchment, application of the guidelines might over-allocate the aggregated total of dam capacities in the Lower catchment and under-allocate the totals in the Middle and Upper catchments. The State Natural Resources Management

Plan 2006 mentions that outside the prescribed area, surface water and watercourse water use may be allowed up to 25% of the annual predevelopment median flow as the sustainable limit. This means farm dam capacities should not exceed 50% of the median flow, allowing another 25% of flow being for dam water evaporation and losses (State Water Plan, 2000).

Inclusive of the reservoirs, the capacity to predevelopment flow has been increased to 180% or 3.6 times the allowable level (16 100 ML) limit of sustainability defined in SWP 2000.

There is a potential for further reduction of inflows into the reservoirs by up to 4200 ML of the median flows if farm dams were allowed to be developed to its maximum 50% rule capacity and dam water use were increased to 70% of storage capacity.

RECOMMENDATIONS

REVIEW NORTHERN ADELAIDE AND BAROSSA CATCHMENT WATER MANAGEMENT PLAN 2001–2006 GUIDELINES

The NAB CWMP 2001–2006 guidelines for farm dam development should be modified in the light of the findings on the percentage runoff for the different subcatchments of the South Para River catchment determined in this study. For ungauged catchments, where runoff is deemed to be similar to that observed in the South Para subcatchments, the Tanh curves produced in this report may be used to estimate runoff via estimation of the mean annual rainfall for the subcatchments.

Future policies for farm dam development should also take into account:

- the sizes and spatial distribution of farm dams in the upstream catchment
- the possible increased usage of dam water from the assumed current level of 30% of the storage capacity to as high as 70%
- the need to provide environmental flows downstream of the dams.

Since the greatest flow reductions have been shown to be in the reaches downstream of the reservoirs, consideration should be given to instituting environmental flow releases from the reservoirs.

INFORMATION GAPS

The following are recommendations to address information gaps:

- establish streamflow monitoring stations upstream of the Warren and South Para Reservoirs in order to monitor the inflows to the reservoirs
- monitor the diversion from the Barossa diversion weir to the Barossa reservoir
- verify the accuracy of the empirical rating curves for the spills over the Barossa diversion weir and the Warren reservoir with field measurements
- account for flows via the reservoir and weir scour valves
- meter transfers from the River Murray to the Warren reservoir and Barossa Infrastructure Limited (BIL) Scheme
- quantify the recharge and discharge zones within the South Para River catchment

- survey the irrigation water use, separating the contributions from surface and ground water
- improve the accuracy of estimation of dam volumes, usage and losses via evaporation and leakage, particularly for large irrigation dams
- investigate the effects on downstream flows of variations in the sizes and spatial distributions of farm dams when aggregated into a single effective dam volume
- investigate the separate effects on downstream flows of the irrigation dams and of the changed vegetation and land practices associated with the dams.

1. INTRODUCTION

1.1 PURPOSE

This report describes the methodology and results of a hydrologic study into the impact of farm dams on the stream flow in the South Para River catchment. The study is funded by the Mt Lofty Ranges Initiative Program with the DWLBC as the lead agency, in partnership with the NABCWMB and SA Water.

1.2 BACKGROUND

South Para River catchment lies in the area administered by the NABCWMB, now the Adelaide and Mt Lofty Ranges Natural Resource Management Board (AMLRNRMB). Under the *Natural Resource Management Act 2004*, the NABCWMB is required to manage the development and use of all water resources within the catchments within its administrative area.

In 2001, the NABCWMB produced a Catchment Water Management Plan 2001–2006 (NABCWMP), which clearly identified the unsustainable use of water resources as the main cause of catchment degradation. To maintain sustainable water use, one of the strategy actions in the Plan recommended a review of farm dam development in non-prescribed areas.

The South Para River catchment fits into this description. There is increasing demand for farm dams to irrigate the expansion of viticulture beyond the Barossa Valley. SA Water also has a substantial interest in the water resources of the South Para River catchment, via its diversion of water to its supply systems via the Barossa diversion weir. The reaches downstream of the Barossa weir are particularly impacted by these diversions (Philpott, et al. 1999) and there is pressure to institute environmental flow releases from all storages in order to address this issue.

1.3 APPROACH TO STUDY

The approach to the study has involved five steps:

1. Sourcing, processing and validating the available data, including rainfall, evaporation, streamflow, farm dam operations and land use.
2. Constructing a hydrological model and performing a model calibration using this data.
3. Identifying modelling scenarios for current and future farm dam development. Five modelling scenarios have been identified for the South Para River Catchment.
4. Performing runoff simulations under these scenarios, varying the level of annual dam water demand from the dams in steps of 30%, 50% and 70% of their storage. Daily rainfall records from 1884–1998 were used for runoff simulation in order to include a wide range of historical climatic conditions.
5. Interpreting and presenting the runoff simulation results for these different scenarios under different operational assumptions.

2. CATCHMENT DESCRIPTION

2.1 OVERVIEW

The South Para River catchment is located about 60 km northeast of Adelaide. The catchment above the junction of the South Para River with the North Para River has an area of 337 km^2. However, for this study, the catchment was modelled up to the SE of Gawler Station giving a total of 324.1 km^2 of catchment area. The catchment model was subdivided into three major subcatchments, namely the Upper (118.6 km^2), Middle (115.4 km^2) inclusive of the Barossa reservoir catchment, and Lower (90.1 km^2) catchment as shown in Figure 1.

Catchment elevations vary from 630 m at the northeast corner of the Upper catchment to 50 m in the western floodplain of the Lower catchment. The rainfall distribution reflects the elevation, declining from 800 mm/a in the northern Upper catchment to 475 mm/a in the western Lower catchment. The mean annual rainfall across the entire South Para River catchment is about 700 mm.

There are two major on-stream reservoirs (Warren and South Para) and a major off-stream reservoir (Barossa) receiving flow from the catchment and providing water supplies to cater for the Metropolitan Adelaide and Northern Region water supply systems. The reservoirs have a combined storage of 54 600 ML. Additional water can be imported to these reservoirs from the River Murray via the Swan Reach to Stockwell (SRSP) and Mannum to Adelaide pipelines (MAP). Past records show that on average, an annual 21 000 ML of water has been diverted from the catchment to water supply, of which 16 800 ML originates from the catchment and an additional 4200 ML is supplied from the River Murray.

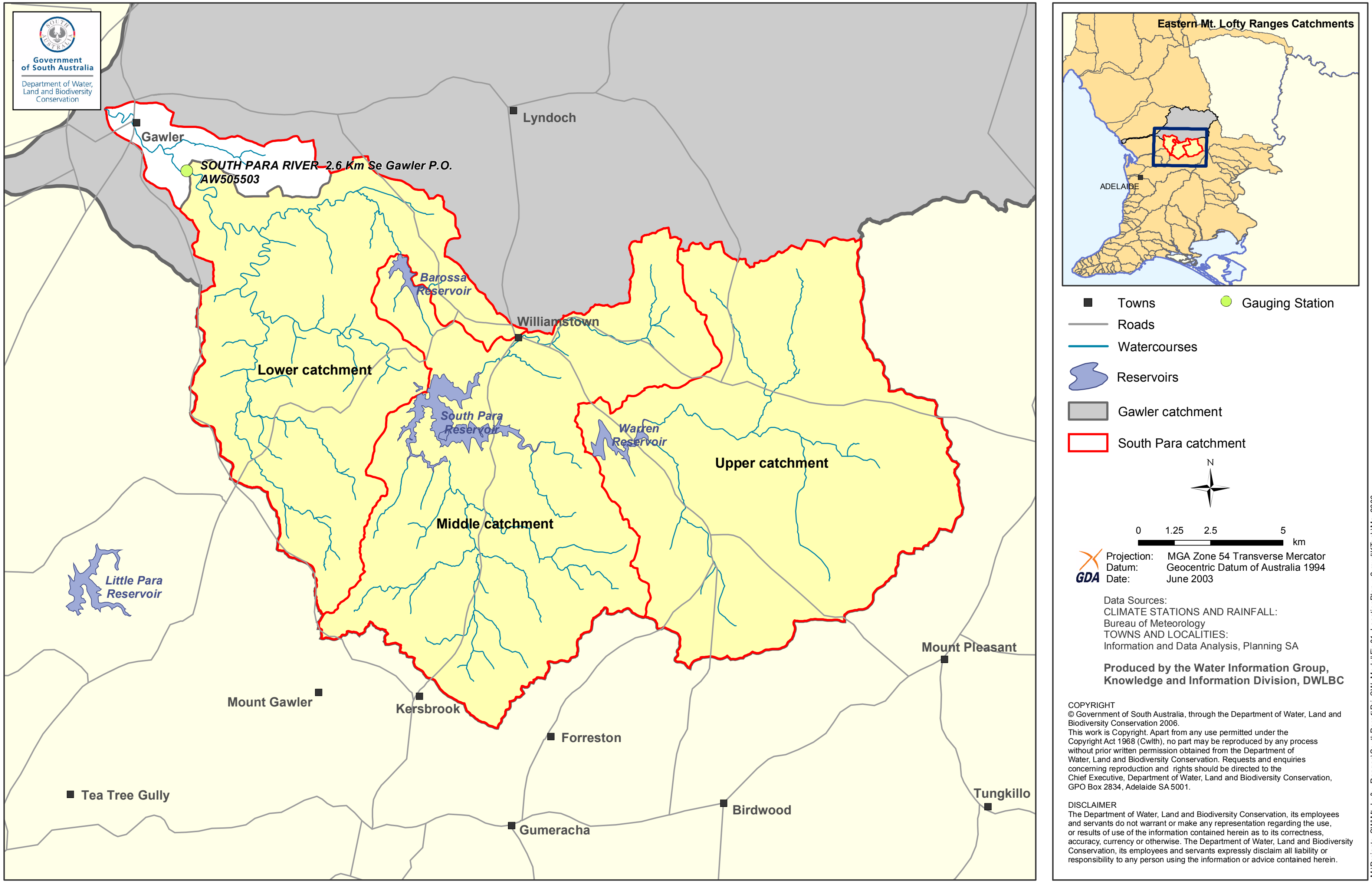
In addition to these diversions, there are an estimated 979 farm dams located in the catchment, with an aggregated storage volume of nearly 3000 ML. Dam water is diverted from these for domestic purposes, stock watering and irrigation of pastures, horticulture and viticulture. Recently, the latter sector has undergone substantial expansion, resulting in the rapid increase of farm dam storage volume within the catchment.

The diversion of catchment water has heavily impacted on the natural flow regimes of the catchment. It is estimated that the combined effect of all diversions has reduced the flow at the SE of Gawler Station (AW505503) to about 10% of the original natural flow. Currently the median annual flow at the station is 3200 ML.

Since 1968, spills over the Barossa diversion weir have only occurred on six occasions. The lack of water, infrequent flushing flows and inappropriate sequencing have all greatly reduced the opportunities for species maintenance and migration. In particular the reaches downstream of the Barossa diversion weir are identified as ecologically stressed (Philpott, 1999).

In 2002, with 96% of the catchment having been surveyed, the land use information showed that broadscale grazing and field crops occupied 55% of the area, followed by 40% occupied by forestry and protected and recreation areas. Intensive irrigation comprised 2%, while the remaining 3% of the area was occupied by miscellaneous and mining/extraction categories.

Figure 1: South Para River catchment locality plan



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2.2 CATCHMENT SUBDIVISION

2.2.1 MAJOR SUBCATCHMENTS

The separation of the three major subcatchments into smaller subcatchments for rainfall to runoff modelling has been based on major stream systems, available rainfall data locations and isohyet patterns, locations of storages, land uses, or a combination of these considerations. The aim of subcatchment separation is to enable the input of data into the model which is compatible with the availability of data and the understanding of the processes involved with the variable nature of the catchment. This increases the efficiency of the catchment rainfall-runoff modeling process and, in this study, enables the spatially variable impact of farm dams on runoff to be specifically modelled.

2.2.2 MINOR SUBCATCHMENTS

The major criterion used for the further subdivision of the three major subcatchments is the presence of a significant on-stream farm dam (‘controlling dam’) or group of smaller dams, which is deemed to control or block the flow from the upstream catchment area. In the absence of major on-stream dams, other factors such as rainfall, topography and land use variability are used in the subdivision.

A total of 67 subcatchments were identified for the total catchment, comprising 21 in the Upper catchment, 22 in the Middle catchment and 24 in the Lower catchment (Fig. 12). The Barossa reservoir catchment is modeled as part of the Middle catchment as it acts as an off-stream storage for flows released from the South Para reservoir and diverted via the Barossa weir. Details of the minor subcatchment areas, aggregated dam storages, farm dam densities, etc are listed in Appendix C.

2.3 FARM DAMS

There are thousands of farm dams within the Mt Lofty Ranges. They are mainly used to store water for irrigation, stock and domestic purposes. Most farm dams are situated on-stream and intercept the catchment runoff and reduce the flow passing downstream. Some farm dams are supplemented by extraction of groundwater.

It is necessary to quantify the impact of these farm dams on streamflow regimes to avoid the situation where increasing diversions will lead to degradation of the water dependent ecosystems.

The quantification of the extent of farm dam development within the South Para River catchment was based on an aerial photographic survey in 1999 by the NABCWMB. The photographs were ortho-rectified, scanned and digitised. A sample of the dam surface areas obtained from the photographs was compared with ground truth surveys. A relationship between the surface area (S) of the dams at full capacity and their maximum storage capacity (V) was estimated by Pikusa (1999) as:

$$V(ML) = 0.0002 * S(m^2)^{1.2604}$$

This formula was adopted for the estimation of the volumes of all the dams within the catchment.

The survey shows 979 farm dams within the catchment with an estimated aggregated storage capacity of 2960 ML. This equates to an average storage density of 9 ML/km^2 of catchment area. The density provides a measure of the intensity of farm dam development. The Lower catchment, with a dam density of 5 ML/km^2 is less developed than the Middle and Upper catchments with densities of 10 ML/km^2 and 12 ML/km^2 respectively.

At a smaller scale the variability of density ranges from less than 1 ML/km^2 in the forested subcatchments to 166 ML/km^2 in the highly irrigated subcatchments. The spatial distribution of farm dam density is shown in Figure 2.

When the 54 600 ML of SA Water supply reservoir storage is included, the average density is dramatically increased from 9 ML/km^2 to 171 ML/km^2.

Farm dam storages can be categorized into seven size-classes varying from less than 0.5 ML to greater than 50 ML as shown in Table 1. Irrigation dams are considered to be those with storage greater than 5 ML. Those with smaller capacities are considered to be stock and domestic dams. The 868 dams with less than 5 ML each of storage capacity constitute 38% of the total farm dam capacity. Conversely, the 21 farm dams with greater than 20 ML of storage capacity represent 34% of the total capacity. Eleven of these are found in the Upper catchment, seven in the Middle catchment and three in the Lower catchment.

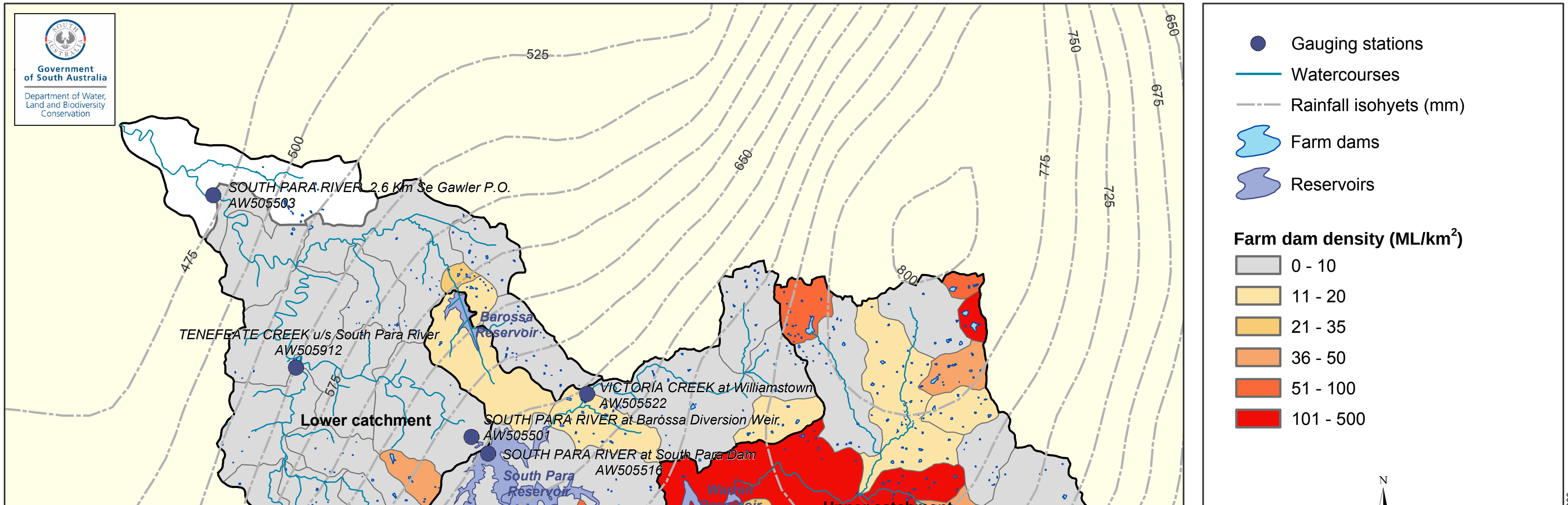
Table 1. The distribution of farm dam size and volume

Vol class	Size class (ml)	Lower catchment (110 km^2)[a]		Middle catchment (108 km^2)[b]		Upper catchment (118.6 km^2)		Total catchment (337 km^2)		
		Nos	*Aggregated volume*	*Nos*	*Aggregated volume*	*Nos*	*Aggregated volume*	*Nos*	*Aggregated volume*	*Percentage*
0	<0.5	93	25	70	18	74	16	237	59	2%
1	0.5–2	112	119	167	179	171	198	450	496	17%
2	2–5	44	125	70	208	67	215	181	548	19%
3	5–10	11	76	26	177	23	167	60	419	14%
4	10–20	3	48	16	224	11	152	30	424	14%
5	20–50	2	50	6	168	5	148	13	366	12%
6	>50	1	54	1	59	6	537	8	650	22%
	Total	**266**	**497**	**356**	**1 033**	**357**	**1 431**	**979**	**2 961**	**100%**
SKM (2001)		214	308	314	764	305	1 158	833	2 230	
Farm dam density (ML/km^2)		4.5		9.6		12.1			8.8	

Note a - area is up to the junction of North Para and South Para Rivers and it includes the Barossa weir catchment

Note b - Barossa weir catchment is not included.

Figure 2: Distribution of farm dams density in South Para River catchment



Projection: MGA Zone 54 Transverse Mercator
Datum: Geocentric Datum of Australia 1994
Date: June 2003

Data Sources:
CLIMATE STATIONS AND RAINFALL:
Bureau of Meteorology
TOWNS AND LOCALITIES:
Information and Data Analysis, Planning SA

Produced by the Water Information Group, Knowledge and Information Division, DWLBC

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2.3.1 COMPARISON WITH SINCLAIR KNIGHT MERZ DATA

The SKM report (2001) contains some differences in numbers and volumes of dam storages from this study, even though both studies are based on the same survey data set.

SKM identify 833 dams in comparison to 979 in this study (SKM 2001, pp6). The SKM aggregated storage is also smaller. Many of the very small dams might have been considered insignificant by SKM and omitted. It is also likely that different formulae may have been used for estimating dam volumes.

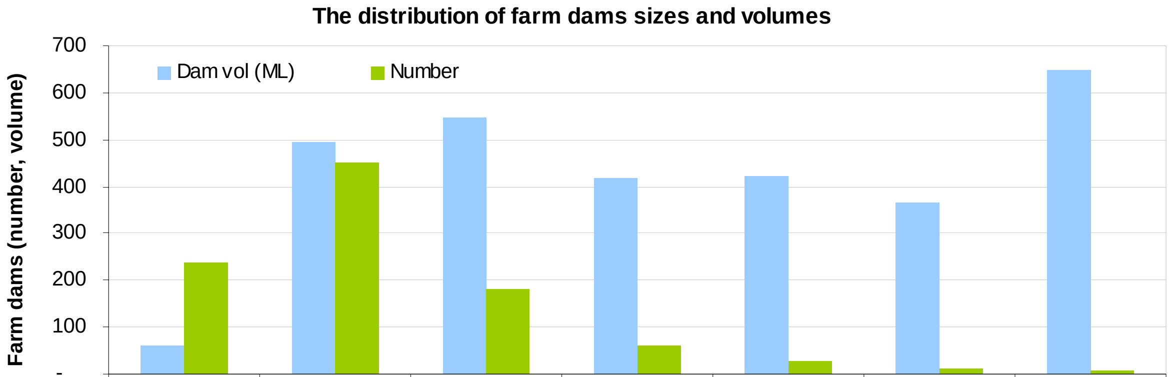
More significantly, the aggregated storage for irrigation dams (>5 ML) estimated by SKM is only 321 ML (SKM Table 2.2) compared to 1859 ML estimated in this report (Table 1). Using SKM demand factors, the annual water usage for irrigation would be 1416 ML. This equates to a ratio of 1416/321 = 4.4 as the ratio of usage to storage. This is very high. By comparison, the ratio obtained using the DWLBC data (obtained in Section 2.5.3) would be only 1496/1859 = 0.8 for irrigation dams, or 1496/2960 = 0.5 if all the dams were included (Section 2.5).

2.4 WATER SUPPLY SYSTEM AND CONSUMPTION DATA

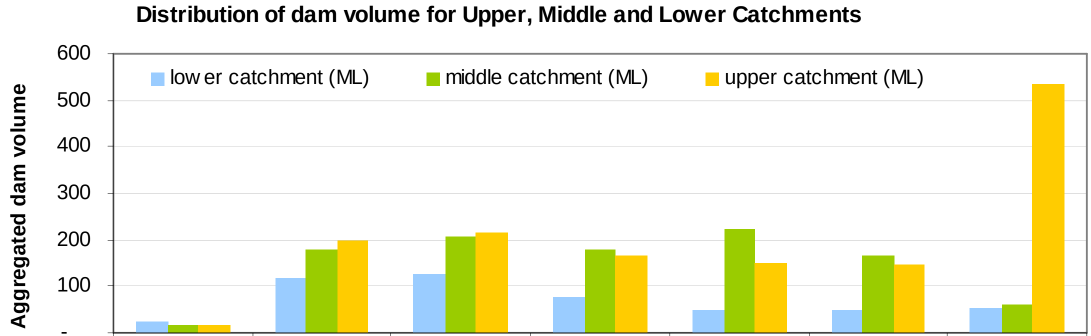
The Upper and Middle catchments provide the main source of surface water to the Northern Metropolitan Adelaide and the Barossa Valley water supply system. There are three major reservoirs constructed for this purpose, namely the Warren, South Para and Barossa reservoirs with a combined storage capacity of 54 600 ML. The Warren and South Para reservoirs are on-stream reservoirs while the Barossa reservoir, having only a small catchment, is an off-stream dam receiving water diverted from the Barossa diversion weir downstream of the South Para reservoir. Water from the Barossa reservoir is treated and then supplied for consumption. A schematic diagram showing the reservoirs and water supply systems is presented in Figure 4.

The diagram shows how the water supply system is operated. When the natural intake from the Upper and Middle catchments to the reservoirs is low, supply can be supplemented from the River Murray via the SRSP (constructed in 1969) or the MAP (constructed in 1955). The SRSP is connected to the Warren Trunk Main (WTM) which discharges to the Warren reservoir. A spur line connected to the WTM allows water from either the SRSP or the Warren reservoir to be discharged into the South Para reservoir at Coleman’s Dissipater.

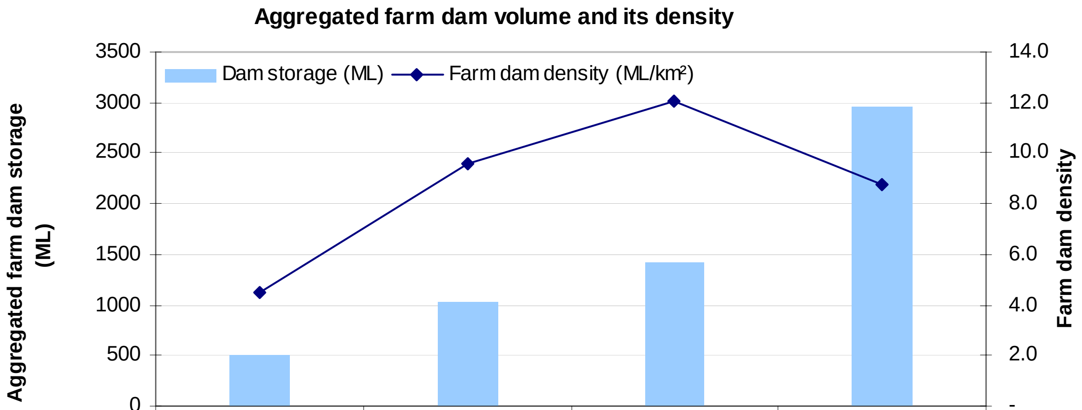
Originally both the SRSP and the MAP could supply water directly from the River Murray into the Warren reservoir. However, since February 1998, when the SRSP started to carry filtered water, supplementation via this pipeline ceased. In December 2001, a new scheme established by BIL was added to the system and water delivery was re-configured. The BIL scheme was constructed to supply irrigation water from the River Murray to the Barossa Valley, using the Warren reservoir for holding the storage. Water use data shows that between 1967–96 an average of 4233 ML/a was pumped from the River Murray via the SRSP and the MAP to supplement the water diverted from the South Para reservoir for water supply at Barossa reservoir. In four years (between 1976–78 and in 1995) supplementation exceeded 10 000 ML while there were two years (1971 and 1974) when supplementation was zero or negligible.



	< 0.5	0.5 - 2	2 - 5	5 - 10	10 - 20	20 - 50	> 50
Dam vol (ML)	59	496	548	419	424	366	650
Number	237	450	181	60	30	13	8



	0	1	2	3	4	5	6
low er catchment (ML)	25	119	125	76	48	50	54
middle catchment (ML)	18	179	208	177	224	168	59
upper catchment (ML)	16	198	215	167	152	148	537



	low er catchment	middle catchment	upper catchment	Total catcment
Dam storage (ML)	497	1033	1431	2961
Farm dam density (ML/km²)	4.5	9.6	12.1	8.8

Figure 3. 1999 farm dams statistics

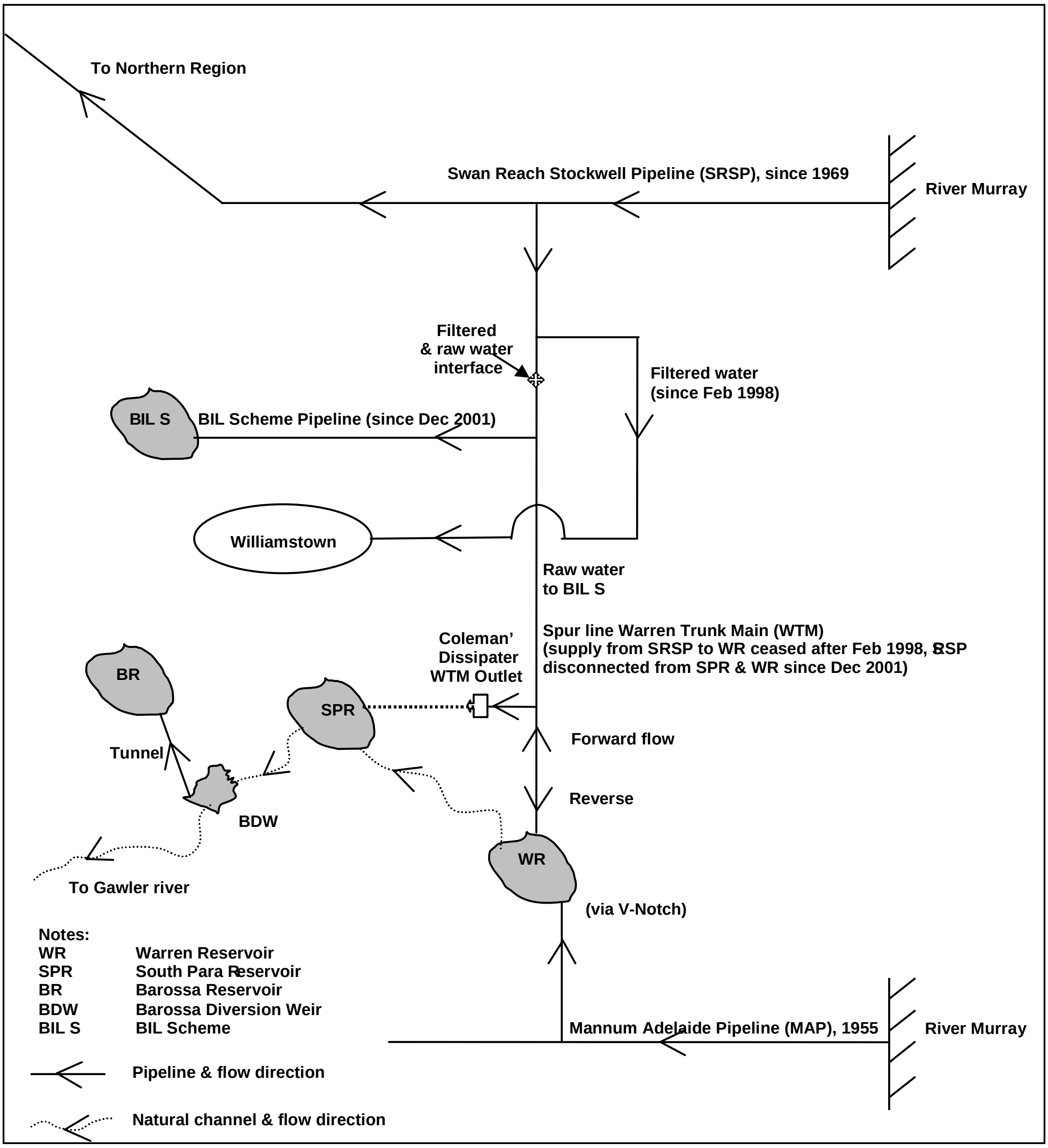


Figure 4. Warren and South Para reservoirs water supply system

Subtraction of the 4233 ML/a of inter-basin transfers into the South Para and Warren reservoirs from the 21 671 ML/a annual water consumption derived from the Barossa and Warren reservoirs (1967–96) means that 17 438 ML/a was diverted from the Upper and Middle catchments to water supply. The estimated average pre-development inflow from these catchments is ~30 200 ML/a (Table 11), ~2130 ML/a would have been intercepted via farm dams and 3529 ML/a spilled via the Barossa weir. By difference evaporation and other unaccounted losses from the reservoirs are therefore 7103 ML/a. This is equivalent to a loss of 1160 mm/a depth of water over the combined surface areas of the reservoirs at full supply level. Detailed annual pumpage and water consumption data are presented in Appendix B.

2.5 LAND USE AND IRRIGATION VOLUME

Land use information for the South Para River catchment was obtained from data developed by the Environment Protection Authority's (EPA) Mount Lofty Ranges Watershed Protection Office and the NABCWMB. It incorporated the land use surveys conducted on June 2001 through to March 2002, and provided multiple levels of information regarding land cover and land use, including links to the Australian New Zealand Draft Land Use Codes (ANZLUC).

The information is categorised and listed in Table 2 below for the irrigated and non-irrigated areas, which also includes information extracted from Table 3-2 of SKM 2001 report for comparison.

Table 2. Irrigated and non-irrigated areas in the catchment

Landuse categories	Class	Lower[a] catchment	Middle catchment	Upper catchment	Total
Irrigated areas in ha (2002 data)					
Horticulture - row crops	Others	2	2	7	11
	Vines	18	247	210	476
Horticulture - trees	"all types"	17	53	9	79
Livestock	Intensive grazing	90	9	9	108
Total		127	312	235	674
Irrigated areas in ha (Table 3-2, SKM 2001, 1993 MLR data)					
Horticulture—row crops	Others	–	38	–	38
	Vines	17	84	100	201
Horticulture—trees		–	53	2	55
Livestock	Intensive grazing	–	6	–	6
Total		17	181	102	300
Non-irrigated areas in ha (2002 data)					
Field crops	Cereals	532	–	–	532
Forestry	Exotic vegetation	16	886	4 148	5 050
Forestry/protected areas	Native vegetation	864	2 026	1 257	4 147
Livestock	Broadscale grazing	5 904	5 661	5 541	17 106
Mining/extraction		121	25	3	149
Protected/recreation	Recreation/protected areas	2 323	1 178	241	3 743
"miscelleneous"	Utilities/other/etc	197	535	210	942
Total		**9 957**	**10 311**	**11 400**	***31 668**

* Not all the South Para River catchment area was covered in the survey for land use information

Note a: The boundary is the same as Table 1 of this chapter

2.5.1 IRRIGATED AREA

In the categories shown in Table 2 it was assumed that irrigation was required for:

- Horticulture—trees
- Horticulture—row crops
- Livestock—intensive grazing only.

Hence based on this, 674 ha, or only 2% of the South Para catchment is irrigated, comprising of 79 ha of horticulture trees, 487 ha of row crops and 108 ha of intensive grazing. The SKM 2001 report (based on the 1993 Mt Lofty land use surveys) showed that in 1993, there were only 300 ha of irrigated area. This implies a 125% increase over a span of 10 years. The majority increase is in vine planting, which has undergone a 140% increase from 201 ha in 1993 to 476 ha in 2002, most of which occurred in the Middle and Upper catchments. By comparison, the horticulture trees planting has only had a slight increase from 55 ha to 79 ha over this period. Intensive grazing, mainly in the Lower catchment, has increased from zero ha to 90 ha.

Given the significance of these areas in estimating irrigation volume, this data warrants further field verification.

2.5.2 NON IRRIGATED AREA

Table 2 shows that broadscale grazing and field crops are the largest non-irrigated land use classes (17 106 ha and 536 ha respectively), occupying about 55% of the catchment. This is followed by forestry, protected areas and recreation areas occupying 40% (12 940 ha) of the catchment. The remaining 3% is made up by miscellaneous and mining/extraction land use classes.

2.5.3 IRRIGATION VOLUME

By applying estimated irrigation application rates (Thomson, pers. comm.) to the respective categories and areas of irrigation, the current level of irrigation water applied within the three major subcatchments is estimated to be 1500 ML (Table 3). Using the data and formulae presented by SKM (2001) to their estimate of 300 ha of irrigated area, the irrigation water applied in 1993 would be 1416 ML. This high value reflects the high irrigation application rates used by SKM. It is proposed that the revised values based on the Thomson (Thomson, pers. comm.) application rates shown in Table 3 should be accepted as the better estimates.

2.5.4 RATIO OF IRRIGATION WATER TO FARM DAM STORAGE

A significant proportion of the estimated irrigation volume (1496 ML) shown in Table 3 would be sourced from groundwater. A 50:50 split between surface and ground water would be consistent with the situation in the Clare valley, another fractured rock groundwater regime (Cresswell, pers. comm.). An assumption of 50% (750 ML) derived from surface water implies that the surface water usage would amount to about 25% of the aggregated farm

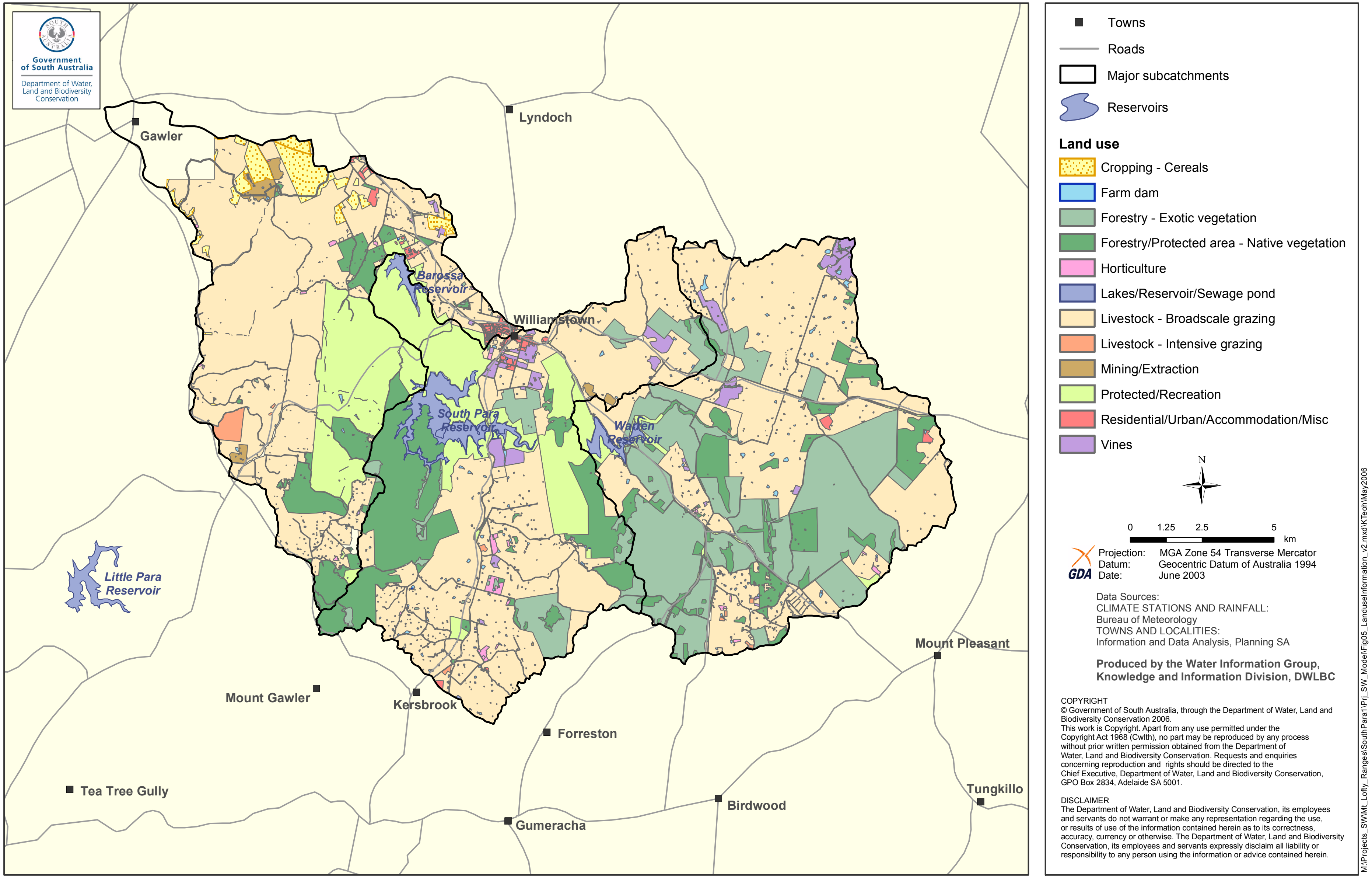
Table 3. Irrigated volume for the Lower, Middle and Upper catchments

Land use	Class	Appl rate mm/ha (Thomson)	Lower		Middle		Upper		Total
			Area ha	*Vol ML*	*Area ha*	*Vol ML*	*Area ha*	*Vol ML*	*ML*
Horticulture—row crops	Berries	400	0	0	0	0	1	3	3
	Exotic flowers	650	1	9	2	13	6	41	63
	Native flowers	400	1	2	0	0	0	0	2
	Vines	120	18	22	247	297	210	252	571
Horticulture—trees	Citrus	400	0	2	0	0	0	0	2
	Nuts	400	1	3	0	0	1	5	8
	Orchards/ miscellaneous	400	15	61	2	6	3	13	80
	Pomefruit	400	0	1	51	202	4	16	219
	Stonefruit	400	0	1	1	5	0	1	6
Livestock	Intensive grazing	500	90	449	9	47	9	45	542
	Total		**127**	**550**	**312**	**570**	**235**	**377**	**1 496**

dam capacity (2960 ML). This value agrees with McMurray (2004) who found usage rates to be of the order of about 20% of dam volumes in the Mt Lofty Range catchments. However, at the subcatchment level, the data gives usage to capacity percentages within for the Lower, Middle and Upper catchments of 55%, 28% and 13% respectively, suggesting that there may be different groundwater use components in each of the subcatchments.

Current seasonal pattern of irrigation water use was assumed to be 30% of the aggregated dam storage capacity. This is termed the *Current farm dam development situation*. Water use was assumed to occur in the summer months only.

Figure 5: Land use information for the South Para River catchment



3. CATCHMENT HYDROLOGY

3.1 RAINFALL

3.1.1 DATA AVAILABILITY AND VALIDATION

Rainfall stations located in and around the study area, obtained from the Bureau of Meteorology (BoM), were found to have good long-term records. Based on their proximity to the catchment and their length of record, 14 stations that were evenly distributed across the catchment (Fig. 6 and Table 4) were chosen as a basis for analysing the catchment rainfall trend over time. The same stations were used to provide rainfall data at a daily time step for input to the WaterCress runoff simulation program.

Table 4. Rainfall stations

No	Station name	BoM No	Location	Period	Mean mm/a	Median mm/a
1	GAWLER PO.	M023078*	outside	1884–	466	460
2	Lyndoch PO.	M023309*	outside	1887–	560	559
3	Lyndoch (Pewsey Vale)	M023313*	outside	1884–1970	776	765
4	Birdwood PO	M023705*	outside	1887–	728	728
5	Golden Gove	M023717*	outside	1906–1965	603	604
6	Gumeracha DO	M023719*	outside	1884–	793	793
7	Cudlee Ck (Milbrook)	M023731*	outside	1914–	859	853
8	Mt Pleasant PO	M023737*	outside	1884–	671	651
9	Williamstown PO	M023752*	inside	1884–	684	674
10	Williamstown (Glen Gillian)	M023756	inside	1951–	686	703
11	KERSBROOK (MABENJO)	M023758	inside	1951–	736	719
12	Williamstown (Mt Crawford forest)	M023763	inside	1954–1996	725	723
13	South Para Res (EWS)	M023820	inside	1968–	689	662
14	Para Wirra Rec Park	M023836	inside	1965–2002	646	650

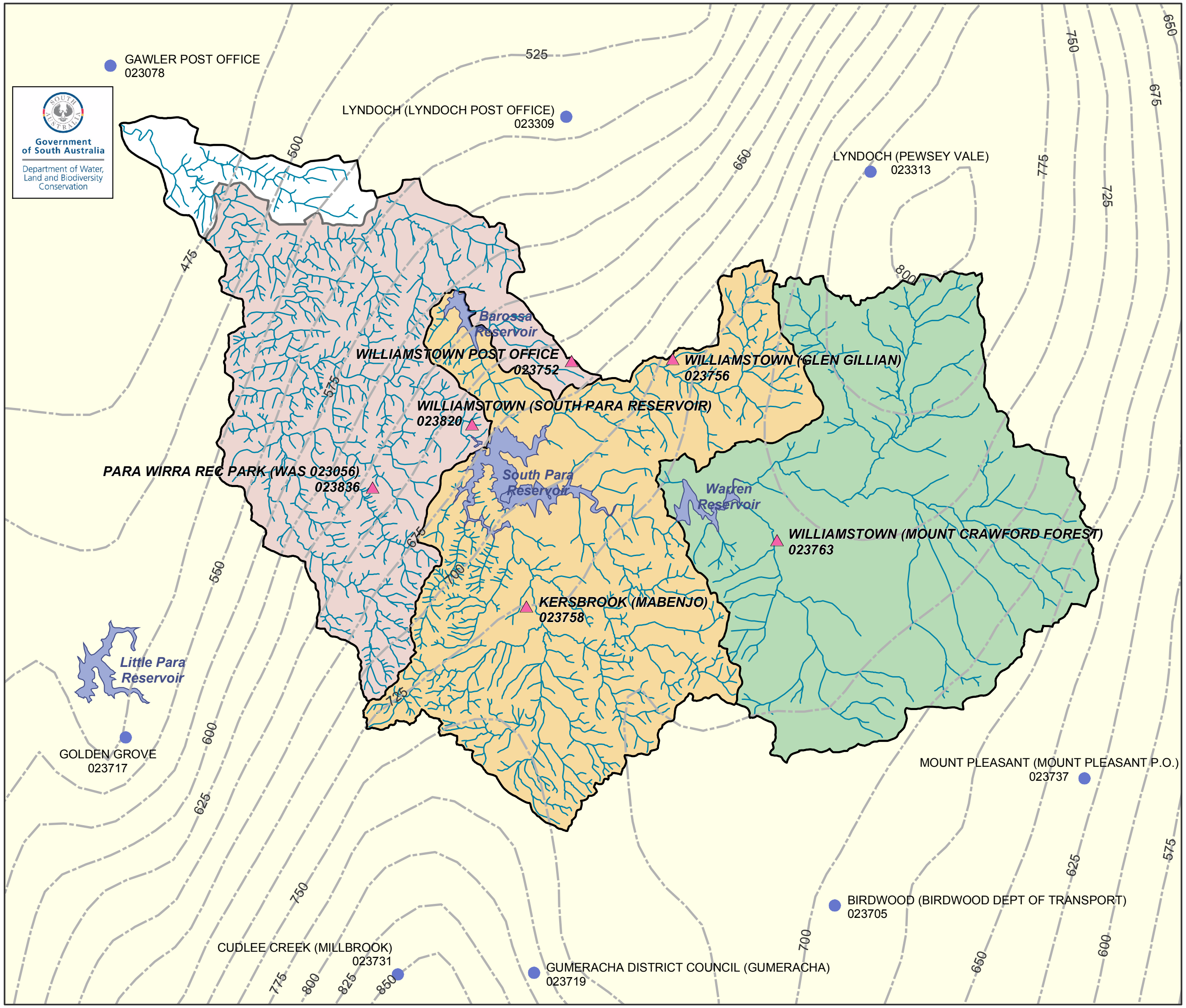
* rainfall station used as control station

Prior to input into the model, the data for these stations were first processed and validated by:

- infilling the estimated rainfalls on days where readings are identified as missing
- re-distributing the aggregated rainfall records over weekends and public holidays
- checking the homogeneity of monthly rainfall data used for the model.

Infilling the missing records and disaggregation of accumulated rainfall data of a station were provided by Sinclair Knight Merz (SKM, 2000) for DWLBC. The methodology used for infilling and disaggregation is based on Porter and Ladson (1993). The double mass curve method was used to verify the homogeneity of the rainfall records.

Figure 6: Rainfall isohyets map and location of rainfall stations



Rainfall stations used in the model
Rainfall stations
Rainfall isohyets (mm)
Streams
Reservoirs

Major subcatchments

Lower catchment
Middle catchment
Upper catchment

N

0 1.25 2.5 5 km

GDA
Projection: MGA Zone 54 Transverse Mercator
Datum: Geocentric Datum of Australia 1994
Date: June 2003

Data Sources:
CLIMATE STATIONS AND RAINFALL:
Bureau of Meteorology
TOWNS AND LOCALITIES:
Information and Data Analysis, Planning SA

Produced by the Water Information Group, Knowledge and Information Division, DWLBC

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A rainfall isohyet map has been previously produced by DWLBC using a broader set of rainfall data locations, readings and topographic interpolation. It was anticipated there would be a small discrepancy between the mapped data and the point-station data and adjustments have been made where differences were noted.

3.1.2 DATA ANALYSIS

3.1.2.1 Spatial distribution of rainfall

The annual rainfall isohyet map (Fig. 6) shows that rainfall decreases progressively from 800 mm in the north-eastern corner of the South Para River catchment to 450 mm at the confluence with the North Para River. Likewise, the decreasing trend occurs from the middle of the catchment moving westwards towards the lower gauging station. Rainfall remains fairly constant between 725–750 mm in the middle and eastern parts of the catchment.

Based on the data from the 14 rainfall stations, the mean annual spatially averaged rainfall across the catchment over the period from 1884–1998 is 683 mm.

The spatially averaged values of rainfall over the subcatchments used for rainfall to runoff modelling were estimated from the isohyet map. A single record from one of the (nearest) rain gauges is used to provide the temporal variation of rainfall within these subcatchments.

Where the spatially averaged rainfall derived from the isohyets was found to be different from the rain gauge average, an adjustment factor has been applied to the rain gauge record to compensate for the difference. The factors were not found to in excess of +/- 3% from 100%.

3.1.2.2 Annual trend

The 14 station averaged residual mass curve was used for analysing the long-term rainfall trend for the period 1884–1998. A residual mass curve is a plot of the progressive cumulative deviation of an average of a set of data values over a stated period of years from the mean value of the data set over the whole period. A slope trending upward indicates a higher than average rainfall period and that trending downward indicates the reverse is true. Figure 7 indicates that there have been two long-term trends over the whole period 1884–1998, i.e. ignoring short term fluctuations, the residual mass curve trends upward to 1925, indicating a period of generally wetter than average years. From 1925–98, the trend was in reverse indicating drier than average years, although there were a few years of high rainfall, such as 1992.

Between 1884–1925 (51 years) the 14 station mean annual rainfall was 14 mm above the long-term average of 683 mm/a while between 1925–98 (73 years) the mean annual rainfall was 10 mm below 683 mm/a.

3.1.2.3 Decadal trend

Figure 8 shows the decadal trend where annual rainfalls were averaged over 10 year periods. The number shown in the square box shows the number of years within the period when the annual rainfall exceeded the long-term average of 683 mm/a.

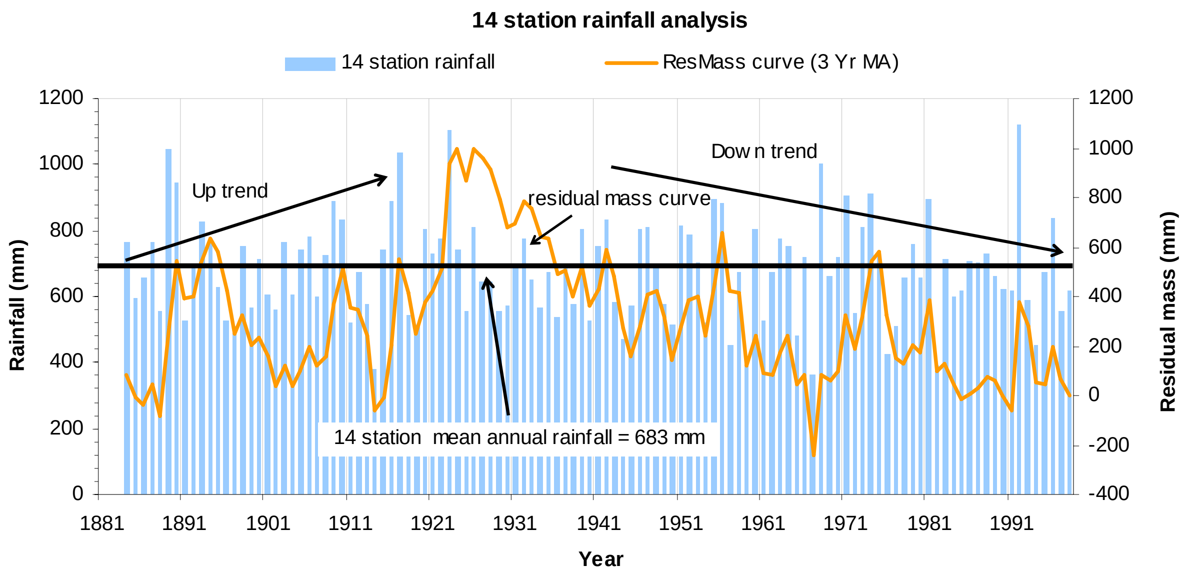


Figure 7. 14 station long term rainfall trend

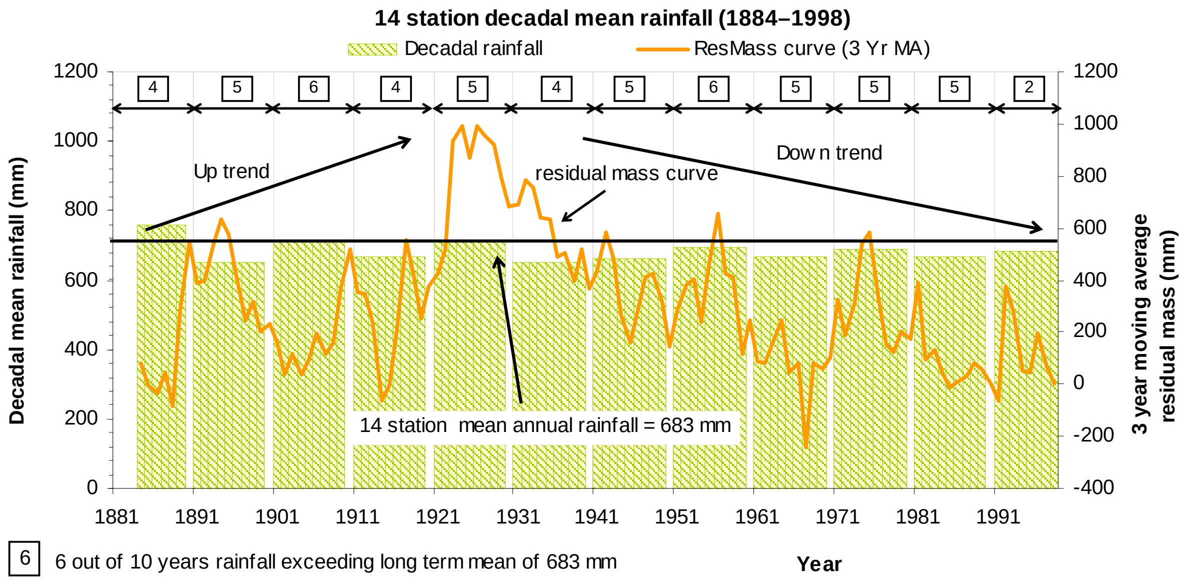


Figure 8. 14 station decadal mean rainfall

The decadal trend confirmed the analysis of the long-term trend, with three decades (1880s, 1900s, 1920s) of rainfall well above 683 mm/a and none greater from the 1930s onwards.

Historically, the wettest years in ranking order were 1992, 1923, 1889 and 1917 while the driest years were 1967, 1914, 1959 and 1982.

3.1.2.4 Monthly rainfall

Analysis shows that on average 70% of the annual rainfall occurs in the winter months May to October.

Residual mass curves for each individual month from January to December were plotted and superimposed with that of the annual mean rainfall as shown in Figure 9. The chart showed that the June residual mass curve closely followed the annual trend while the trend for July rainfall appeared to run in a counter direction. For all other months, no trend could be visually identified. This implies the trend of annual rainfalls may have been largely influenced by June rainfalls.

The effect of a reducing June rainfall leads to a delay in the start of the wet season. This has been noted in many catchments in the Mt Lofty Ranges.

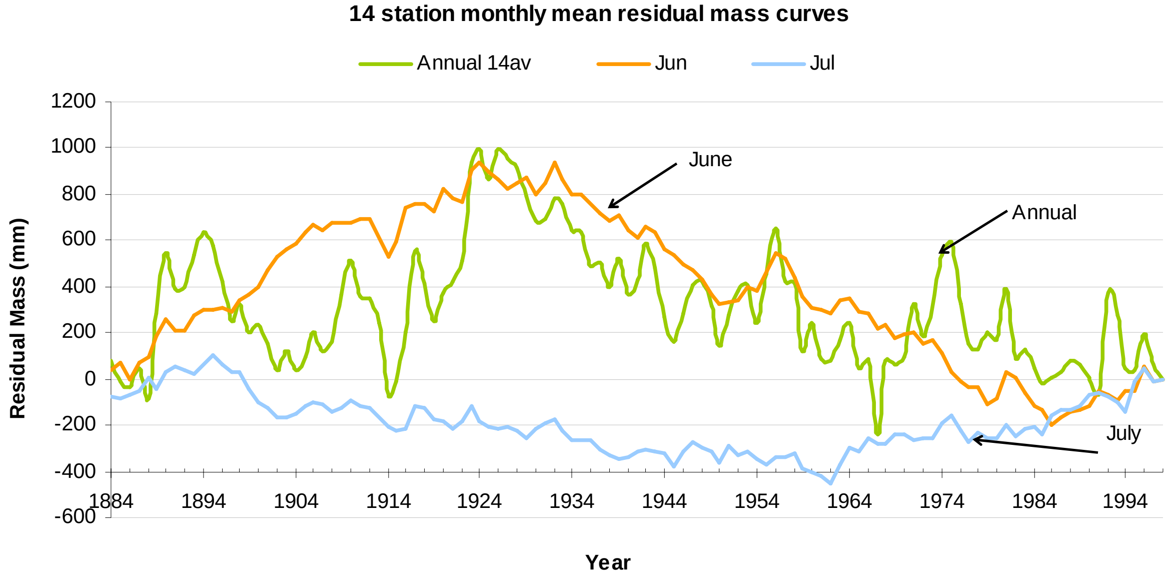


Figure 9. Monthly residual mass curve

3.1.2.5 Rainfall data for modelling

Only six of the 14 rainfall stations were selected for modelling purposes (Table 5). The homogeneity of these six stations was checked against the averages of nine of the 14 stations that have in excess of 115 years of record. Only one of the selected six stations (Williamstown Post Office, M023752) had an unbroken record over this whole period. The records for the other five stations required to be filled by correlation with a nearby station. Two reference stations (Williamstown Post Office and Cudlee Creek at Millbrook, M023731) were used to provide the records for the infilling periods after a correlation between their records and each of the records requiring to be infilled had been established over their common period of record. In this way a record for each of the six stations was established over the period 1884–1998 (115 years).

Table 5. Modelled and Reference stations

Model station (MS)	Location	Correlation Factor	Mean annual rainfall		Ratio MS/RS	Reference Station	Period
			MS	*RS*			
M023750	**WTPO** Williamstown Post Office	–	–	–		–	1884–1998
M023756*	**WTGG**, Willamstown (Glen Gillian)	0.977	686	676	1.015	M023752	1884–1950
M023758*	**KB**, Kersbrook (Mabenjo)	0.971	736	676	1.089	M023752	1884–1913
M023758**	**KB**, Kersbrook (Mabenjo)	0.974	736	861	0.855	M023731	1914–1950
M023763*	**WTCF**, Williamstown (Mount Crawford Forest)	0.972	725	676	1.072	M023752	1884–1953
M023763*	**WTCF**, Williamstown (Mount Crawford Forest)	0.972	725	676	1.073	M023752	1997–1998
M023820*	**SPRE**, South Para Reservoir EWS	0.988	689	676	1.019	M023752	1884–1967
M023836*	**PWRP**, Para Wirra Rec Park	0.976	646	676	0.956	M023752	1884–1964 1993–1998

*, Reference station (RS) M023752 is located at Williamstown PO (**WTPO**);

**, Reference station (RS) M023731 is located at Cudlee Creek (Millbrook)

Table 6 shows the six stations used for modelling in the left columns and, in the right columns, which of the two reference stations were used to infill their records over the period of missing record shown. Also shown is the correlation (R^2) between the model and reference station records and the ratio used to adjust the reference record used for infilling, derived from the mean annual rainfall of the modelled station (MS) and that of the reference station (RS).

Table 6. The location of gauging stations

GS Station	Location	Data start	Data end	Remarks
AW505500	Warren Reservoir	28/08/73	Current	Has gaps
AW505516	South Para Reservoir	28/07/81	07/09/98	No gaps
AW505501	Barossa Diversion Weir	21/05/82	15/10/93	Has gaps
AW505522	Williamstown	22/06/77	31/05/89	No gaps
AW505503	SE of Gawler Station	28/05/68	Current	Has gaps
AW505912	Tenefeate Creek	30/06/97	Current	No gaps

3.2 EVAPORATION

Evaporation data used in the study was based on station no. M023820 located at the South Para reservoir. The records consist of measurements using a Class A Pan with a standard bird guard installed in February 1968 and operated to date.

Within this period 0.52% of the data was missing and these were infilled using correlations with the nearest evaporation stations at Parafield Airport, Turretfield Research Station and Thorndon Park reservoir.

The monthly time step data was adjusted for homogeneity using double mass plots based on these nearby stations. These plots identified a major break in slope for the South Para record at February 1995. This date was associated with a known change in the site of the pan. It was decided to decrease the South Para readings for the period February 1995 to August 1998 by 12.5% based on the double mass slope with the Turretfield recordings.

The mean annual evaporation for South Para River catchment after adjustment was taken as 1465 mm. The average monthly values making up the total were identified from the adjusted data.

3.2.1 STREAMFLOW DATA AVAILABILITY

The streamflow gauging station data maintained in the DWLBC Hydsys data base for the South Para River catchment are listed in Table 6. The SE of Gawler Station (AW505503) remains the only current streamflow station with long-term records.

Gauging station AW505522 for Victoria Creek catchment ceased monitoring in 1989. The Bureau of Meteorology has only recently installed a station at Tenefeate Creek (AW505912) for flood warning. Due to its limited record length it was not used in this study. Water level, storage and spillway discharges are recorded at the Barossa diversion weir and the Warren and South Para reservoirs.

As a whole, data on streamflows within the catchment is fairly limited and the estimations of spill from the reservoirs are based on hydraulic formula of uncertain accuracy. The paucity of data limits the ability to model the catchment flows accurately, particularly in the Upper and Middle catchments. This is discussed in section 3.2.4.

3.2.2 DATA ANALYSIS

3.2.2.1 Annual flow

Streamflow analyses carried out for the gauging stations AW505503 (SE of Gawler Station) and AW505522 (Victoria Creek at Williamstown) are summarised in Table 7. The median annual flow for the SE of Gawler Station is 3170 ML and Victoria Creek is 1750 ML. Since water passing downstream of the Barossa diversion weir is an infrequent event, the median flow at AW505503 can be considered a good indicator of the natural flow produced by the Lower catchment alone. With a catchment area of 90 km^2 (excluding the Barossa reservoir catchment), this equated to a median year runoff coefficient of 6% of the mean annual rainfall. With the Upper and Middle catchments included as the contributing catchment (a total of 324 km^2), the impact of the reservoirs and farm dams has reduced the runoff coefficient for the total catchment to only 1% of the rainfall.

The Victoria Creek with, a catchment area of 20.6 km^2 has a runoff coefficient of 12%. This is within the range found for the drier subcatchments within the Onkaparinga River catchment (Teoh, 2002). The lower coefficient for the Lower catchment, when compared to the Victoria Creek catchment, can be attributed to the lower annual rainfall received in the area.

Table 7. Flow records from the gauged catchments

GS Station (rainfall)	Location	Catchment Area km^2	Annual flow (ML) *Median*	*Average*	*Max*	*Min*	*Std Dev*	Runoff coefficient	Coefficient of Variability Cv
AW505522	Williamstown	20.5	1 750	2 010	5 830	190	1 420	0.12	0.7
(727 mm)			(1978–1988)						
AW505503	SE of Gawler Station	324*	3 170	8 110	60 840	86	13 800	0.01	1.7
			(1969–2000)						
(602 mm)**		90.1**	3 170	5 077				0.06	1.7
			(1983–1997)						

* Total catchment area

** Lower catchment area only (minus Barossa Reservoir catchment)

Plots of streamflow over time for the AW505503 and AW505522 gauging stations are shown in Figure 10. The records for AW505503 showed particularly high variability from one year to another. The zigzag character of the residual mass curve is mainly due to spills passing the Barossa diversion weir. Without further analysis (e.g. system modelling) it is impossible to identify any flow trend. The coefficient of variability (Cv) which measures flow variability, at 1.7 is high in comparison to the mean Cv for Australian arid zone streams of 1.27 found by McMahon (1982) and is due to the effect of the spills.

For Victoria Creek, the Cv was 0.7 only, which is typical of the drier Onkaparinga River major subcatchments.

3.2.2.2 Monthly flow

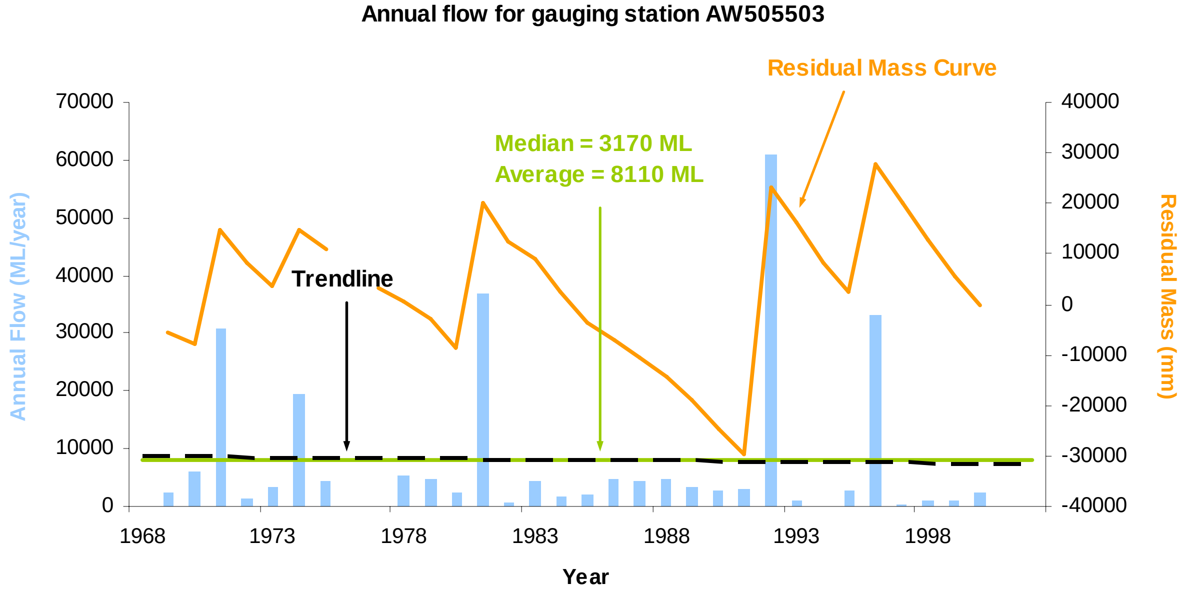
The distribution of monthly streamflow for the SE of Gawler and Victoria Creek Stations are shown in Figure 11.

Both charts exhibit a typical monthly distribution pattern of flows with 98% of runoff occurring in the winter months May–October. The difference between the monthly mean and median flows for the SE of Gawler Station are greater than for Victoria Creek station because of the spills from the reservoirs.

3.2.3 STREAMFLOW DATA FOR MODELLING

Victoria Creek catchment has about 12 years of daily streamflow data (AW505522) for flow calibration. This record has been used to provide information for calibration of the Middle catchment.

Daily streamflow records from the SE of Gawler Station (AW505503) were used for calibration of the Lower catchment after subtraction of the spills over the Barossa diversion weir. These spills were estimated using empirical rating curves applied to the water level records for the spillways at the Barossa diversion weir (AW505501) and the South Para reservoir (AW 505516), allowing time lag and flow attenuation (App. B).



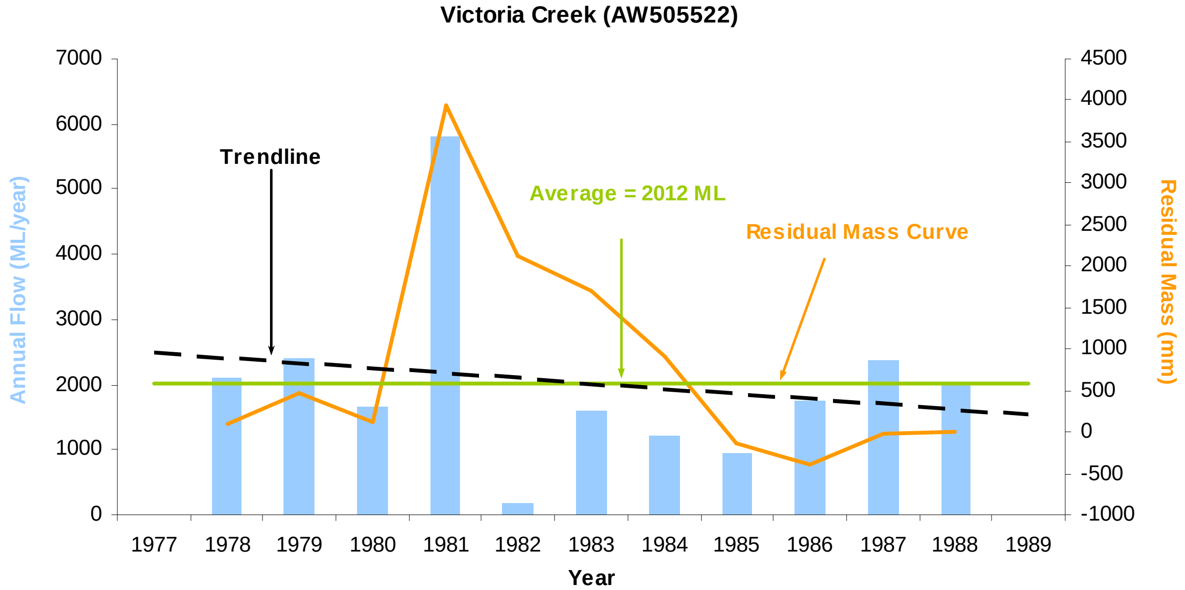
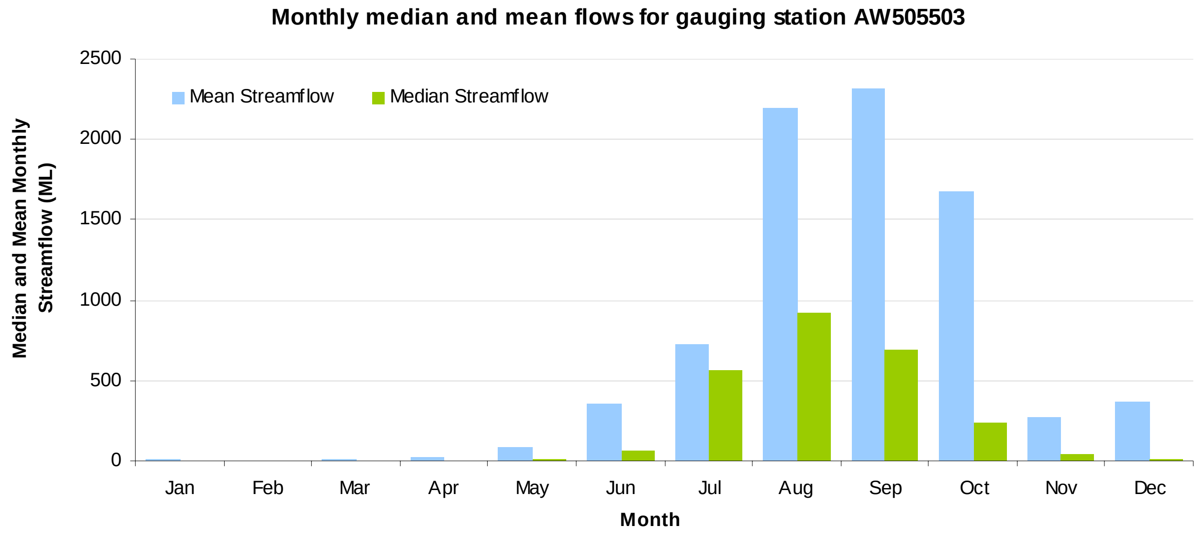


Figure 10. Streamflows of gauging stations at SE of Gawler Station and Victoria Creek

There is no streamflow gauging station in the Upper catchments. However, Tomlinson (1996) has used the data available for the Warren and South Para reservoirs to construct estimates of monthly inflow to and spill from them. These estimates were used as surrogate records for calibration of catchment flows in the Upper and Middle catchments.

It is believed that the flow data used by SKM in their TEDI model (SKM, 2001) were derived in a similar manner to those of Tomlinson and agreed closely with his estimates.



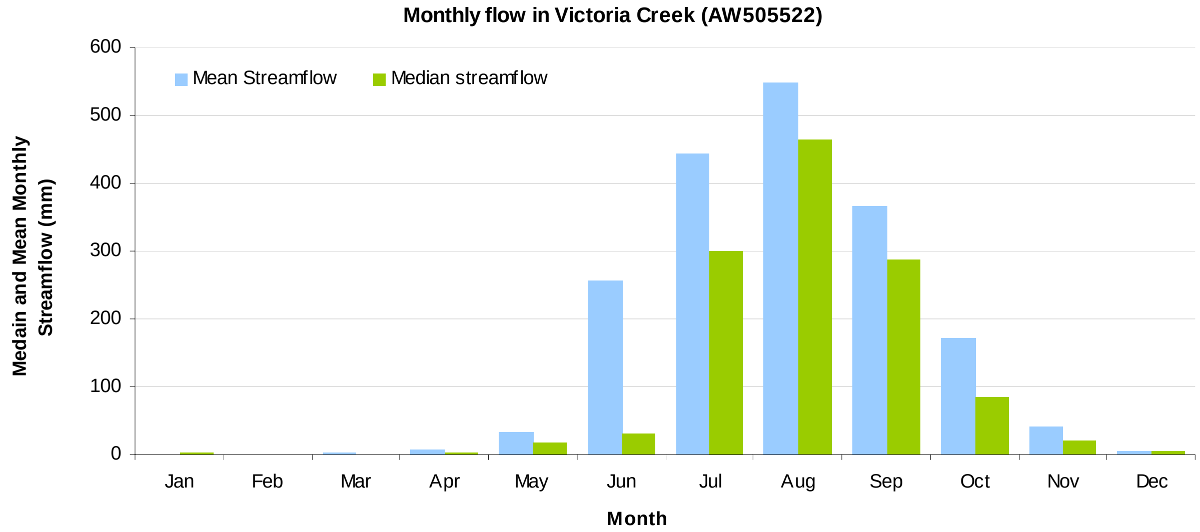


Figure 11. Monthly flow data at SE of Gawler Station and Victoria Creek gauging station

3.2.4 LIMITATIONS OF STREAMFLOW DATA FOR THE MIDDLE AND UPPER CATCHMENTS

If accurate data were available on water levels, diversions, releases, leakages, spills and evaporation, water balance calculations could provide accurate estimates of inflow and outflow from the reservoirs, suitable as alternatives to the direct measurement of these flows using streamflow stations. However, because of gaps or inaccuracies in these measurements (and the assumptions inherent within the formulae used in the water balance calculations) the estimates of flow derived from water balance calculations are rarely very accurate.

As an alternative it is recommended that either:

- streamflow monitoring stations are established upstream of the Warren and South Para reservoirs where feasible, or
- greater attention is paid to increasing the accuracy of measurements involved in the water balances of these storages in order to improve the accuracy of estimates of inflow and

outflow. This could be a condition of the licence to divert water from these structures and would involve the improvement in establishing spillway ratings, scour releases and losses due to evaporation and leakage

- As a minimum it is recommended that the empirical rating curves for the spill over the Barossa diversion weir and Warren reservoir is verified with field measurement to establish its level of accuracy. It was noted that Tomlinson (1996) raised the difficulties of reconciling the reservoir water balance with some historical flow data and discarded the spill data of extreme events like that of December 1992.

These recommendations are in line with the review of the adequacy of hydrological monitoring being undertaken by DWLBC in consultation with other agencies. As part of this, Greenwood, et al. (2001, draft report) recommended the old gauging station at Victoria Creek catchment be re-activated.

4. MODELLING

4.1 OVERVIEW

Mathematical modelling provides a good tool for investigation and better understanding of the hydrological behavior of catchments under varying conditions. In this study, long-term daily rainfall data were used as input to the WaterCress (Cresswell, 2000) rainfall to runoff and water systems model, in order to simulate the long-term runoff within subcatchments of the South Para River catchment. The model can take into account the effect of the establishment and operation of reservoirs and farm dams. The model was calibrated using streamflow (runoff) and other data and was then used to assess the likely impacts of the dams on the streamflow, under different past and future development and operational scenarios.

WaterCress allows different water systems components to be incorporated in a model. The components can be a combination of any of the following:

- demands; including rural, industrial and public supply demands
- catchments; which generate runoff from rural and urban catchments
- storages; including reservoirs, aquifers, tanks, and farm dams
- treatments; including sewage treatment works and wetlands
- transfers; including pipes, channels, weirs and routing effects.

The modeling platform incorporates several commonly used Australian rainfall to runoff models viz., AWBM, SFB, HYDROLOG and WC–1. WC–1 is a widely used model in South Australia and hence was used in this study.

Hence catchment modelling essentially involves model construction, calibration, running different scenarios and interpreting the results.

4.2 MODEL CONSTRUCTION

A model is constructed as a series of “nodes” performing a set of functions occurring within the water systems. The nodes are linked to provide the flow direction between the nodes.

The South Para River catchment was first subdivided into a series of rural subcatchments (Fig. 12). Each subcatchment consists of a rural catchment node and an off-stream dam node representing the aggregated volume and surface area of dams within the catchment. The off-stream dam node is chosen because factors within the node can allow the node to operate anywhere within the range between 100% off-stream to 100% on-stream. A proportion is chosen within this range to represent the proportion of the catchment which is “free to flow”.

The input data for each rural subcatchment node includes:

1. its area
2. the time series record of daily rainfall and monthly evaporation (as data files)

3. estimated values for the 10 parameters incorporated within the WC–1 rainfall to runoff model, viz., median soil moisture content, interception storage, catchment distribution, ground water discharge, soil moisture discharge, pan factor, fraction ground water loss, storage reduction coefficient, ground water loss and creek loss
4. where the outlet of the catchment coincides with the location of a gauging station, a time series record of the daily flows (as a Calibration data file).

The input data for each off-stream dam node includes:

1. The aggregated storage within the subcatchment.
2. The associated time series record of daily rainfall and monthly evaporation data (as data files).
3. The aggregated dam capacity to aggregated surface area relationship.
4. The maximum rate of daily diversion to the dam (taken to be equal to the maximum capacity of the aggregated dams, thus converting a proportion of the dams to on-stream dams).
5. The fraction of the total catchment area diverted to the dam. The value depends on the number, size and location of the individual dams making up the aggregated total and thus the proportion of the generated total catchment runoff that is deemed to be ‘free to flow’ unrestricted to the outlet. The value will be 1.0 if:
   - there are no dams, or
   - there is a single large on-stream dam located at the catchment outlet, or
   - multiple small dams distributed evenly across the whole catchment area (but, when aggregated, also represented by a single dam at the outlet).

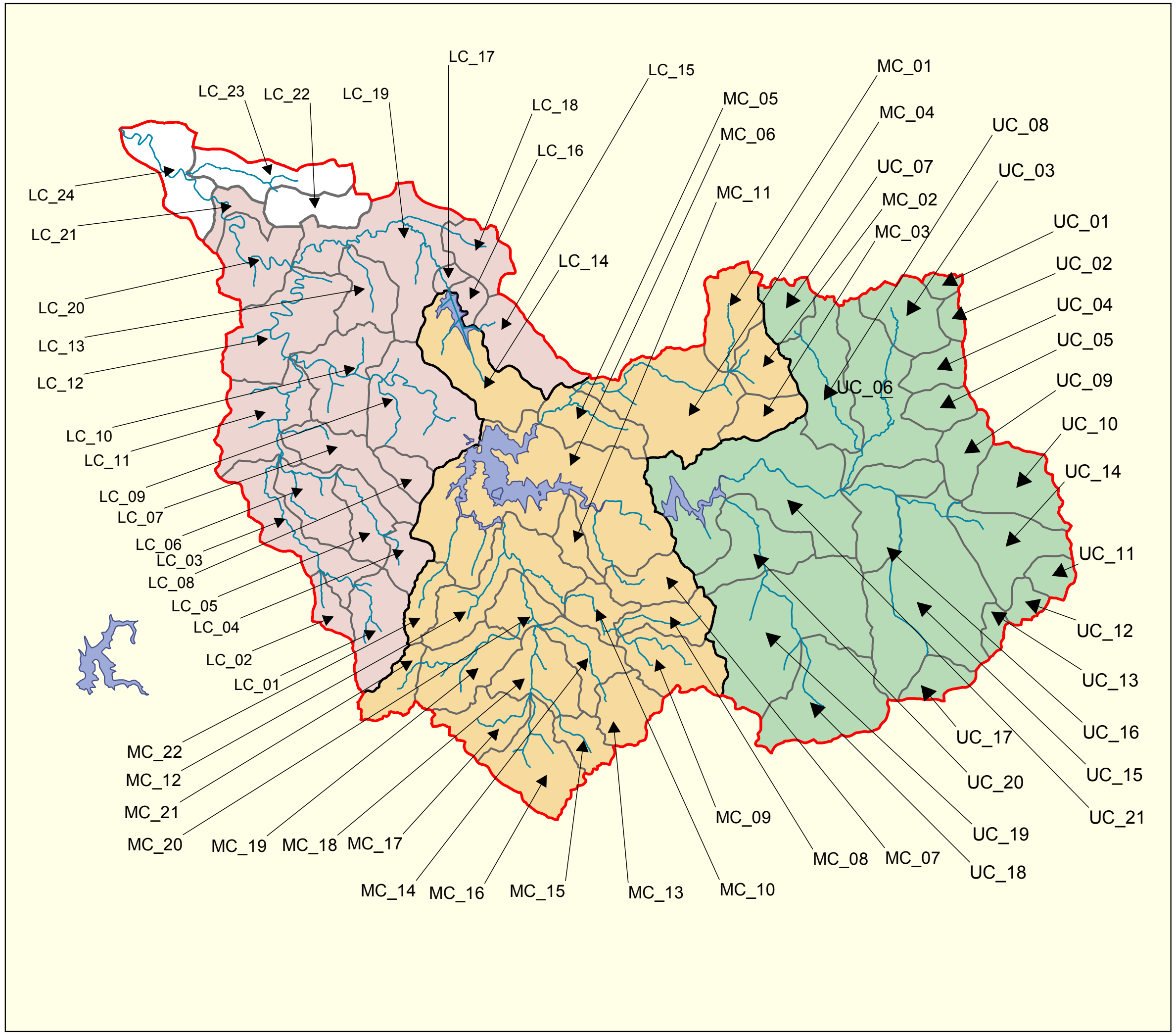
   The value is reduced as the dams are located more unevenly in both size and location, thus potentially increasing the proportion of the catchment flow which can reach the outlet without passing via a dam on the way to the outlet.
6. Water diverted from the dams to irrigation usage. In Section 2.5.4 ”Ratio of irrigation Water to farm dam storage”, the percentages of usage (derived from surface water) to dam capacity were estimated at 55%, 28% and 13% for the Lower, Middle and Upper catchments respectively, giving a mean of 25%. There is much uncertainty about these estimates and thus, for the purposes of modelling usage percentages were investigated at values between 30% and 70%. This range is higher than the 25% estimated in order to check on more severe usage situations.

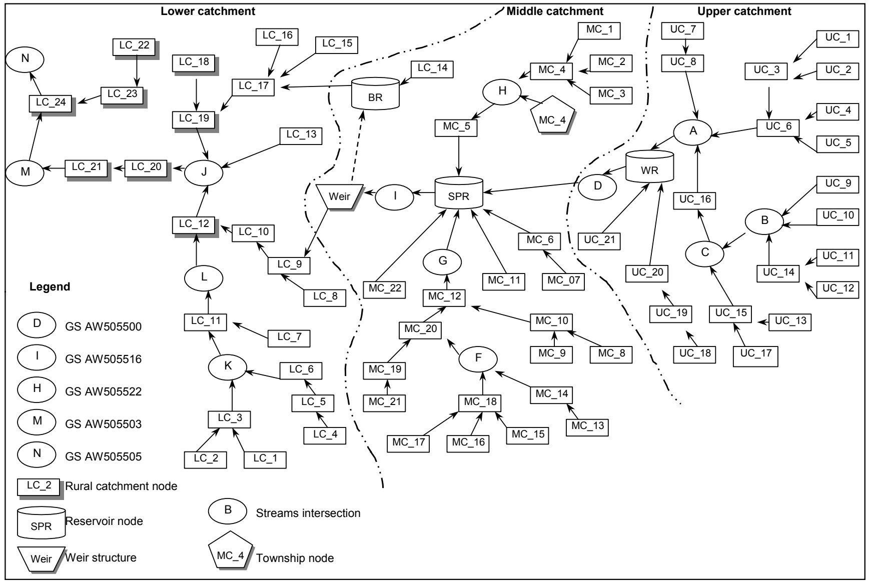
Runoff from Williamstown was modeled using an urban catchment node. Routing nodes were added to improve flow calibration at the daily time-step as per Table 25 in Appendix C, which provides details on all model nodes.

4.3 MODEL CALIBRATION

The rainfall runoff relationship of a catchment is represented in the model by a series of mathematical equations. These equations are incorporated within the working of the catchment node that represent the various processes involved in the land phase of the hydrological cycle viz., rainfall, interception storage, evaporation, transpiration, infiltration,

Figure 12: South Para River catchment hydrological model





Watercourses

Reservoirs

South Para catchment

Major sub-catchments

Upper catchment

Middle catchment

Lower catchment

Below S.E. Gawler

N

0 2.5 5 10 km

Projection: MGA Zone 54 Transverse Mercator
Datum: Geocentric Datum of Australia 1994
Date: June 2003

Data Sources:
CLIMATE STATIONS AND RAINFALL:
Bureau of Meteorology
TOWNS AND LOCALITIES:
Information and Data Analysis, Planning SA

Produced by the Water Information Group, Knowledge and Information Division, DWLBC

M:\Projects_SWIMl_Lofty_Ranges\SouthPara1\Prj_SW_Model\Fig12_SouthParaRiverCatchmentHydrologicalModel_v2.mxd\KTeoh\May2006 percolation, baseflow, etc. The mathematical equations contain about 15 variables which together influence the temporal estimation of flow resulting from the rainfall. Model Calibration is an iterative process involving the following main steps:

1. input data to the model — one or more measured sets of hydrological data (e.g. daily rainfalls, monthly evaporation, daily streamflow records)
2. iteratively vary some or all of the 15 variables which influence the estimation of flow (e.g., pan factor for soil, interception storage, ground water discharge, etc.) to mathematically simulate the catchment runoff
3. compare the simulated values to the measured values and continue the iteration process until a ‘good correlation’ is obtained between the simulated and measured flow records. The calibrated model is that which is deemed to provide the best correlation
4. use the calibrated model with a new set of input variables (e.g. dam sizes, usage, etc) for modelling further scenarios.

Since the hydrological cycle involves a large number of parameters that are not defined or measured, efficient calibration of hydrological models requires good knowledge of the major catchment conditions influencing runoff and a good understanding of the workings and limitations of the models.

Calibrations were carried out separately for the Victoria Creek, Upper, Middle and Lower catchments. For Victoria Creek and the Lower catchment, the flow data used for calibration were daily streamflow measured by the gauging stations AW505522 (Victoria Creek at Williamstown) and AW505503 (South Para River at SE of Gawler Station) respectively. Estimates of spills over the Barossa Diversion Weir were deducted from the flows measured at the SE of Gawler Station when calibrating the Lower catchment. The monthly flow data obtained by Tomlinson (1996) were used for the Upper and Middle catchments.

The “best” calibrations were selected on the basis of comparisons between observed and modelled flows presented as i) time series plots at daily, monthly and annual time steps and daily and monthly flow duration curves, and ii) statistically by seeking high R-square and coefficient of efficiency values for observed and modelled flows at annual and monthly time steps. Table 8 shows the calibrated statistical values. The final values of the 10 parameters for each catchment rainfall to runoff models are presented in Appendix D.

Flow duration plots of the observed and modelled flows are shown in Figure 13 for the Upper, Middle, Lower, and Victoria Creek catchments.

Calibration was found to be sensitive to small changes in the model’s soil moisture discharge (SMD) and groundwater discharge (GWD) parameters.

The calibration calculated for the daily flow results gave an apparent worse fit than for the results aggregated at the monthly and annual time steps. This is normal and is generally due to timing or aggregation errors in the daily rainfall records which do not apply when the results are presented at the monthly and annual time steps.

Table 8. Statistical results of calibration

(3) Statistics		No. of samples	R square	Coeff of efficiency	Variation of CV	Std error of estimate	% diff in volume
Upper catchment	Daily	N/A	N/A	N/A	N/A	N/A	N/A
	Monthly	311	0.92	0.84	-0.09	61.8	0.67
	Annual	25	0.94	0.89	-0.08	875	0.86
Middle catchment	Daily	N/A	N/A	N/A	N/A	N/A	N/A
	Monthly	299	0.9	0.82	-0.13	55	-0.7
	Annual	25	0.93	0.86	-0.16	774	-0.8
Lower catchment	Daily	9516	0.73	0.42	0.05	0.37	-0.81
	Monthly	312	0.86	0.74	-0.05	25.2	0.75
	Annual	26	0.91	0.83	-0.04	345	0.7
Victoria Creek	Daily	4758	0.77	0.58	-0.09	0.17	-0.5
	Monthly	143	0.89	0.80	-0.10	12.3	-0.2
	Annual	12	0.93	0.87	-0.09	155	-0.2

The model did not calibrate well for low flow events less than 1 ML/d flow, as shown by the flow duration curves. This could be due to several reasons:

- the majority of flows less than 1 ML/d are base flows discharged from adjacent fractured rock aquifers. These are not well understood and the simple functions available in most rainfall-runoff models are generally poor at simulating the complex processes taking place
- the general overestimation of low flows by the model for the rural catchments may reflect inaccurate assumptions on the operation of the dams or the proportion of the catchment flow deemed to be captured by the dams.

Low flow measurements are more subject to large random errors than medium flows.

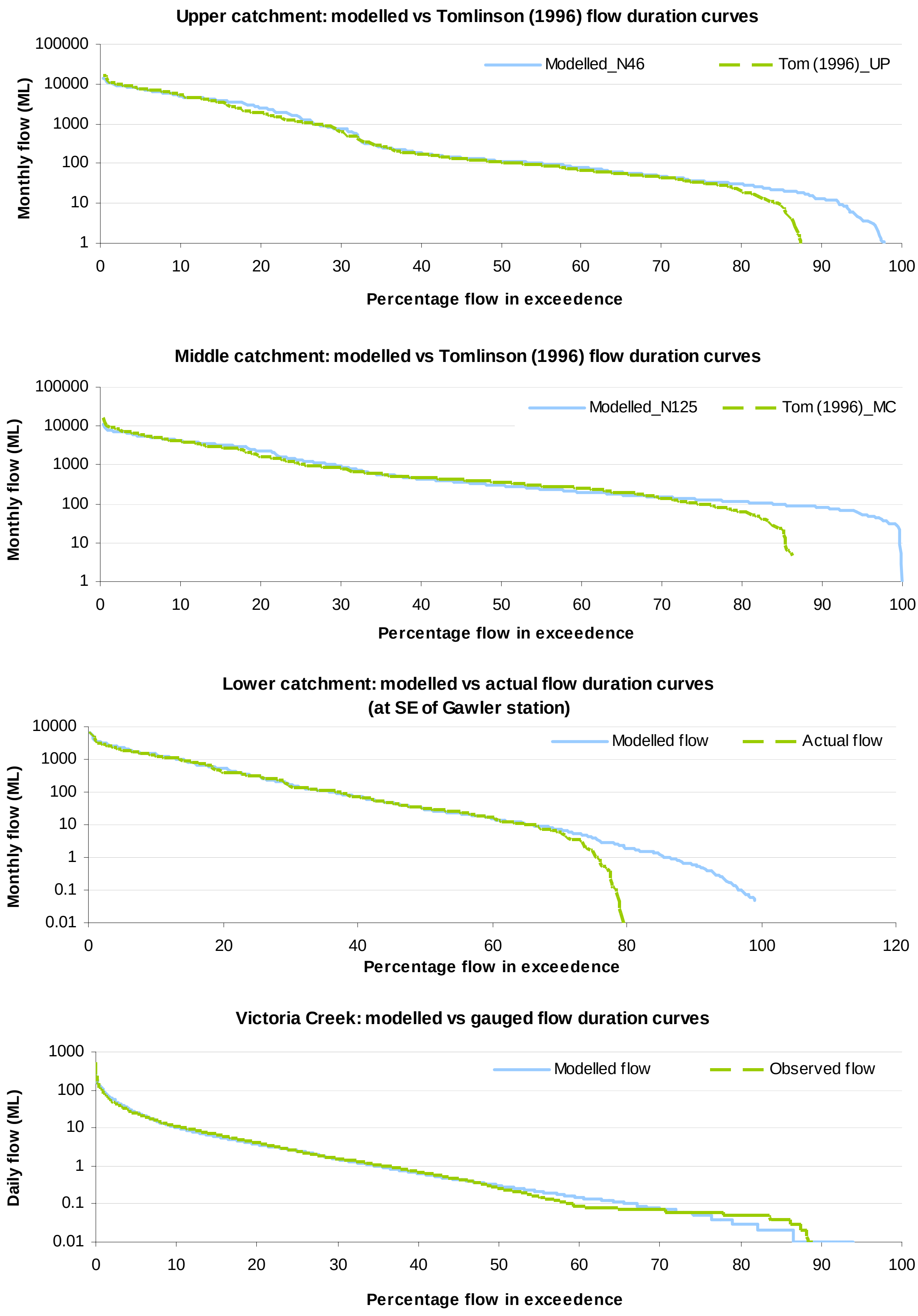


Figure 13. Plots of calibrated flow duration curves

5. RESULTS

5.1 MODELLING SCENARIOS

After flow calibration was completed, five scenarios were modelled in order to study the impact of current and future levels of farm dam development on catchment yields. Results for an additional scenario (Scenario 2a) could be obtained by calculation from the results of Scenarios 1 and 2 (see below).

Scenario 1 (WFD)	This is the 'as calibrated' scenario using 1999 farm dam survey data, with an aggregated farm dam storage volume of 2960 ML (the current farm dam development scenario). While an annual dam water use of 30% of the storage capacity was assumed in the calibration, 2 other levels of water usage are also investigated (see below).
Scenario 2 (WOFD)	In this scenario all the farm dams were removed. The catchment yields obtained define the predevelopment flows for the individual catchments.
Scenario 2a	In this scenario the effects of the reservoirs are also removed. This is calculated simply by addition of the catchments flows from the Upper to the Lower catchment.

To assess the potential impact of future levels of farm dam development on catchment flow, rules developed by the Boards and the SWP 2000 for dam development were adopted and applied as three further scenarios.

Scenario 3 (5%RF)	The 5% rainfall rule assumes farm dam volumes are developed to a level where their volumes equal 5% of the mean annual rainfall volume falling on their upstream catchment area. (This will be the same as given in NABCWMP 2001–2006 under conditions where it is assumed that runoff is equal to 10% of the mean annual rainfall volume falling on the upstream catchment area, then limits dam volumes to 50% of this volume).
Scenario 4 (30%RL)	The 30% rule assumes farm dam volumes are developed to a level where their volumes equal 30% of the calculated predevelopment flow generated from their upstream catchment area in a median year.
Scenario 5 (50%RL)	The 50% rule assumes farm dam volumes are developed to a level where their volumes equal 50% of the calculated predevelopment flow generated from their upstream catchment area in a median year. This is the "50% Rule" based on the SWP 2000 and is generally taken to be the maximum allowable level of dam development compatible with sustainable outcomes.

A review of the land use data suggests that, assuming that forest areas and national parks are assumed to remain uncleared into the future, the maximum percentages of catchment area that could be available for activities associated with future farm dam development in the Upper, Middle and Lower catchments under Scenarios 3–5 are 50%, 53% and 70% respectively.

Table 9 and Figure 14 show the aggregated farm dam volumes for the Upper, Middle, Lower and Victoria Creek catchments based on the existing land use areas adopted for Scenario 1 and the maximum areas developed for irrigation adopted for Scenarios 3–5 under the dam development rules set out above, within the individual small subcatchments used in the model. In some instances, the existing dam volumes are already in excess of the maximum volumes calculated by application of these rules. In these cases the existing aggregated dam volumes have been used in the model.

Table 9. Aggregated allowable farm dam capacities (ML) under each development scenario

Scenario	Upper (118.6 km^2)	Middle (115.4 km^2)	Lower (90.1 km^2)	Total (324.1 km^2)	Victoria Ck (20.4 km^2)
S1 (WFD)	1431 (12.1)	1041 (9.0)	452 (5.0)	2924 (9.0)	135 (6.6)
S3 (5%RF)	2575 (21.7)	2300 (19.8)	1956 (21.7)	6831 (21.1)	609 (29.9)
S4 (30%RL)	2380 (20.1)	1955 (16.9)	897 (10.0)	5232 (16.1)	392 (19.2)
S5 (50%RL)	3551 (29.9)	3185 (27.6)	1356 (15.0)	8092 (25.0)	654 (32.1)

Note: The figures in bracket represent the farm dam density with unit ML/km^2

Middle catchment for the model includes Barossa Reservoir catchment area

Lower catchment modelled with catchment area up to SE of Gawler Station. The Barossa Reservoir catchment was excluded from this catchment although the stream system flows into Lower catchment

In order to study the catchment yield under a wide range of rainfall conditions, the runoff simulations were performed using the historic daily rainfall data from 1884–1998.

For each modelling scenario involving farm dams, three levels of dam water use (30%, 50% and 70% of the storage capacity) were investigated, with the 30% level being assumed for the current level of dam water use. The higher levels are investigated in anticipation that future usage rates might rise in response to possible future further restrictions of dam volumes.

Hence 3 runoff simulations were performed for each of Scenarios 1, 3, 4 and 5, and only one for Scenario 2 giving a total of 13 simulations.

5.2 PRESENTATION OF RESULTS AND DISCUSSIONS

The results and discussions are presented in the following order:

1. The annual runoff, rainfall-runoff curves and runoff coefficients for the Upper, Middle and Lower catchments are defined for the current level of farm dam development (Scenario 1) and the pre-development condition with all the farm dams removed (Scenario 2).
2. The differences between the flows under Scenario 1 and 2 are examined in greater detail at the monthly level.

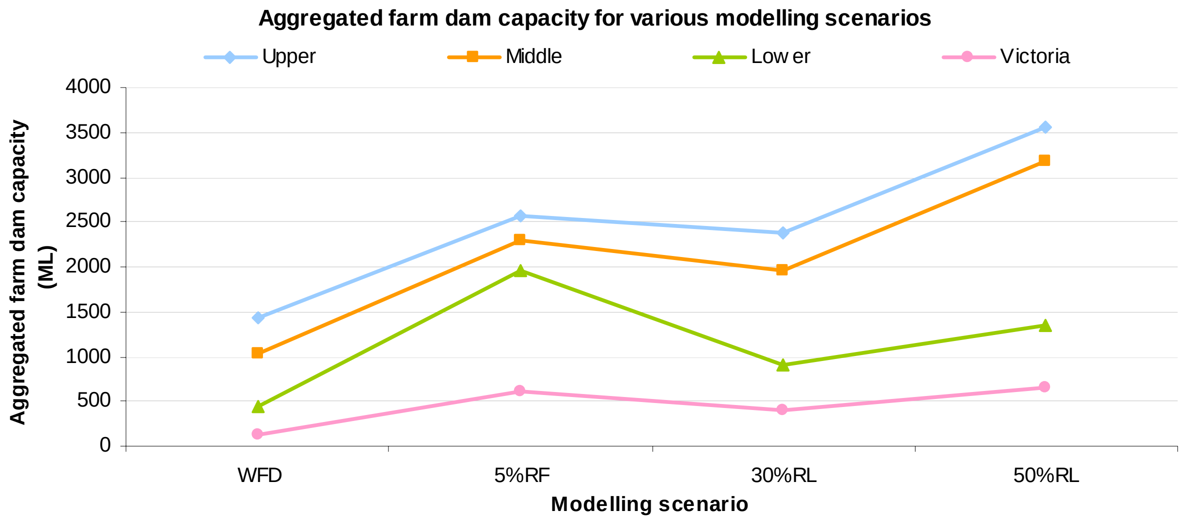


Figure 14. Aggregated farm dam capacity for various modelling scenarios

3. The sensitivity of the flow estimates to assumptions of the annual dam water usage rate (from 30–70% of the dam storage capacity) is explored.
4. The predevelopment flows downstream of the Barossa diversion weir and at the SE of Gawler Station are calculated over the period 1983–97 assuming that the reservoirs are also removed, assuming that the reservoirs are removed (Scenario 2a). These flows are compared to the present day flows and the results are also compared with those given in the SKM report. Comparison is also made for the frequency of daily flows at both locations over the period 1968–98. Plots of annual flows for the same period are also presented.
5. The impacts on catchment flows of the various levels of future farm dam development under Scenarios 3–5 are assessed and expressed as percentage reductions to the predevelopment flows.
6. As above, but the catchment flow reductions are converted into actual flow impacts (ML/a) on the inflows to the Warren and South Para reservoirs.

5.3 RESULT 1—CURRENT AND PREDEVELOPMENT RESOURCE AVAILABILITY

5.3.1 CURRENT CATCHMENT FLOWS (SCENARIO 1)

The long-term (1884–1998) median and average annual flows, and the driest and wettest period flows for each of the catchments (at current levels of farm dam development, assuming 30% dam capacity water usage) are given in Table 10 below.

Since the catchment areas, dam volumes and rainfalls for the Upper and Middle catchments are similar, the flows are also similar, except that during the defined dry period, the Middle catchment is shown as generating substantially more runoff (7700 ML) than the Upper catchment (2400 ML).

Table 10. Long-term catchment flows with current farm dam development

Catchment location	Median year 1884–1998 (ML)	Driest period 1957–1959 (ML)	Wettest period 1917–1919 (ML)
Upper	13 100		
118.6 km^2	(14 700)	(2 400)	(28 000)
Middle	12 900		
115.4 km^2	(14 000)	(7 700)	(22 570)
Lower	3 860		
90.1 km^2	(5 020)	(1 930)	(10 220)
Total	29 860*		
324.1 km^2	(33 720)	(12 030)	(60 790)

Figures in brackets are average flow values. *Median flows are summed for approximation.

A post study review of the results suggests this may be caused by the selection of model parameters, which give a very persistent baseflow in the Middle catchment. (Fig. 13) shows that whilst the Tomlinson data shows zero monthly flow occurring for about 10% of the time, the model gives in excess of 10 ML/month at all times. This will cause the model to over-estimate flows in dry years.

The runoff for the Lower catchment is less on account of its lower rainfall and smaller area.

5.3.2 PRE-DEVELOPMENT CATCHMENT FLOWS (SCENARIO 2)

Table 11 presents the same results as above, except under pre-development conditions.

Table 11. Pre-development flows

Catchment location	Median year 1884–1998 (ML)	Driest period 1957–1959 (ML)	Wettest period 1917–1919 (ML)
Upper	14 400		
118.6 km^2	(15 500)	(3 000)	(29 100)
Middle	13 600		
115.4 km^2	(14 700)	(8 480)	(23 300)
Lower	4 200		
90.1 km^2	(5 340)	(2 200)	(10 590)
Total	32 200*		
324.1 km^2	(35 540)	(13 680)	(62 990)

Figures in brackets are average flow values. *Median flows are subsumed for approximation.

The pre-development flow in the median year is widely used for management planning and policy development. Appreciation of the large variation in flow between driest and wettest conditions is important in risk management assessment.

It can be seen that the estimated impact of the present level of farm dam development is not having a major effect on catchment flows in a median year but greater impact in the defined dry year (Fig. 15).

5.3.3 RAINFALL RUNOFF RELATIONSHIPS

The annual rainfall to runoff relationships for each of the catchments were developed for Scenarios 1 and 2 over the period 1884–1998.

Runoff is insignificant when rainfall is below 400–450 mm/a. It then rises slowly with a maximum rate of increase at about 600–650 mm/a. Logic dictates that at very high rainfalls, the rate of increase in runoff volume cannot exceed the rate of increase in rainfall volume. These characteristics are best described by a Tanh curve equation. The form of equation adopted has been modified from that proposed by Grayson et al. (1996) by the addition of two constants (App. E). These provide a better fit to South Australian annual rainfall and runoff data. The results are presented in Figure 16.

5.3.4 RUNOFF COEFFICIENTS

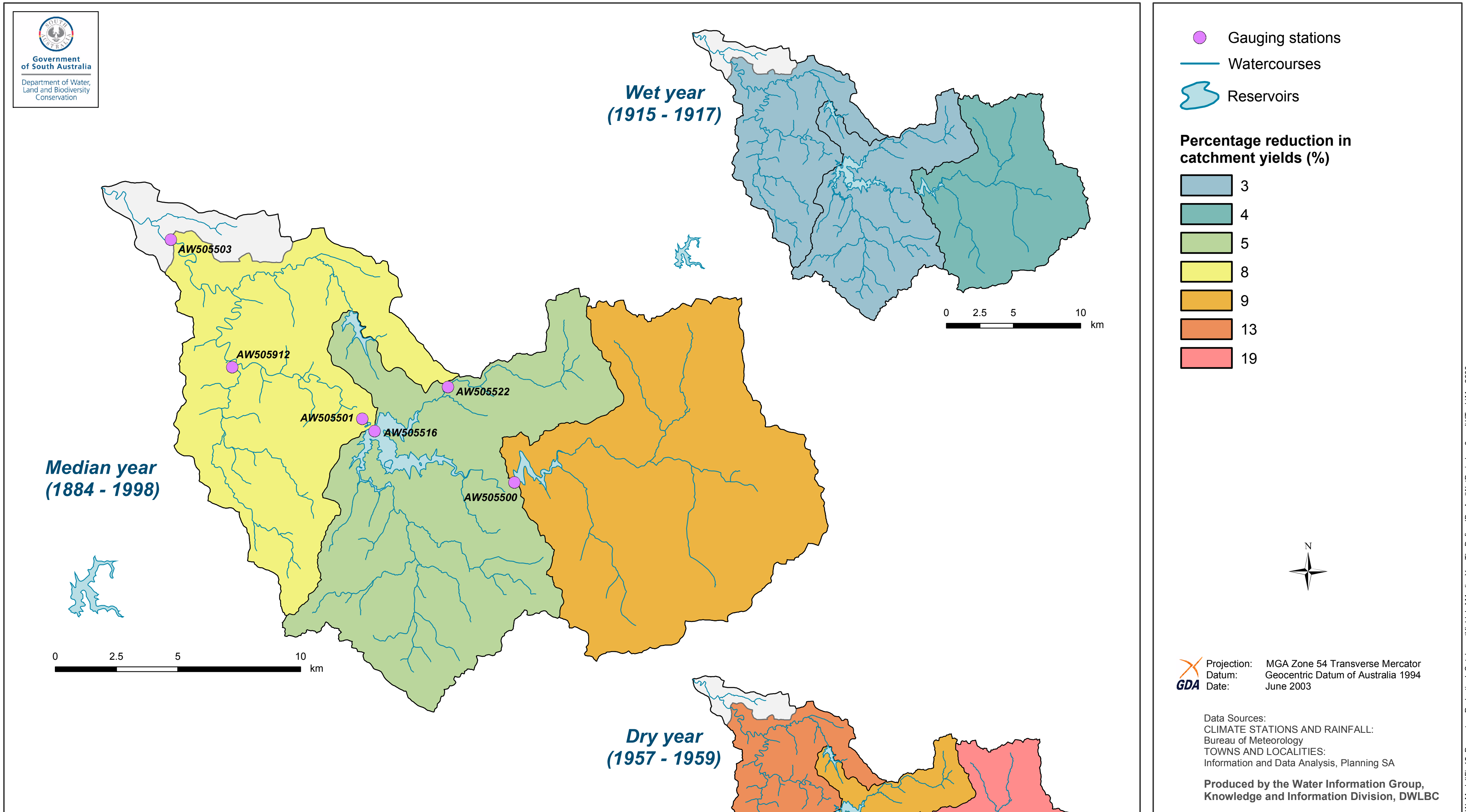
The runoff coefficient is the proportion of the rainfall volume that leaves the catchment as surface water runoff, where the rainfall and runoff are both measured in the same units (e.g. volume or mean depth over the whole catchment area). The coefficient may be calculated over any stated period of record. Thus a 50-year average annual coefficient of 0.10 means that an average of only 10% of the rainfall leaves the catchment as annual surface flow when calculated over a specified 50-year period, with each expressed as a volume or depth per annum.

The pre-development runoff coefficients for the Upper and Middle catchments were both found to be 16%. This is in line with the value of 12% calculated for the Victoria Creek catchment under the current level of farm dam development (Table 7).

Similarly, the runoff coefficients for the Lower catchment were found to be 8% and 6% for the pre-development and present farm dam conditions.

These results indicate that application of the NABCWMP 2001–2006 guidelines (as per Scenario 3), which assume that 10% of the catchment rainfall becomes surface flow, will overestimate the resource availability in the Lower catchment by 20% (and therefore place environmental values at risk) while underestimating the resource availability in the Middle and Upper catchments by 60% (thus leading to a potential underdevelopment of the area’s economic value).

Figure 15: Percentage reduction in catchment yields in different climatic conditions



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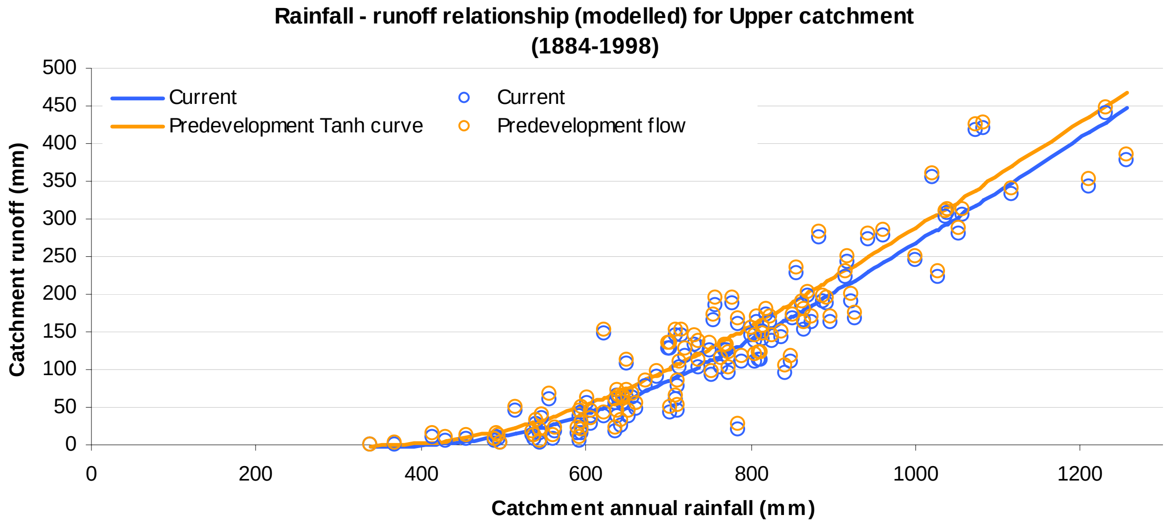
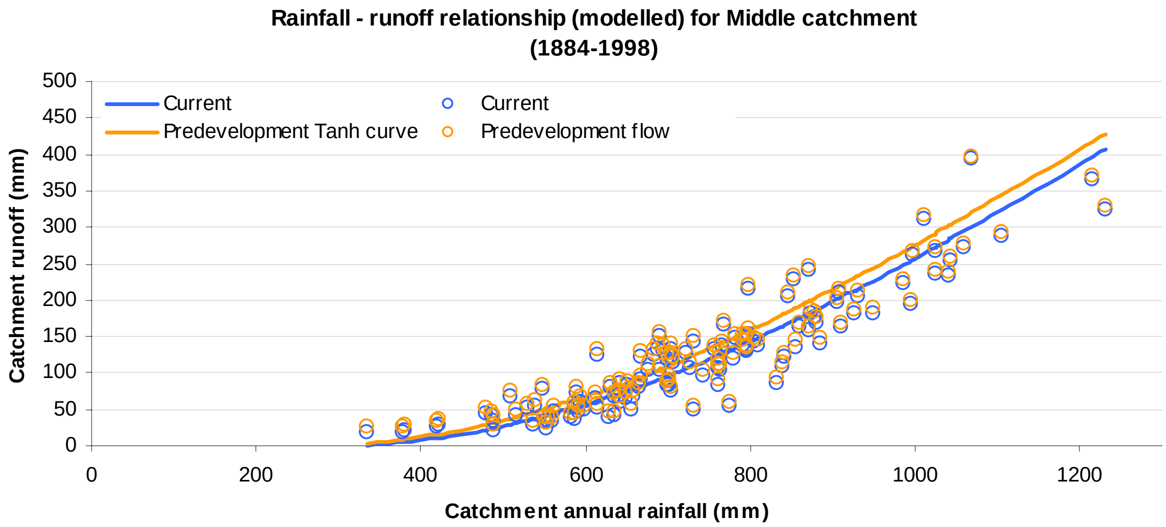




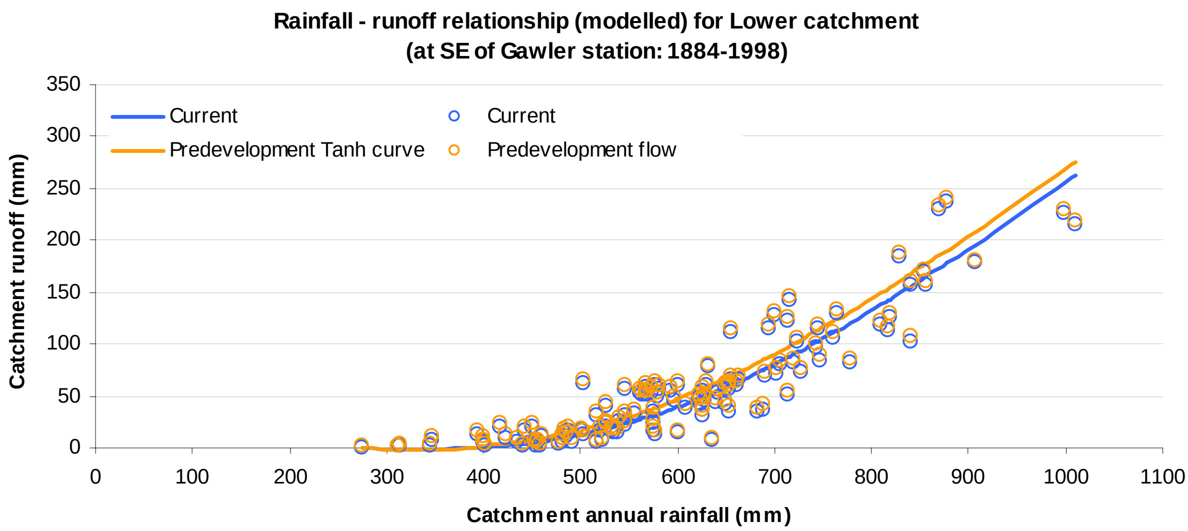


Figure 16. Rainfall-runoff relationship for the major subcatchments

5.4 RESULT 2—IMPACTS OF FARM DAMS ON MONTHLY FLOWS

Further analysis of the flows modelled under Scenarios 1 and 2 showed that summer months experienced the highest percentage flow impacts, varying from about 10% in November up to 60% in February. In the winter months the impacts are minimal. This is as would be expected, as in the summer the dam storages are drawn down by greater usage and evaporation losses and thus have greater potential for interception of upstream flows.

The results are presented in Table 12 and plotted in Figure 17. All values are average flows (ML) for that month from the modelled results for the period 1884–1998.

Table 12. Monthly flows (ML) and % impacts caused by farm dams

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Upper													
Predevp	109	84	81	162	360	1774	2859	3718	3117	2094	880	268	15 506
Current	55	42	42	124	286	1618	2742	3647	3085	2032	797	198	14 669
% Reduct	49%	50%	48%	23%	21%	9%	4%	2%	1%	3%	9%	26%	5%
Middle													
Predevp	256	220	242	333	564	1577	2400	3062	2715	1984	935	413	14 700
Current	122	112	141	276	537	1570	2410	3073	2711	1924	820	274	13 970
% Reduct	52%	49%	42%	17%	5%	0%	0%	0%	0%	3%	12%	34%	5%
Lower													
Predevp	24	21	26	61	131	563	891	1248	1156	823	318	79	5340
Current	10	8	11	39	91	501	849	1227	1146	799	287	55	5024
% Reduct	58%	60%	57%	37%	31%	11%	5%	2%	1%	3%	10%	30%	6%

5.5 RESULT 3—EFFECT OF DIFFERENT ASSUMED LEVELS OF WATER USE ON CATCHMENT YIELDS

Calibration of the model against the recorded (present day) flows has been undertaken assuming that usage from the dams has been 30% of the dam volume. However, in future, the usage rate as a proportion of the dam volumes could be increased if, for example, a ban was placed on further dam development, but not on the usage taken from the dams.

The effect of such an increased usage rate, assuming dam volumes remained at their current level, is indicated in Tables 13 and 14 below.

In all cases, increasing the usage rate causes a greater reduction in flows, as might be expected. It should be noted that the impact is caused by both withdrawal to use and evaporation loss. Although there is an overall greater reduction as the usage rate increases, there is a smaller (partially compensating) reduction in evaporation loss due to the smaller surface areas of water exposed in the dams associated with the greater usage.

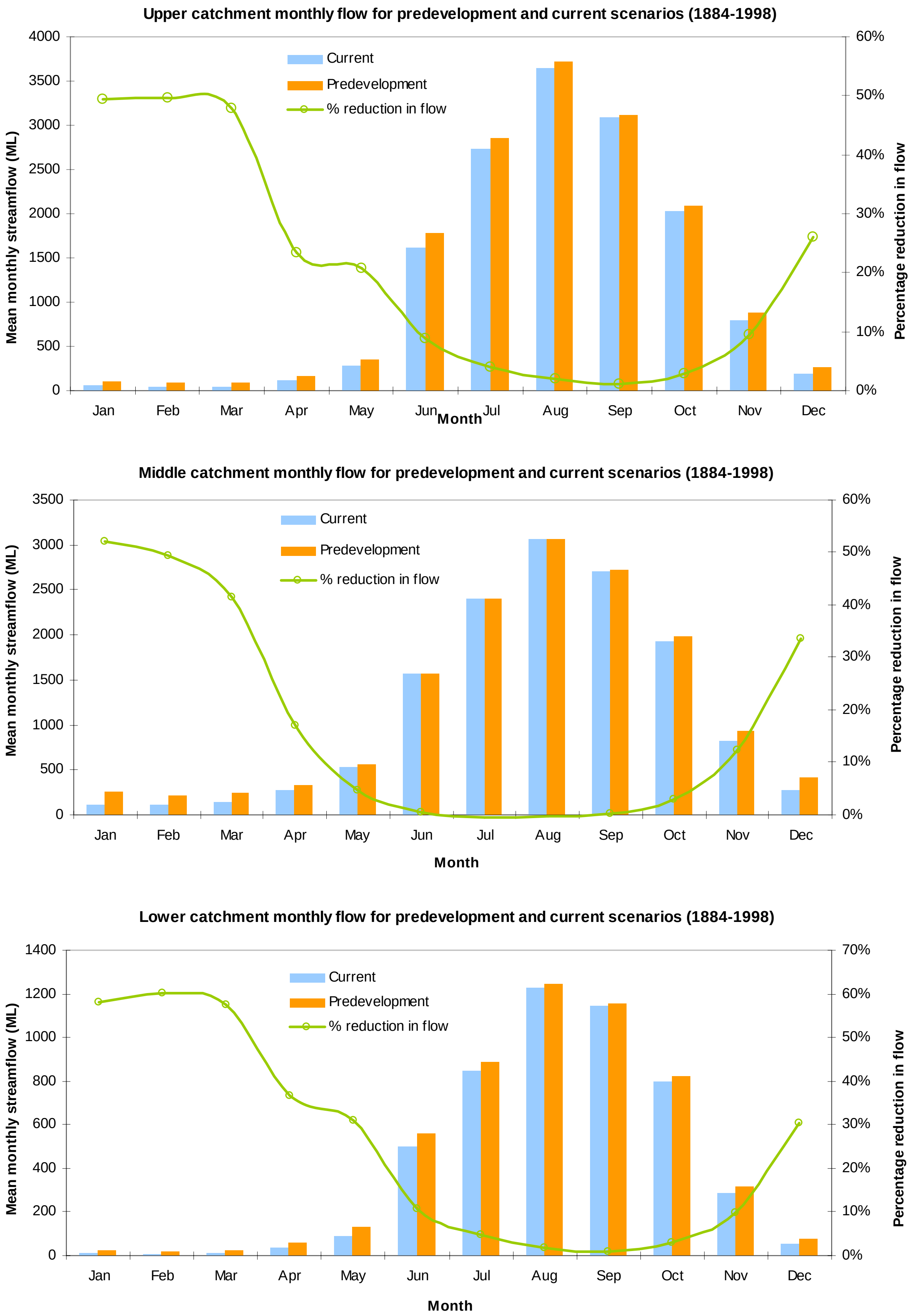


Figure 17. Monthly flow for predevelopment and current scenarios

Table 13. Percentage flow reduction in a median year (1884–1998)

Scenarios	Upper catchment			Middle catchment			Lower catchment		
Predevp flow, ML	14 400 (15 500)			13 600 (14 700)			4 200 (5 340)		
Storage use factor	**0.3**	**0.5**	**0.7**	**0.3**	**0.5**	**0.7**	**0.3**	**0.5**	**0.7**
Flow reduction by	9%	10%	11%	5%	7%	8%	8%	10%	12%
Flow diverted, ML	1 300 (1 395)			700 (735)			340 (336)		

Note: Figures in bracket are average value

Table 14. Percentage flow reduction in the defined dry and wet periods

Dry period (1957–59)	**Upper catchment**			**Middle catchment**			**Lower catchment**		
Predevp flow, ML	3 000			8 480			2 200		
Storage use factor	**0.3**	**0.5**	**0.7**	**0.3**	**0.5**	**0.7**	**0.3**	**0.5**	**0.7**
Flow reduction by	19%	21%	22%	9%	11%	13%	13%	15%	17%
Flow diverted, ML	580			780			270		
Wet period (1915–17)	**Upper catchment**			**Middle catchment**			**Lower catchment**		
Predevp flow, ML	29 100			23 300			10 600		
Storage use factor	**0.3**	**0.5**	**0.7**	**0.3**	**0.5**	**0.7**	**0.3**	**0.5**	**0.7**
Flow reduction by	4%	4%	5%	3%	4%	5%	3%	4%	5%
Flow diverted, ML	1 100			700			370		

As would also be expected, the reduction in flow is far greater in dry years than wet years. The results also reflect the influences of differences in rainfall and farm dam density across the three catchments.

5.6 RESULT 4—PRE-DEVELOPMENT FLOWS WITH RESERVOIRS REMOVED

In Scenario 2 the pre-development flows have been modelled for each subcatchments as a separate entity. This has justification in so far as the Warren and South Para reservoirs are situated at the outlets of the Upper and Middle catchments and block most of the natural catchment runoff from passing downstream as natural flow.

By adding the flows from the Upper catchment through the Middle catchment to the Lower catchment a reasonable estimate can be made of the pre-development flows in the era before either farm dams or reservoirs were constructed. These are the flows considered in Scenario 2a. The actual flows may have differed from these estimates, but probably not to a large extent, because allowance is not made in the original calibrations for losses from the reservoir surfaces nor, in the addition process, for possible increased losses from the additional upstream flows in the downstream channels.

It should be recalled that the actual flows recorded at the SE of Gawler Station will have included the effects of the infrequent spills from the Barossa weir into the Lower catchment.

These spills were however removed before calibration of the model used to predict the runoff from the Lower catchment.

The results described below show that the diversion of surface flows by the Warren and South Para reservoirs (via the Barossa weir) have had a far greater impact on flows than the farm dams. The extent of the impact can be quantified by comparing the annual, monthly and the daily flow patterns of the individual catchments (previously considered as stand alone catchments) with what the flows would have been if they had not been diverted via the reservoirs.

The results were also compared with the study made by consultants SKM (SKM, 2001).

5.6.1 THE ANNUAL PRE-DEVELOPMENT (PRE-RESERVOIRS) CATCHMENT YIELDS

5.6.1.1 At the SE of Gawler Station site

The observed flow at the SE of Gawler Station site for the period 1983–97 was 8606 ML/a. Of this 5077 (8606–3529) ML/a originated for the Lower catchment with the difference originating from spills over the Barossa weir (Tables 15 and 16). The Lower catchment runoff is estimated to rise to 5417 ML/a (5077 + 340) (Table 13) if the farm dams had not been established.

Table 15. Current and pre-development flows passing the Barossa Diversion Weir (1983–97)

Month	DWLBC Model			SKM Model (SKM, 2001)		
	Pre-development flow	*Flow passing BDW*	*Reduction*	*Natural* [1]	*Current* [2]	*Reduction*
Jan	373		100%	204		100%
Feb	307		100%	148		100%
March	332		100%	235		100%
April	332		100%	298		100%
May	521		100%	915		100%
June	1 862		100%	2 557		100%
July	5 752		100%	6 348		100%
August	7 440		100%	9 874	256	97%
September	6 968	1 096	84%	8 092	942	88%
October	3 498	1 304	63%	3 228	1 431	56%
November	1 635	334	80%	897	138	85%
December	1 182	794	33%	1 172	593	49%
Annual	30 202	3 529	88%	33 967	3 361	90%

Note: all the figures are average values.

1 The term “natural” used by SKM is equivalent to the pre-development flow.

2 The term “current” used by SKM is equivalent to the flow passing Barossa Diversion Weir

Table 16. Current and pre-development flows at SE of Gawler Station (1983–97)

Month	DWLBC Model			SKM Model		
	Pre-development flow	*Gauged flow*	*Reduction*	*Natural*	*Current*	*Reduction*
Jan	400	12	97%	219	12	95%
Feb	326	2	99%	150	2	99%
March	358	2	99%	238	2	99%
April	368	5	99%	303	5	98%
May	584	29	95%	948	29	97%
June	2 008	190	91%	2 796	203	93%
July	6 186	616	90%	7 016	563	92%
August	8 629	1 605	81%	11 589	1 625	86%
September	8 489	2 918	66%	10 634	2 615	75%
October	4 610	2 025	56%	5 606	2 243	60%
November	2 055	417	80%	1 326	441	67%
December	1 345	785	42%	1 980	804	59%
Annual	35 359	8 606	76%	42 805	7 935	81%

Note: all the figures are average values.

Addition of the Upper, Middle and Lower catchment pre-development flows shows that, in the pre-development, pre-reservoir era, the flow at the SE of Gawler Station gauging site would have been of the order of 35 359 ML/a. Hence the diversions by the combined Warren, South Para and Barossa Reservoirs and the farm dams have reduced the flows to only 24% (8606/35 359) of their pre-development levels.

When expressed in terms of median, rather than mean flow, the reduction is much greater. The predevelopment median flow would have been about 32 200 ML/a, compared to the current recorded median flow of 3170 ML/a (Table 13) or only about 10% of the original level. The farm dams are only responsible for 7.2% of the 90% reduction.

A comparison of the current and predevelopment, pre-reservoir annual flows since 1968 is plotted in Figure 18. Such massive flow reductions are believed to be placing significant stress on the water dependent ecosystems below the major diversion points.

There are significant differences between these results and those given by SKM. SKM estimates the pre-development, pre-reservoirs flows at the downstream gauging site to be 42 805 ML/a. This is 7446 ML/a higher than the DWLBC estimate herein.

There appear to be inconsistencies within the SKM results. For example the SKM model predicts that the Lower catchment, alone, would generate 8838 ML/a (i.e. 42 805–33 967 ML/a, see Tables 15 and 16) while their observed flow data (calculated for the period 1983–97) showed only 4574 ML/a (i.e. 7935–3361 ML/a). It is therefore concluded that the SKM estimate of 42 805 ML/a as the mean flow for the Lower catchment appears to be an over-estimate by about 4000 ML/a, likely due to double accounting for spills at the Barossa weir, and that the DWLBC model and procedures produce results more consistent with the historical and Tomlinson (1996) datasets.

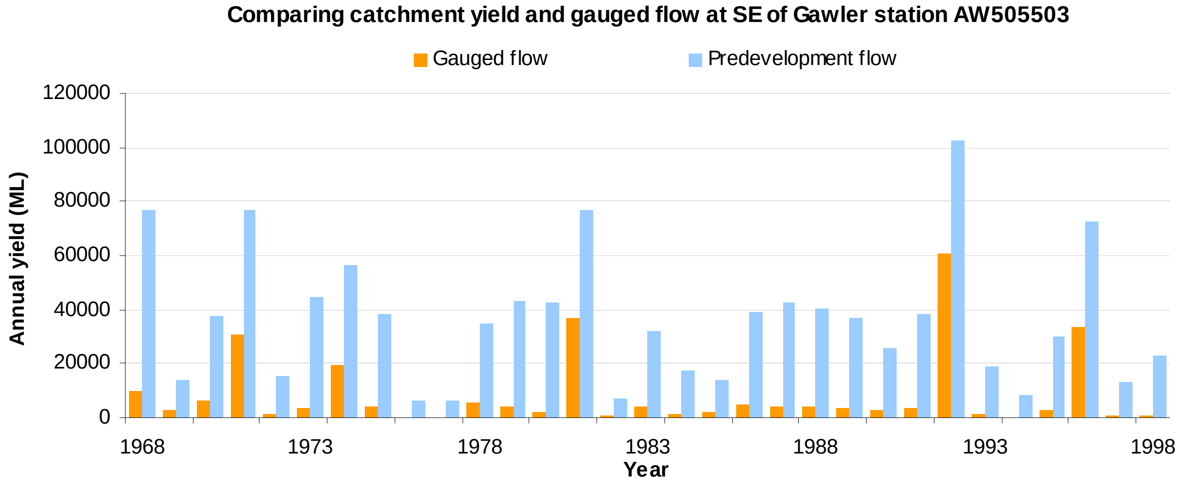


Figure 18. Comparing the annual predevelopment flow with gauged flow at SE of Gawler Station

5.6.1.2 At the Barossa diversion weir

The annual predevelopment, pre-reservoir and present day flows estimated to pass downstream from the Barossa weir for the period 1968–98 are shown in Figure 19. It can be seen that there were only six spills over the period from 1968–1998 (1968, 1971, 1974, 1981, 1992 and 1996).

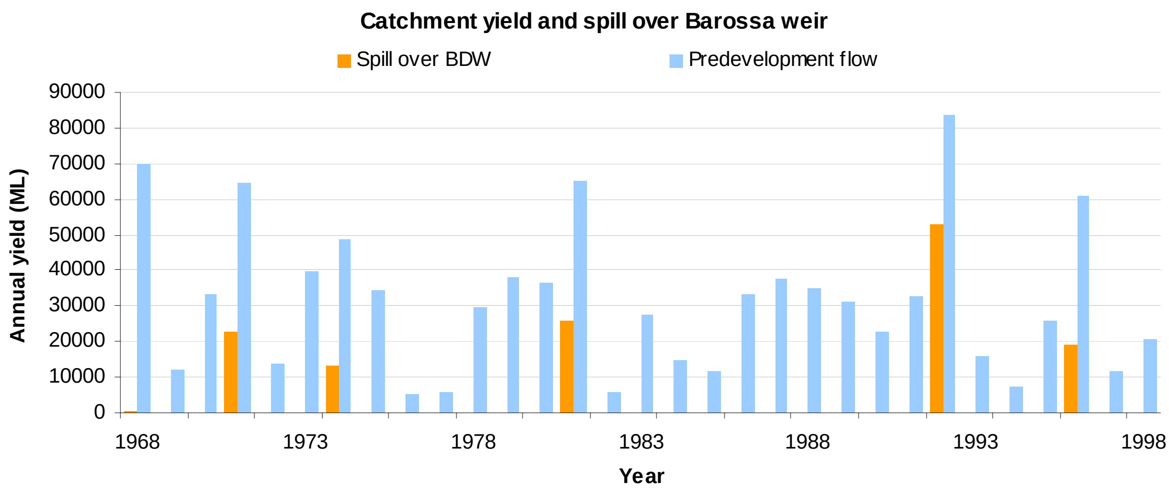


Figure 19. Predevelopment flow and spills over Barossa weir

For the period 1983–97, the average pre-development, pre-reservoirs flow at the Barossa weir site estimated from the model is 30 202 ML/a (Table 15). The actual flows passing this same location (i.e. the spills over the weir) are estimated to average 3529 ML/a. This means that only about 12% of the pre-development, pre-reservoirs flow now passes the weir site into the downstream river system. Thus, as would be expected the effects of the reservoirs have a greater impact directly downstream of them, than at some point further downstream where the addition of catchment inflows tend to ameliorate the situation.

If the flows are expressed as their values in a median year, the predevelopment flow would have been 28 000 ML/a, but the recorded median spill would have been zero. Thus in a median year farm dams and reservoirs divert all of the natural flow, resulting in a 100% flow reduction.

These results compare better with the SKM results (SKM, 2001) for the Barossa weir site than they do for the SE of Gawler Station site. The SKM results for the Barossa weir show present flows reduced to 10% of their pre-development, pre-reservoir level of 33 967 ML/a. Thus, although the annual yield modelled by SKM is 3765 ML higher than that of the DWBC model, uncertainty associated with the water budget calculations for the reservoirs suggests either estimate could be equally valid.

Note that the flows intercepted by the Upper and Middle catchments include an estimated 7103 ML/a of unaccounted losses which are equivalent to an average annual net loss to evaporation (i.e. evaporation – rainfall) of 1160 mm calculated over the combined reservoir surface areas at full supply.

Large dams (i.e. the reservoirs) can be seen to be much more efficient than the smaller (farm) dams when measured in terms of the percentage that the water use (i.e. the supply from the dam) comprises of the total reduction in flow caused by the dam. For the period 1967–96 the reservoirs supplied 21 671 ML/a (see water use data, App. B), while the total difference between inflow and outflow was this amount plus 7103 ML/a, giving an efficiency of 75.3%. For the farm dams only about 750 ML/a was supplied (see Section 2.5.4) while the difference between inflow and outflow is 2130 ML/a (Table 13), giving an efficiency of only 35.2%. The difference is due to the greater surface area per unit storage volume of the farm dams. It is likely that many of the smaller, shallower farm dams (particularly those used for stock watering only) have supply efficiencies of only a few %. These low efficiencies imply that the use of groundwater may be a far more efficient means for supplying water in many situations.

5.6.2 IMPACTS AT THE MONTHLY LEVEL

The pre-development flows at the Barossa diversion weir and the SE of Gawler Station (i.e. the combined pre-development outflows for i) the Upper and Middle catchments and ii) the Upper, Middle and Lower catchments for the period 1983–97, were further analysed at the monthly level. Results produced by SKM (SKM, 2002) were also extracted from their report and are presented alongside those of the DWLBC model in Tables 15 and 16. Plots of the monthly flow patterns are shown in Figure 20.

The tables show that although winter months provide the largest volumetric flow diversions, the smaller flows in the summer months are more greatly impacted in terms of percentage flow reduction. The figures also confirm the expectation that impacts will be felt to a greater extent at the weir location rather than at the SE of Gawler Station.

For example, no flow passed over the weir during January to August over the 14 year period 1983–97 and no flow passed over the weir at all during the nine years 1983–92. This is likely to cause great stress to the downstream water dependent ecosystems that rely on seasonal flows for breeding and other activities.

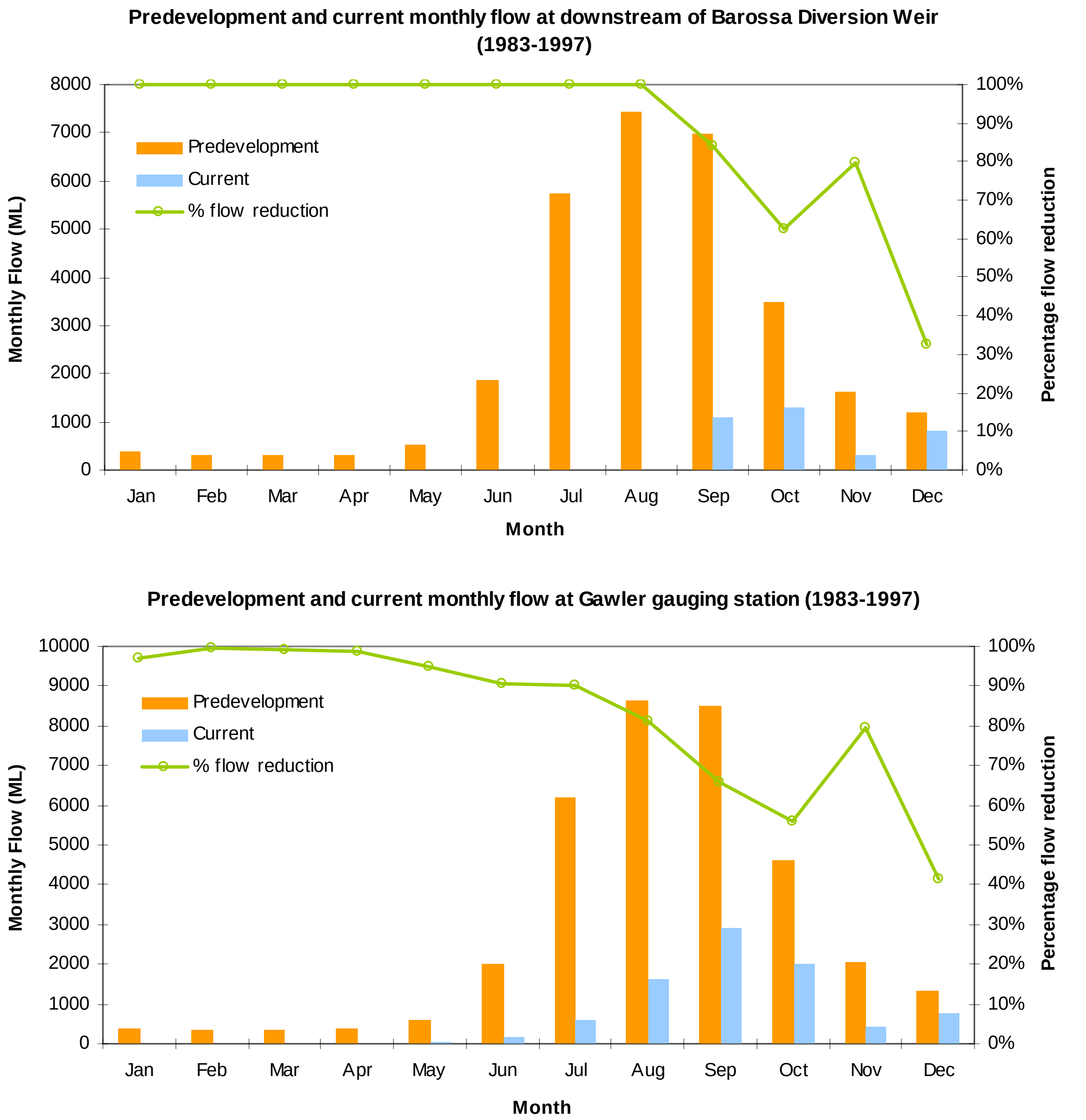


Figure 20. Predevelopment and current monthly flow pattern

It is also noted that SKM reported higher winter flows and smaller summer flows than the DWLBC. Without better streamflow records for the Upper and Middle catchments, no comments can be made on these discrepancies, other than to suggest caution when using these data and results.

5.6.3 IMPACT ON THE FREQUENCIES OF DAILY FLOW

Flows at the SE of Gawler Station from 1968–98 were used to investigate how current farm dams and reservoirs have impacted on the frequency of daily flows within a particular flow band within each month. Table 17 summarises the results.

Table 17. The number of days flow occurred at SE of Gawler Station

Month		13 ML/d	5 ML/d	10 ML/d	15 ML/d	20 ML/d	30 ML/d	50 ML/d	100 ML/d
Jan	Predevp	31	31	20	7	3	1	0	0
	Gauged	3	0	0	0	0	0	0	0
Feb	Predevp	28	28	17	7	2	1	0	0
	Gauged	1	0	0	0	0	0	0	0
Mar	Predevp	31	31	19	7	2	0	0	0
	Gauged	2	0	0	0	0	0	0	0
April	Predevp	30	30	24	9	2	0	0	0
	Gauged	5	1	0	0	0	0	0	0
May	Predevp	31	31	28	16	8	2	2	1
	Gauged	9	4	2	2	2	1	1	1
Jun	Predevp	30	30	29	25	17	10	5	4
	Gauged	16	6	4	4	3	3	2	1
July	Predevp	31	31	31	29	25	20	15	11
	Gauged	25	17	14	11	9	6	4	2
August	Predevp	31	31	31	31	28	24	18	14
	Gauged	29	23	19	16	14	11	7	4
September	Predevp	30	30	30	29	27	23	18	13
	Gauged	27	22	18	14	11	9	7	4
October	Predevp	31	31	31	27	23	18	12	8
	Gauged	25	15	9	7	6	4	3	3
November	Predevp	30	30	28	22	16	10	6	4
	Gauged	15	5	3	2	2	1	1	1
December	Predevp	31	31	24	15	10	4	3	1
	Gauged	6	1	1	1	1	1	1	0
Annual	Predevp	365	365	312	223	163	113	79	55
	Gauged	163	94	71	57	48	36	25	15

Predevelopment = flow without reservoirs and farm dams scenario

Gauged = gauged streamflow (1968–98)

For example, in its pre-development state there were 24 days in April when the flow exceeded the 10 ML/d flow level. This frequency has reduced to zero with the current level of diversion from farm dams and reservoirs. Similarly, at the 100 ML/d flow level, the flows in August have been reduced from 14 days to four days only.

Figure 21 plots the number of days flows occurred within each flow band under Scenario 1 and Scenario 2a.

5.7 RESULT 5—POSSIBLE IMPACT OF FUTURE FARM DAM DEVELOPMENT ON CATCHMENT FLOWS

Rules for future farm dam development were adopted from the catchment water management plans developed by the NABCWMB and the SWP 2000. Using these rules, three scenarios as described above (Section 5.1) were developed for the Upper, Middle and Lower catchments respectively. They are:

- 5%RF Scenario 3, based on the NABCWMP 2001–2006.

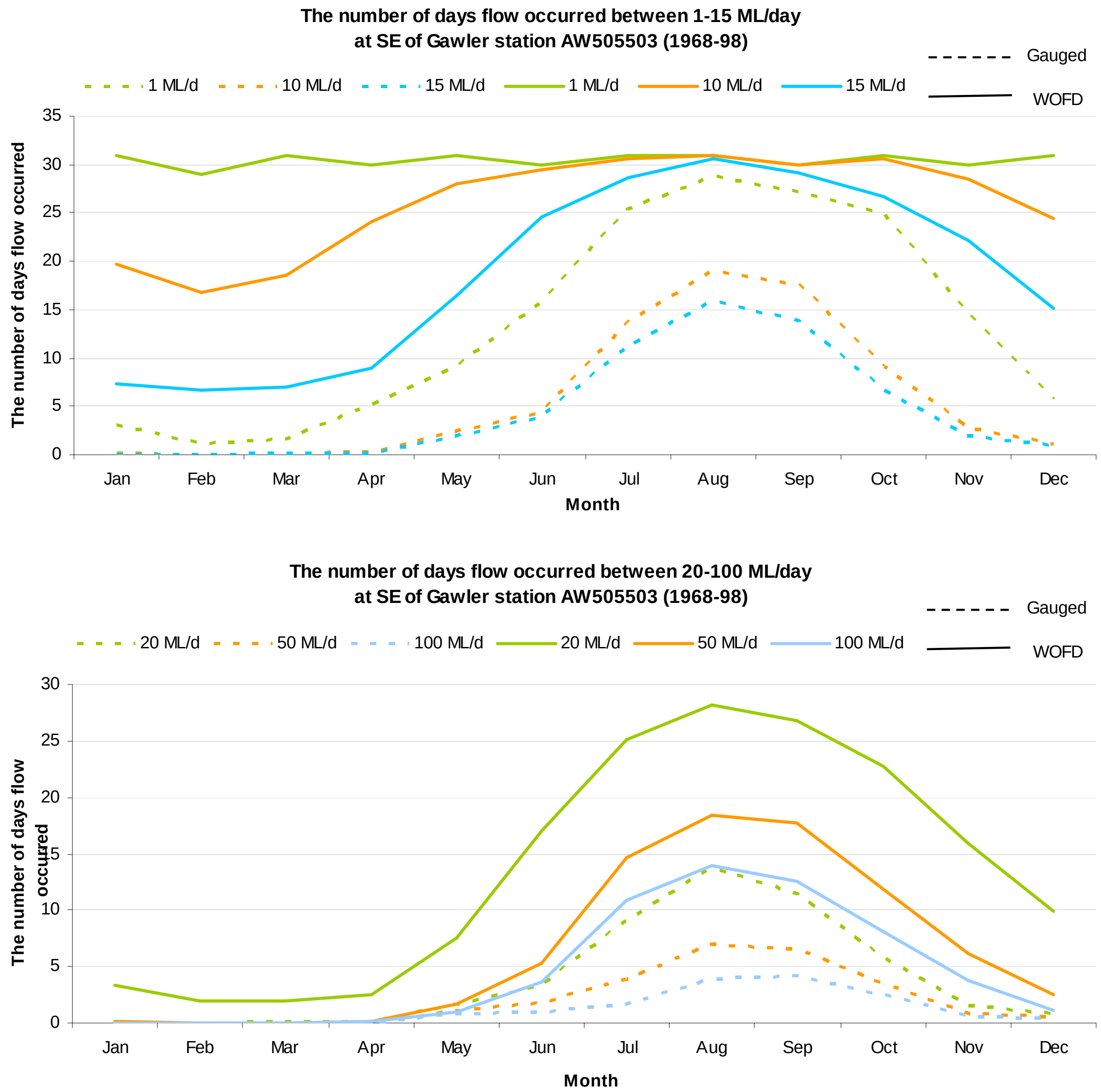


Figure 21. The number of days flow occurred at SE of Gawler Station

- 30%RL Scenario 4, as modified from the River Murray Catchment Water Management Board (RMCWMB) Plan 2003–2008.
- 50%RL Scenario 5, based on the SWP 2000 50-50 rule.

The percentage figures are the maximum allowable dam capacity, in terms of either the rainfall or median pre-development flows.

The assumed land areas on which the dams could be established are given in Table 2. Areas of forests and national parks are preserved at their current levels. Similarly at subcatchments scale level where the existing farm dam has reached or exceeded the allowable limit of development, then they are preserved at their current capacities.

For each scenario, three levels of annual dam water use (30%, 50% and 70% of the dam storage capacity) were assumed.

The percentage reduction from the pre-development flow level caused by the dam development is termed the impact at the specified level of assumed water use.

The results are presented in Table 18 and Figures 22–24.

Table 18. Percentage flow reduction from pre-development levels due to farm dams

Median (1884–1998)	**Upper catchment**			**Middle catchment**			**Lower catchment**		
Storage use factor	**0.3**	**0.5**	**0.7**	**0.3**	**0.5**	**0.7**	**0.3**	**0.5**	**0.7**
Scenarios									
S2, Predevelopment, ML		14 400 ML			13 600 ML			4200 ML	
S3, 5%RF	14%	17%	20%	10%	13%	16%	27%	36%	44%
S4, 30%RL	13%	16%	19%	9%	11%	14%	14%	18%	22%
S5, 50%RL	18%	23%	27%	13%	17%	21%	20%	26%	31%
Dry period (1957–59)	**Upper catchment**			**Middle catchment**			**Lower catchment (AW505503)**		
Scenarios									
S2, Predevelopment, ML		3000 ML			8480 ML			2200 ML	
S3, 5%RF	32%	38%	40%	16%	19%	23%	37%	46%	54%
S4, 30%RL	30%	35%	37%	15%	18%	21%	22%	26%	30%
S5, 50%RL	42%	49%	51%	21%	26%	30%	29%	35%	41%
Wet period (1915–17)	**Upper catchment**			**Middle catchment**			**Lower catchment (AW505503)**		
Scenarios									
S2, Predevelopment, ML		29 100 ML			23 300 ML			10 600 ML	
S3, 5%RF	6%	8%	9%	6%	8%	10%	14%	16%	19%
S4, 30%RL	6%	7%	8%	5%	7%	8%	7%	8%	9%
S5, 50%RL	9%	10%	12%	8%	11%	13%	10%	11%	13%

Some observations from the results in Table 18 are:

- Generally, for a given level of dam development, higher assumed levels of water use have a greater impact on flows, leaving less flow available to downstream users. Increasing the usage from 30–70% of the dam capacity (an increase of 2.3 times) generally results in a 1.5–1.8 times increase in the percentage impact on flows.
- For the Upper and Middle catchments, the impacts under Scenarios 3 and 4 are very similar because the 5%RF and 30%RL give about the same level of aggregated farm dam storage. Scenario 5 has the greatest impact since 50% of the median pre-development flow in these higher rainfall catchments is larger than 5% of the catchment rainfall. Scenario 5 applying in a dry period in these catchments gives the worst impacts—as high as 51% and 30% respectively.
- Impacts are greater when and/or where runoff is less.
- Results for the Lower catchment confirm that for all dam use levels, Scenario 3 (which sets dam volumes at 5% of the rainfall) gives a greater impact than Scenario 5 (which sets dam volumes at 50% of the median runoff) because the median runoff is less than 10% of the rainfall (Section 5.3.4).

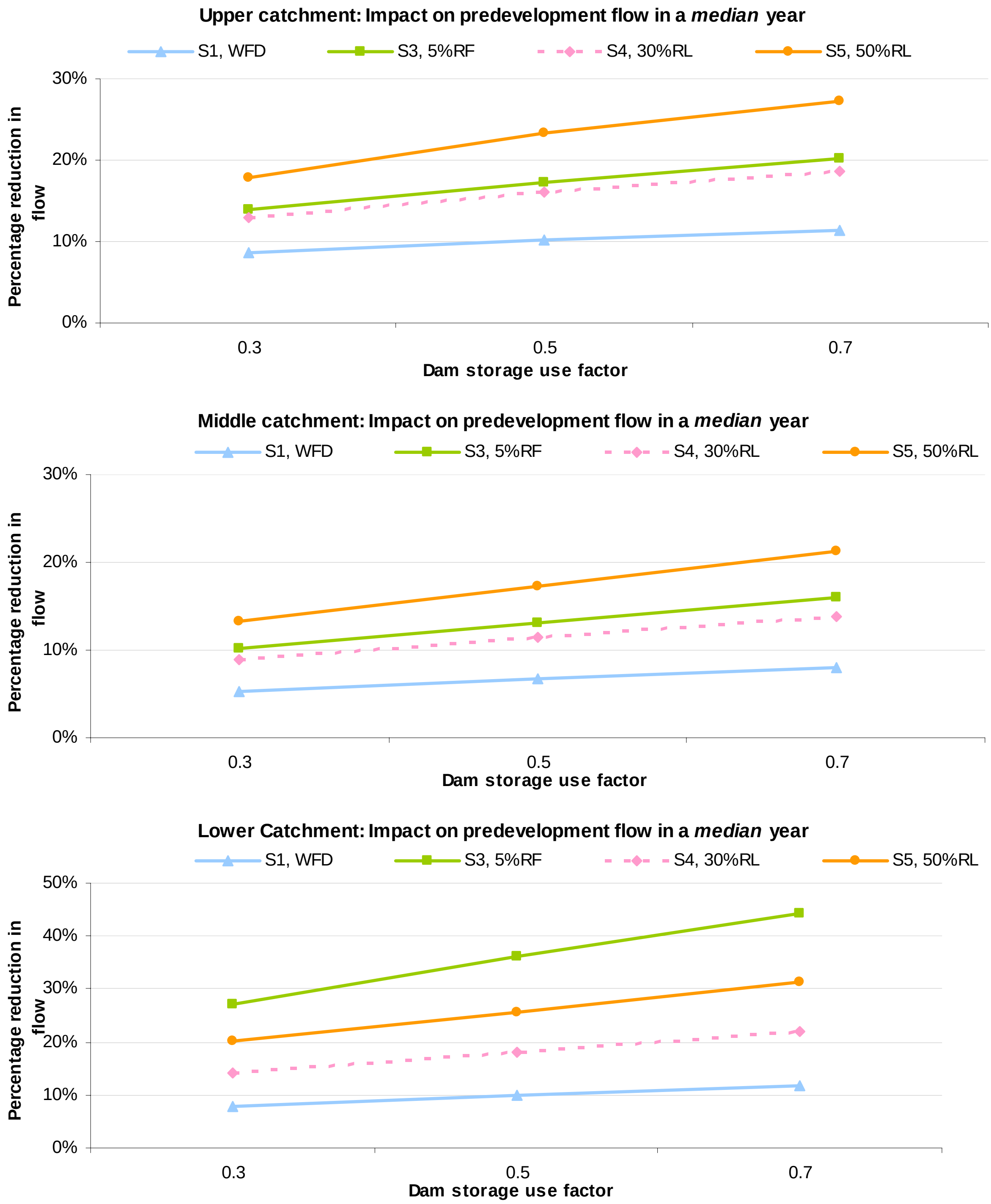


Figure 22. Percentage reduction of predevelopment flow for various scenarios in a median year (1884–1998)

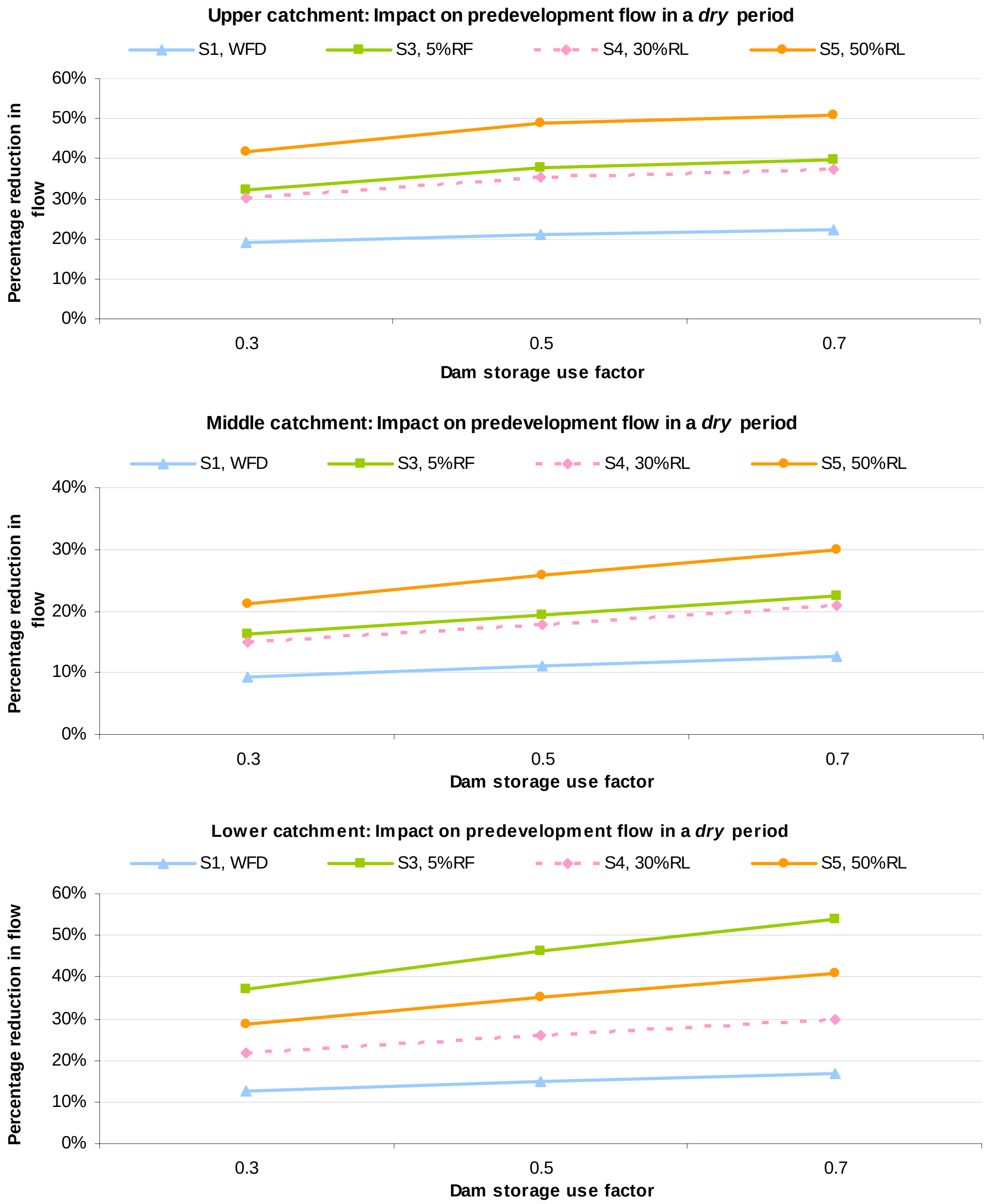
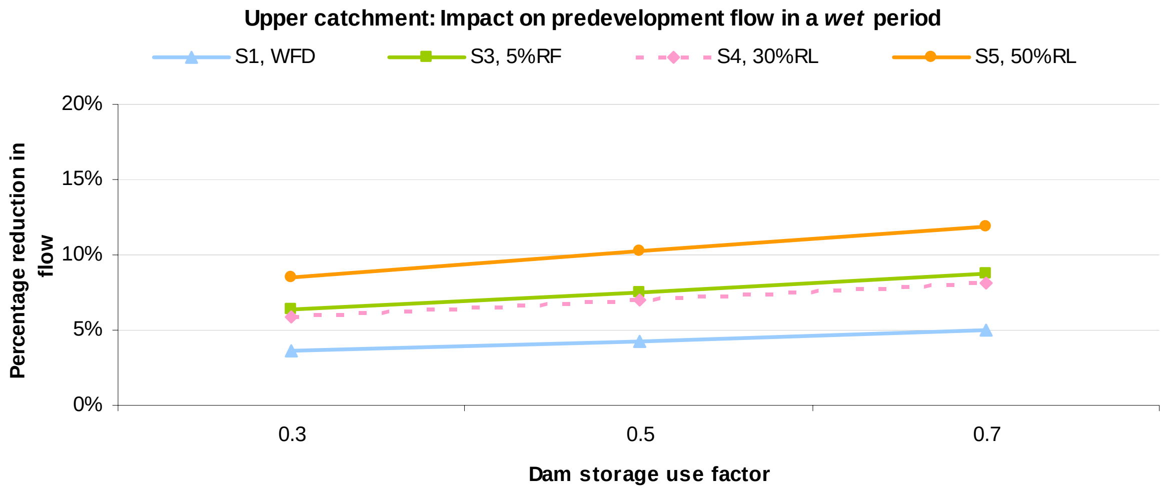
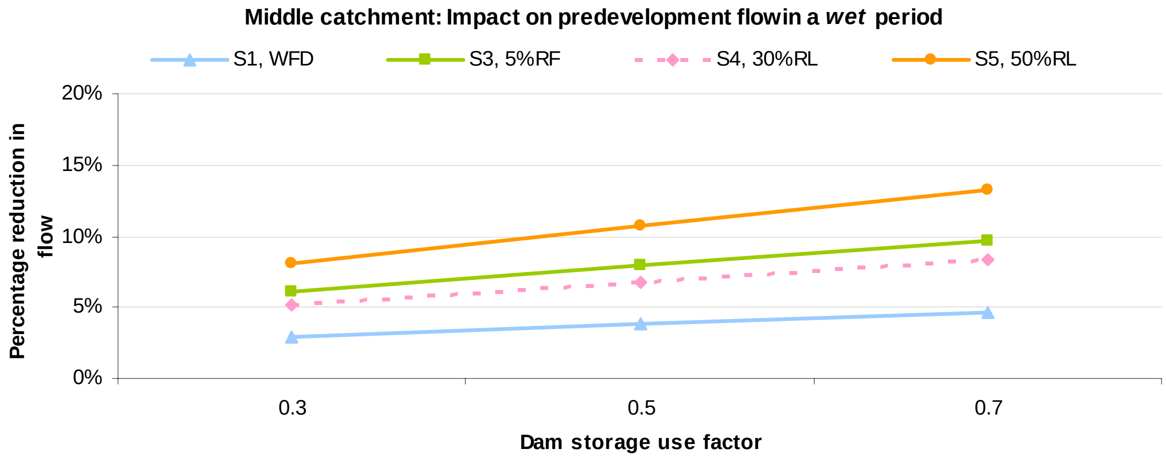


Figure 23. Percentage reduction of predevelopment flow for various scenarios in the defined dry period (1957–59)





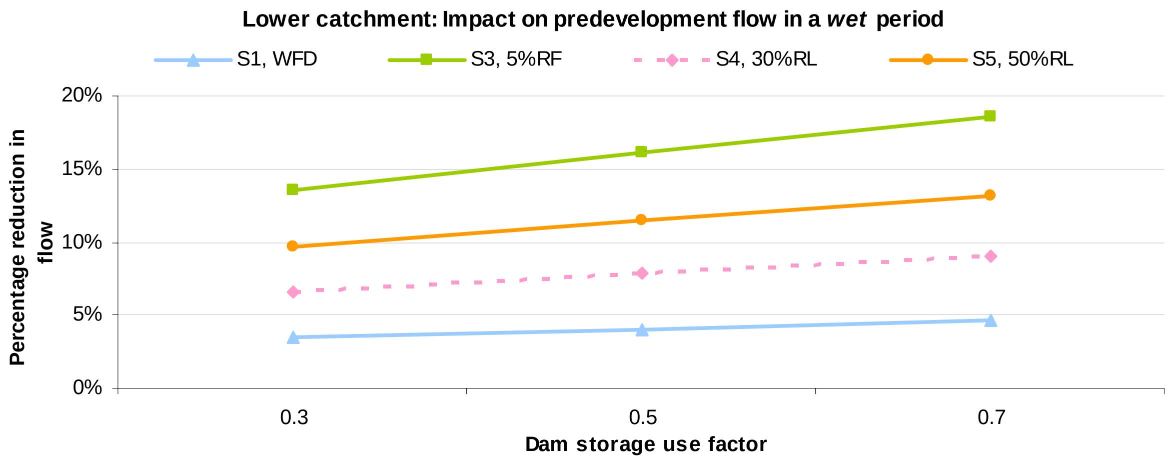


Figure 24. Percentage reduction of predevelopment flow for various scenarios in the defined wet period (1915–1917)

These results highlight the shortcomings of using empirical formulae, rather than flow records for limiting dam capacities. In a typical Mount Lofty Ranges landscape, rainfall-runoff relationships follow a non-linear type Tanh curve function with a threshold level at about 450–500 mm/a (see earlier section). Thus where empirical rules must be employed, they should reflect the nature of this non-linear relationship between rainfall and runoff.

Existing farm dam development rules for the low rainfall catchments, based on the NABCWMP 10% mean rainfall criteria, could potentially exceed the sustainable limits defined by the SWP 2000 (50%RL) guidelines. Conversely, the rule if applied to the higher rainfall areas of the Upper and Middle catchments would under-estimate the potential for irrigation.

5.8 RESULT 6—POTENTIAL FLOW REDUCTION INTO THE RESERVOIRS

The Upper and Middle catchments provide the main source of surface water to the Northern Metropolitan Adelaide and the Barossa Valley water supply system. Considering that the combined estimated pre-development average annual flow from the Upper and Middle catchments is only ~30 200 ML it can be seen that the potential exists for the reservoirs to divert virtually 100% of the flow out of the catchment.

Any further increase in farm dam storage within the Upper and Middle catchments would therefore have very little impact on the flows downstream of the Barossa weir, but would continue to reduce the flows into the Warren and South Para reservoirs, which in turn would have to be compensated by additional pumping from the River Murray.

Table 19 shows the potential reduction in average annual flows from the Upper and Middle catchments into the reservoirs for various levels of farm dam development (with three levels of assumed dam water use varying from 30–70% of the dam capacity).

On average, the potential flow reduction into the Warren and South Para reservoirs would vary from 400–4800 ML/a. Scenario S5 with a 70% level of dam water use provides the greatest impact for a median year, with a potential flow reduction of 4200 ML/a, assuming that all other operating conditions remain as at present.

Table 19. Annual flow (ML) reduction into the Upper and Middle Catchments

Scenarios	Median year [1] (1884–1998)			Driest 3-year average (1957–59)			Wettest 3-year average (1915–17)		
Storage use factor	0.3	0.5	0.7	0.3	0.5	0.7	0.3	0.5	0.7
S1, WFD	–	400	760	–	220	400	–	400	780
S3, 5%RF	1300	2000	2700	1000	1400	1700	1500	2300	3100
S4, 30%RL	1000	1700	2400	820	1200	1500	1200	1900	2600
S5, 50%RL	2020	3200	4200	1700	2300	2700	2600	3700	4800

[1]average flow values are used here.

6. CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

6.1.1 REPRESENTIVITY OF HYDROLOGICAL DATA

6.1.1.1 Rainfall

The six rainfall stations used in the modelling provide a good representation of the spatial distribution of rainfall across the South Para River catchment, also taking topography into account. They also have relatively long records, thus providing a good representation of the temporal distribution, with the station at Williamstown having more than 115 years.

6.1.1.2 Streamflow

The Lower catchment, downstream of the South Para dam to the SE of Gawler Station, has more than 30 years of continuous streamflow records (to the present). Accounting for spills from the South Para dam via the Barossa weir into the Lower catchment introduces uncertainties, but these have been rare events and therefore a minor issue when taken over the longer term.

Victoria Creek had about 12 years of record before monitoring ceased in 1988. Both this and the Lower catchment were calibrated using 1999 farm dam data.

Other than for Victoria Creek, there are no streamflow records for the Middle and Upper catchments. However, monthly flows derived by Tomlinson (1996), using water balances based on operational data for the reservoirs, were used for model calibration. Tomlinson had checked his estimates of catchment inflows against flows recorded for the adjacent Torrens River catchment at the Gorge weir. However flow estimates based on water balances tend to be subject to many sources of data error and are generally less reliable than direct estimates by streamflow gauging.

6.1.1.3 Evaporation

Evaporation data used in the model were obtained from the station located at South Para reservoir; its position is central to the catchment and it has more than 30 years of good quality records.

6.1.2 AVAILABILITY OF SURFACE WATER RESOURCE

The surface water resource is defined as the long-term annual predevelopment median flow. In this report it has been calculated via the use of a WaterCress rainfall to runoff model, established and operating with dams at the level surveyed in 1999 and calibrated to the observed flow for the period 1984–98, but with the effect of the farm dams then removed (i.e. the estimated pre-development flows).

The resource for the Upper, Middle and Lower catchments was estimated to be 14 400 ML, 13 600 ML and 4200 ML respectively, giving a total of about 32 200 ML/a, (or 35 500 ML if expressed as the average value). This average is about 7300 ML less than the 42 800 ML reported by consultants SKM (SKM, 2001). Based on the recorded median flow of 3200 ML at SE of Gawler Station, it appears that SKM may have over-estimated the Lower catchment flow by as much as 4000 ML (Table 20).

The estimated total resource can ranged from 13 680 ML/a average over the three driest years (1957–59) to 63 000 ML/a average over the three wettest years (1957–59).

Table 20. Surface water resource of the South Para catchment

	Upper catchment	Middle catchment	Lower catchment	Total
Total period 1884–1998 (median)	14 400 ML	13 600 ML	4 200 ML	32 200 ML[2]
(average)	15 500 ML	14 700 ML	5 300 ML	35 500 ML
Dry period (1957–59) (average)	3 000 ML	8 480 ML	2 200 ML	13 680 ML
Wet period (1915–17) (average)	29 100 ML	23 300 ML	10 600 ML	63 000 ML

The results show that the total resource is split between the Upper, Middle and Lower catchments in the proportions 0.45: 0.42 and 0.13.

An accurate estimation of the resource of the individual catchments is important for management planning. The results confirm that the Upper and Middle catchments are important sources of surface water for water supplies, while the Lower catchment is a relatively low yielding catchment.

6.1.3 RUNOFF COEFFICIENTS

The runoff coefficient derived from the pre-development flows will be expected to be higher than the catchment flows with diversions via the farm dams. Thus the runoff coefficient obtained for the Lower catchment predevelopment flow is 8% as compared to the 6% calculated from the observed flows (Table 15). Likewise the runoff coefficients for the Upper and Middle catchments predevelopment flows are both equal to 16%, while the runoff coefficient for Victoria Creek catchment calculated from observed flows gives 12%.

The management guidelines for the NABCWMP 2001–2006 are based on the assumption of a runoff coefficient of 10%, with the capacity of farm dams being then limited to 50% of this level of runoff. It can be seen that application of this rule might lead to over-use of the resource in the Lower catchment (with possible undesirable impacts on stream environments) and under-use in the Middle and Upper catchments (with possible under development of the catchment's economic potential).

[2] This value would be slightly different if the individual major subcatchments were simulated as a whole from upstream of SE of Gawler Station as strictly speaking median flows from individual catchments cannot be summed.

6.1.4 RAINFALL–RUNOFF RELATIONSHIP

The mean relationship between annual rainfall and runoff for the catchments is best represented by a Tanh curve. The fitted relationships show that catchment runoff is near zero when annual rainfall is below 400–450 mm/a. Runoff increases slowly as rainfall increases to 600–650 mm/a and then increases more rapidly after that to be asymptotic to the 1:1 slope at very high rainfalls (i.e. when the runoff is calculated as an average depth over the catchment area).

6.1.5 IMPACT DUE TO CURRENT FARM DAMS DEVELOPMENT ALONE

The difference between the observed flows and estimated pre-development flows indicates the level of impact that the farm dams (or other possible causes for reduced flows) are having. The reductions associated with the current level of farm dam development are presented in Table 21 for the median, driest and wettest years in the period of modelling using historical rainfall 1884–1998, assuming levels of dam water use at 30% and 70% of storage capacity.

It can be seen that the impacts are significantly higher when the rainfall is low and marginally higher under the assumption of usage at 70% rather than 30% of the dam capacity.

Table 21. Current percentage flow reduction from pre-development levels.

	Upper catchment		Middle catchment		Lower catchment	
(Dam storage use factor)	0.3	0.7	0.3	0.7	0.3	0.7
Median year (1884–1998)	(14 400 ML)		(13 600 ML)		(4 200 ML)	
	9%	11%	5%	8%	8%	12%
Dry period (1957–59)	(3 000 ML)		(8 480 ML)		(2 200 ML)	
	19%	22%	9%	13%	13%	17%
Wet period (1915–17)	(29 100 ML)		(23 300 ML)		(10 600 ML)	
	4%	5%	3%	5%	3%	5%

6.1.6 COMBINED IMPACT DUE TO FARM DAM AND RESERVOIR STORAGES

When the effects of diversions via the Warren reservoir and the South Para reservoir (via the Barossa weir) are included, the impact on the resource rises to 90%, of which only 7% results from farm dams. This result applies to the total catchment resource over the period 1983–97, the period for which flow data were available for comparison. The impact is greater when only the Middle and Upper catchments are considered.

The large amount of water diverted has significantly altered the flow regimes of the downstream river system from that which would have existed before the storages were constructed. For example, over the period 1983–97, no flow passed downstream from the Barossa weir at all during the months from January to August. At the SE of Gawler Station, the number of days on which the flow exceeded 20 ML/d in July reduced from 25 days in the pre-dams period to only nine days afterwards. Over the whole year the number fell from 163 days to only 48 days.

As a result, the water dependent ecosystems below the Barossa diversion weir have become significantly ecologically stressed (Philpott, et al., 1999).

The results show that the reservoirs have a better efficiency than the smaller farm dams when measured in terms of the percentage that the water use (i.e. supply from the dam) comprises of the total reduction in flow caused by the dam. For the reservoirs, the efficiency is 75% while for the farm dams it is only about 35%.

6.1.7 IMPACT DUE TO FUTURE FARM DAMS DEVELOPMENT

For the Upper and Middle catchments, modelling shows that farm dams, if developed up to the limit of the rules based on Scenario 5 of the SWP 2000 (S5, 50%RL) would have a greater impact than those based on either Scenario 3 of the NABCWMP 2001–2006 (S3, 5%RF) or Scenario 4 of the RMCWMB Plan 2003–2008 (S4, 30%RL). This is because Scenario 5 provides the highest aggregated limit to the future volume of farm dams (Table 9).

Scenarios 3 and 4 both exhibit about the same level of (lesser) impact since they allow similar upper limits to aggregated farm dam volumes.

For the Lower catchment, Scenario 3 presents the worst-case impact. This is because the catchment receives a lower rainfall and the median pre-development flow was found to be about 2% less than that 10% assumed by Scenario 5.

This confirms the earlier observation that using the development guidelines of NABCWMP 2001–2006 for farm dams development would have overestimated the resource availability of the Lower catchment and under-estimated that of the Middle and Upper catchments.

6.1.8 POTENTIAL FLOW REDUCTION TO THE RESERVOIRS

Modelling showed that future farm dam development under Scenario 5, with annual dam water use at 70% of the storage capacity, will present the worst-case impact with a 4200 ML reduction in inflows to the reservoirs. This reduction would have to be compensated by doubling the volume of pumping from the River Murray.

Table 21 summarises the potential reduction in inflow for other development scenarios.

6.1.9 INFORMATION GAPS

Accurate assessment of the water resources of a catchment subject to diversions or abstractions requires that all components of inflow or outflow must be accurately measured and recorded. Tomlinson identified several data shortcomings with his estimation of the water balances for the SA Water reservoirs.

Because the water balance method of assessment often involves the estimation of small differences between large volumes and not all values are measured, they tend to be inaccurate. An alternative to be considered is the establishment of stream gauges at the inflows and outflows of the reservoirs. In the case of the inflow to the Lower catchment, field verification of the empirical rating curve used for estimating spills over the Barossa weir would provide a simple method for increasing accuracy.

The other major area of uncertainty relates to the data on farm dams. There is an ongoing problem with accurate estimation of dam volumes, usage and losses via evaporation and leakage. Means for estimating the effects on flow of spatially distributed dams of different sizes requires further investigation. Large farm dams are usually associated with irrigation of crops. The effects on runoff of the crops and the land practices associated with them are generally not known and are usually lumped in with the effects of the dams themselves.

Currently DWLBC is undertaking a number of initiatives to address data related issues such as:

- a review of the State hydrological monitoring network in consultation with other agencies and Catchment Boards
- a review of the methods used for estimating farm dam capacities
- a study on environmental flow releases from the Barossa weir into the downstream reaches where the water dependent ecosystem is most stressed
- a new land use and irrigation survey for the Mt Lofty Ranges catchments.

6.2 RECOMMENDATIONS

6.2.1 NORTHERN ADELAIDE AND BAROSSA CATCHMENT WATER MANAGEMENT PLAN 2001–2006 GUIDELINES

The farm dam guidelines provided in the NABCWMP 2001–2006 should be reviewed for catchments with a mean annual rainfall less than 600–650 mm/a. Where possible, for a catchment which receives less than 600–650 mm/a of mean annual rainfall, the Tanh curve relationship should be used based on observed data for similar catchments.

The NABCWMP 2001–2006 states that the “combined capacity of all farm dams” on any catchment “*shall not exceed 50% of the mean annual run-off of that catchment*” (Vol 1. pp99), and that the annual run-off should be estimated as “*a volume derived from 10% of the mean annual rainfall for the allotment (in millimetres) multiplied by the area (of the catchment) in square kilometres*”, (Vol.1 pp100).

In this study, the Lower catchment was found to have a runoff depth equal to 8% of the rainfall. This should translate to a limit of farm dam capacity of only 4% of the rainfall volume, instead of 5% as stipulated in the NABCWMP (and in accordance with the SWP 2000).

6.2.2 FARM DAM DEVELOPMENT

Policies for future farm dam development should take into account:

- the actual runoff depth estimated from streamflow records, or recognition of the likelihood that runoff depths may be less than 10% of the rainfall in low rainfall areas
- the spatial distribution of farm dam density (defined as aggregated dam volume divided by the catchment area) upstream of the catchment
- that where dam capacities are ‘capped’, dam owners may tend to increase their usage rates from present levels (generally about 20% of the dam capacity) to as high as 70%, particularly where they have a subsidiary source of ‘back-up’ supply from groundwater or reticulation schemes

- provision for environmental flow requirements downstream of the dam.

6.2.3 ENVIRONMENTAL FLOW

These results confirm the findings of Phillpot et al. (1999) that consideration should be given to reverse the ecologically stressed South Para River system between the reaches of Barossa weir and SE of Gawler Station by allowing environmental flow releases to improve the health of river.

6.2.4 INFORMATION GAPS

To address the information gaps identified in this study, the following points should be noted and critically reviewed:

- establish streamflow monitoring station at upstream of the Warren and South Para Reservoirs respectively to monitor the volume of catchment flow on daily basis before entering the reservoirs
- similarly, the diversion from the Barossa Diversion Weir to Barossa Reservoir needs to be monitored in a similar manner
- verify the accuracy of the empirical rating curves for the spill over the Barossa diversion weir and Warren reservoir with field measurements
- losses through the scour valves under the dam retaining wall need to be accounted for
- the inter-basin water transfer from the River Murray to Warren Reservoir and BIL Scheme should be metered at immediately upstream of the exit point for accurate measurement of outflow
- quantify the recharge and discharge zones of the South Para catchment as they also form an important part of the water resource
- survey the irrigation water use, which includes annual dam water usage and the separation of dam storage volume obtained from surface and ground water
- there is an ongoing problem with accurate estimation of dam volumes, usage and losses via evaporation and leakage that needs to be addressed, particularly for large dams associated with irrigation crops
- means for estimating the effects on flow of spatially distributed dams of different sizes also requires further investigation as the effects on runoff of the crops and the land practices associated with them are generally not known and are usually lumped in with the effects of the dams themselves.

APPENDICES

A. METHODOLOGY USED BY SINCLAIR KNIGHT MERZ ("SKM") FOR DISAGGREGATION OF ACCUMULATED RAINFALL DATA AND IN-FILLING OF MISSING RAINFALL RECORDS

Rainfall data is collected at 09:00 on a daily basis in the BoM stations. Rainfall collected during weekends and public holidays is recorded at 09:00 on the next working day. This necessitated disaggregation of the accumulated rainfall for those days when rainfall was not recorded. The methodology used by SKM for disaggregation of rainfall data is based on the method outlined by Porter and Ladson (1993).

The method assumes that the influence of nearby stations, where records are complete, is inversely proportional to their distance from the gauged station. That is if a gauged station **S** has its rainfall accumulated over **m** days, and complete data is available from **n** rainfall stations nearby, on day **j** precipitation at **S** station is given by:

$$\mathrm{P}_{jS} = \frac{\sum_{j=1}^{m} \mathrm{P}_{jS} . \sum_{k=1}^{n} \{ p_{jk} / d_k \}}{\sum_{k=1}^{n} \{ 1 / d_k \}}$$

where $\sum_{j=1}^{m} \mathrm{P}_{iS}$ is total rainfall accumulated over **m** days for the gauged station **S**,

d_k is the distance from a rainfall station ***k*** to the gauged station **S**, and

p_{jk} is that proportion of rainfall fell on day **j** at **k** station over the total rainfall accumulated over **m** days at the same **k** station. That is,

$$p_{jk} = \frac{\mathrm{P}_{jk}}{\sum_{j=1}^{m} \mathrm{P}_{\mathrm{jk}}}$$

To this effect, an automated procedure was developed to redistribute the data. The procedure limits the search to only 15 rainfall stations closest to the station of interest. If no reference can be made from these 15 stations, then it is recommended that redistribution be carried out manually from other nearby stations closest to the station of interest. If no such reference station can be found, then redistribution may be carried out evenly over the period of accumulation.

For in-filling the missing rainfall records, the correlation method was used. The annual rainfall of a station **S** of interest was correlated with that of other nearby stations. The station with the highest correlation factor with **S** that had data concurrent with the missing period was used for in-filling the records. Again, SKM developed an automated procedure for in-filling the data and it was limited to a search of 15 closest rainfall stations only.

B. RESERVOIRS INFORMATION

WARREN RESERVOIR

Warren Reservoir is an on-stream dam located in the Upper catchment (119 km^2) of South Para River. It was built in 1916 with 5100 ML of storage capacity. The reservoir forms part of the Warren and Northern Water Supply System that supplies water to the lower northern Adelaide areas and the Barossa Valley, via the WTM and SRSP systems. It is also connected to the MAP. When the natural runoff is low, water can be supplemented from the River Murray either via MAP or SRSP. It is also linked to South Para reservoir via a spur line connected to the WTM. Through this connection, water can be transferred in a “forward” direction from Warren reservoir to South Para reservoir (Fig. 4). Water transferred from the River Murray via SRSP to Warren reservoir is termed flow in a “reverse” direction.

In February 1998 when SRSP began supplying filtered water, inter-basin water transfer from SRSP to Warren reservoir ceased operating. When the BIL scheme commenced its operation in December 2001, the connection from SRSP to South Para and Warren reservoirs was disconnected to completely discontinue the water transfer. The BIL Scheme draws its water directly from Warren reservoir, which in turn stops supplying water directly via WTM to South Para reservoir. Since Warren reservoir has low storage capacity, it frequently spills and hence South Para reservoir still receives water from the Upper catchment at these times.

There is no gauging station to monitor the natural flow into Warren reservoir. Natural flow into the dam may be estimated from water balance equation of water use returns recorded for the Warren and Northern Region Water Supply system. The derivation of natural intake from the returns is less accurate than would be obtained via gauging station.

SOUTH PARA RESERVOIR, BAROSSA DIVERSION WEIR AND BAROSSA RESERVOIR

South Para Reservoir is an on-stream dam located on the South Para River downstream of the Middle catchment. A short distance below the reservoir is the Barossa diversion weir, which diverts water released from the reservoir to the Barossa reservoir where the water is treated and distributed for water consumption.

Barossa reservoir was constructed in 1902. It is an off-stream dam with a storage capacity of 4500 ML and a natural catchment of 7 km^2. Water is diverted to the reservoir via a tunnel immediately upstream of the Barossa diversion weir.

Currently South Para reservoir is the second largest dam in South Australia after the Mt Bold reservoir. It was constructed and commissioned in 1958 with a current capacity of 45 000 ML and a catchment area of 108 km^2. When movable gates were installed on top of the spillway, the reservoir was able to store an additional 6000 ML of water. Runoff from the Middle catchment and the spill from Warren reservoir are collected by the reservoir. Since it is a large dam in comparison to the size of its catchment yield, the reservoir was able to supply its full quota with the exception of three dry years in 1984–86 when inter-basin water transfer

Table 22. Water supply from Barossa and Warren Reservoirs

Mean (1957–96)	2600	2325	2236	1737	1325	1096	1094	1137	1212	1648	2210	2443	21 064
Mean (1967–96)	2611	2352	2255	1746	1422	1176	1142	1239	1329	1708	2252	2440	21 671
Year	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**Annual**
1956													
1957	1209	1050	996	755	509	536	477	546	522	773	905	1296	9574
1958	1250	991	869	700	518	436	432	450	469	500	1018	1841	9474
1959	2550	2114	2386	2064	1059	970	1168	1055	1287	1664	2277	2441	21 035
1960	2760	2255	1909	1891	536	487	527	582	568	1250	2191	2810	17 766
1961	2914	2633	2637	1568	1100	1591	1664	1541	1259	2569	2610	2938	25 024
1962	2968	2550	2587	2209	1336	350	405	463	955	841	2068	2291	19 023
1963	2077	2173	2010	1778	664	491	532	572	701	2241	2951	3546	19 736
1964	3419	3109	3078	2301	2055	1845	1858	1821	1134	953	1928	2312	25 813
1965	3283	3002	2985	2128	1547	1181	1712	635	796	2198	2312	2942	24 721
1966	3262	2574	2342	1722	1027	667	707	657	924	1714	2570	2090	20 256
1967	2941	2912	2435	1227	704	577	644	407	532	702	1729	1836	16 646
1968	1965	2141	1369	706	498	396	381	417	596	1243	1674	2547	13 933
1969	3183	1982	1950	1554	1105	732	712	767	652	1944	2277	2224	19 082
1970	2280	3026	2457	1299	1003	767	748	618	738	1328	2817	2926	20 007
1971	3420	3229	2321	1986	918	840	912	988	1024	1858	2586	3318	23 400
1972	2941	3153	3859	2548	1536	1459	771	916	1261	2351	2801	2896	26 492
1973	3003	1674	2031	2016	1118	905	801	1186	1271	1874	2986	3059	21 924
1974	3038	2046	2754	1555	1040	1026	1027	1201	1117	1561	2749	3380	22 494
1975	3276	2987	2276	1845	1444	1341	1234	1252	1502	1502	2689	3619	24 967
1976	3487	3155	2821	2215	1993	1025	1345	1692	613	729	1496	2142	22 713
1977	2717	2688	2738	1932	1858	723	232	267	452	1418	2550	2369	19 944
1978	2875	2455	2334	1885	1389	1110	1422	1360	1267	2103	3110	2988	24 298
1979	3059	2132	2396	1490	1647	1478	1090	1209	1651	1606	2782	1952	22 492
1980	1398	1852	2511	1455	1204	1109	1268	1499	2148	2024	3055	2468	21 991
1981	2362	2039	2092	2993	1924	1459	1403	1699	1769	2467	2753	2565	25 525
1982	2498	1877	1592	2339	1557	1336	1102	1738	1777	2149	1976	1709	21 650
1983	1987	2011	1550	1736	1387	1286	1356	1335	1509	2596	2688	2525	21 966
1984	1787	1932	2053	1683	1769	1594	1480	1584	1493	1829	2263	2742	22 209
1985	2747	2410	1971	1645	1208	992	1232	1033	668	1008	2154	2051	19 119
1986	2996	2541	2629	1611	1437	1487	1337	1384	973	1301	2183	2701	22 580
1987	2428	2122	1487	1241	1584	1022	1339	1429	1977	1787	2654	2187	21 257
1988	2639	2010	2013	2126	1904	1331	1628	1624	1854	2448	1915	2194	23 686
1989	2659	2590	2369	2010	1750	1457	1442	1535	1618	1679	1927	2822	23 858
1990	3179	2330	2632	1873	2279	1571	1486	1489	1758	2020	2571	2201	25 389
1991	2871	2735	2347	1701	1595	1525	1392	1321	1746	2061	1934	2724	23 952

Mean (1957–96)	2600	2325	2236	1737	1325	1096	1094	1137	1212	1648	2210	2443	21 064
Mean (1967–96)	2611	2352	2255	1746	1422	1176	1142	1239	1329	1708	2252	2440	21 671
Year	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**Annual**
1992	2652	2555	1815	1512	1756	1576	1713	1579	1454	874	692	747	18 925
1993	1440	1576	1526	1419	1015	1166	1320	1631	1883	2202	1838	1651	18 667
1994	2334	2157	2928	2326	1873	1455	1541	1606	2005	1799	1309	2359	23 692
1995	2198	2206	2513	1408	892	939	1106	1720	1978	1813	1697	2128	20 598
1996	1962	2040	1890	1029	1269	1582	803	679	589	951	1699	2181	16 674

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Table 23. Water transfer from the River Murray into South Para River Catchment

Mean (1967–96)	381	342	445	353	240	277	468	437	298	249	354	388	4233
year	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**Annual**
1966													
1967	132	382	423	555	518	596	605	600	586	614	591	614	6216
1968	604	564	586	564	523	0	0	0	0	0	0	0	2841
1969	0	0	0	0	0	0	23	0	168	255	200	159	805
1970	86	64	64	86	0	0	0	391	0	0	0	95	786
1971	0	0	14	0	0	0	45	0	0	0	0	9	68
1972	14	5	0	0	0	23	75	46	0	18	0	42	223
1973	22	119	46	0	27	66	914	815	227	0	0	0	2236
1974	0	11	42	0	0	0	0	0	0	0	0	0	53
1975	0	0	64	27	48	0	106	8	0	0	0	0	253
1976	0	9	101	29	0	869	1799	2132	1855	1681	1502	1106	11 083
1977	1154	914	1154	9	93	412	1244	1791	1837	1646	2178	1521	13 953
1978	1097	914	1402	1959	1899	1807	2281	579	3	0	0	426	12 367
1979	423	420	471	450	60	2	1399	2062	1302	0	0	376	6965
1980	498	416	226	168	0	0	0	27	0	0	0	272	1607
1981	432	403	48	0	85	339	0	0	0	0	0	411	1718
1982	436	341	465	28	0	28	434	576	889	1404	484	281	5366
1983	516	97	1507	660	0	0	4	0	0	0	0	42	2826
1984	589	505	462	420	28	0	0	306	0	2	196	434	2942
1985	190	0	0	0	413	951	1113	1155	665	465	1255	1324	7531
1986	1177	939	1043	1008	568	420	736	162	0	0	112	406	6571
1987	449	395	322	455	56	0	19	0	0	26	350	448	2520
1988	435	409	421	252	0	0	0	0	0	70	420	448	2455
1989	436	266	434	420	386	112	0	2	0	0	392	434	2882
1990	434	396	434	424	238	183	280	434	0	0	238	441	3502
1991	435	398	438	308	14	7	593	797	264	27	406	434	4121
1992	434	408	347	35	0	0	0	28	0	254	415	404	2325

Mean (1967–96)	381	342	445	353	240	277	468	437	298	249	354	388	4233
year	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**Annual**
1993	532	407	398	448	341	275	167	101	0	24	517	690	3900
1994	141	392	440	154	72	454	500	613	813	618	1007	607	5811
1995	651	997	1771	1716	1488	1406	1357	267	204	276	249	119	10 501
1996	125	101	229	427	353	353	337	217	114	100	100	100	2556

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were required. This was from the River Murray and the Warren reservoir through a spur line connected to the WTM and SRSP system. Since the existence of the BIL scheme, the inter-basin transfer from Warren reservoir and SRSP has ceased.

Again, since there is no gauging station to monitor the natural flow into the South Para reservoir, intake has had to be estimated from the water use returns for the Metropolitan Adelaide Water Supply System. This method provides relatively poor accuracy.

COMMENTS ON ESTIMATING STREAMFLOW DATA FOR THE MIDDLE AND UPPER CATCHMENTS

Apart from the small Victoria Creek catchment, there is no streamflow gauging station in the Middle or Upper catchments. To overcome this information gap, two alternative data source were examined. One was the monthly natural flow data set established by Tomlinson (1996) and the other from the daily natural intake estimated in the water use return sheets of the Metropolitan Adelaide and the Northern Region Water Supply System.

It was found that Tomlinson’s monthly flow data set provided the best available assessment of catchment flows for the Upper and Middle catchments. Hence they were used for the model calibration of these catchments in monthly time steps.

The Tomlinson dataset was probably derived partly from the water use return sheets and partly through validating and infilling of catchment flow by correlation techniques. He used a water balance equation to derive the natural flows for Warren (Upper) and South Para plus Barossa (Middle) catchments from January 1937 to June 1993. The generalised water balance equation used was inflow minus outflow equals the storage change in the reservoir.

Typically, *inflow* includes:
- natural catchment runoff (including rainfall directly onto a reservoir)
- water transferred from other catchments (e.g., the River Murray).

Outflow includes:
- reservoir spill
- reservoir valve (scour valve) outflow
- flow past a gauging station
- water transferred to other catchments
- water distributed to the water supply system (consumption)
- evaporation losses.

For Warren reservoir catchment yield, these factors were relevant:

- Warren reservoir change in storage
- net evaporation losses
- Warren water supply offtake (consumption)
- Warren spill
- transfer from the River Murray (SRSP)
- transfer from the River Murray (MAP).

For South Para reservoir catchment yield, these factors were relevant:

- South Para reservoir change in storage
- Barossa reservoir change in storage
- net evaporation losses
- Barossa water supply offtake (consumption)
- Warren spill
- Barossa diversion weir spill
- transfer from the River Murray (SRSP)
- transfer from the River Murray (WR – MAP).

When estimating the natural flow, Tomlinson highlighted some abnormalities and expressed doubts on the accuracy of some records. For example, he excluded the December 1992 flow record in his data analysis due to the extremely large differential in flow volume when compared with the 55 years December average inflows.

The former flow was 10 188 ML and the later only 208 ML (inclusive December 1992). Another example he cited was “from October 1992 to June 1993, all Warren intakes are negative, for reasons unknown”.

Despite some issues with the flow records, he was able to validate the South Para catchment yield records by comparison with that of the Torrens at Gorge Weir. He infilled the data gaps by correlating with flows from the Gorge Weir catchment. Where he detected changes in slope for different period of records from the double mass curve analyses of the South Para and Gorge Weir catchment yields, he adjusted them by assuming that the earlier periods of the record were correct and the complete records were adjusted to the ratio of those periods.

On the other hand, attempts to reconstruct the daily natural flow of the catchment from the SA Water use returns proved difficult. The water use returns contain information which include inter-basin water transfer volume, water consumption for water supply, reservoir storage, losses due to evaporation from the reservoir, rainfall and natural intake of the catchment. This recording format was probably designed from the perspective of water balance for the water supply system; they were not suited for as a substitute for evaluating streamflow of a catchment. The following factors contribute to the unsuitability:

- it is doubtful if reservoir water level monitored from the gauging station was sensitive enough pick up a small change in natural runoff flowing into the reservoir storage, particularly during the low flow seasons
- losses through scour valves under the dam retaining wall and spills over the weir were not included in the record. This information became difficult to track down, if not lost, over time from the archives of the field books

- in the water use returns, when the “natural intake” (catchment flow to reservoir) derived from the water balance equation gave a negative quantity, it was noted as “unaccounted losses” item and the natural intake was taken as zero. This was for balancing the water supply of the water balance equation, which offers no useful hint as to what the daily catchment flow would be
- the quantity of water transferred from the River Murray via MAP to Warren reservoir, although is not large (around 14 ML/day), appeared not metered at immediately upstream of its outlet point.

When the volume of daily natural intake (catchment flow) estimated by water balance equation was aggregated on monthly basis, it exhibited unusually high “baseflow” over summer months in comparison to a typical Mt Lofty Ranges stream. Comparing the monthly flows derived from the water use returns with that estimated by Tomlinson (1996) for the same period indicated the returns possibly over estimated the natural flows in the summer months and under estimated them in the winter months.

However, when the water use returns data were aggregated on a yearly basis, with unaccounted losses included as the catchment yield, a sample period from July 1984 to June 1991 for the Middle catchment showed that they generally compared well with the yield estimated by Tomlinson (1996) and that of the SKM (2001) dataset, as indicated in Columns 2, 3 and 4 in Table 24. Between 1986 and 1988, the difference appears to be noticeable but is probably acceptable. If the unaccounted losses were not included (column 5) then the discrepancies between the estimates from the water use returns and those of Tomlinson are quite large.

Table 24. Comparison of natural flow for the Middle catchment

Year	Tomlinson, (1996)	SKM, (2001)	Water use returns (inclusive unaccounted losses)	Water use returns (natural intake only)	Water use returns (unaccounted losses only)
1985	9 376	9 376	9 867	7 790	2 077
1986	15 675	15 777	12 532	10 562	1 970
1987	19 702	19 747	16 283	13 897	2 386
1988	19 777	19 803	16 290	13 755	2 535
1989	11 434	11 657	11 093	7 985	3 108
1990	12 728	12 736	13 492	10 530	2 962

When assessing streamflows for the Lower catchment using flow data monitored at SE of Gawler Station, spills over the Barossa diversion weir have to be subtracted. However, a direct subtraction of the spill volume from the flow measured at SE of Gawler Station is not always satisfactory as there is a varying time lag and attenuation between the weir and the SE of Gawler Station depending on the magnitude of the spill event. To overcome this, for high spill events, it was assumed that the spill over the weir to be subtracted from AW505503 was the mean value noted at 5:00am and 9:00am spills over the South Para reservoir (AW505516). For low spill event, no adjustment was made for time lag. Plots of flow from AW505503 and AW505516 (with and without time lag) superimposed on each other indicated that they correlate well in low and high flows based on these assumptions.

C. DATA FOR THE CONSTRUCTION OF SOUTH PARA RIVER CATCHMENT MODEL

The data for building the South Para River catchment model is provided in the following table.

Table 25. Input data for the catchment hydrological model

											Rainfall station						
No	**Subcat**	**Cat Set**	**Rural Node**	**Dam Node**	**Subcat Area** (ha)	**Urban** (ha)	**No of Dams**	**Dam Area M^2**	**VOL_ PIK99**	**Dam Density ML/km^2**	*Location*	*mean*	*isohyet*	*At Centroid of catch*	*Rainfall factor*	*Adj rainfall at centroid*	**Diversion Fraction To Dam**
1	LC_01	3	93	94	512.8		48	60 068	80.7	15.7	KB	736	725	690	0.95	700	1
2	LC_02	3	95	96	150.3		13	13 437	17.4	11.6	PWRP	646	633	656	1.04	669	0.5
3	LC_03	3	97	98	603.1		14	21 124	34.5	5.7	PWRP	646	633	595	0.94	607	0.25
4	LC_04	3	99	100	207.9		17	18 773	24.5	11.8	PWRP	646	633	681	1.08	695	0.8
5	LC_05	3	101	102	331.2		4	2 212	2.4	0.7	PWRP	646	633	650	1.03	663	0.1
6	LC_06	3	103	104	413.7		15	18 050	24.8	6.0	PWRP	646	633	612	0.97	625	0.35
7	LC_07	3	106	107	467.2		12	16 729	27.2	5.8	PWRP	646	633	611	0.97	624	0.5
8	LC_08	3	111	112	175.2		6	29 552	70.2	40.1	PWRP	646	633	651	1.03	664	1
9	LC_09	3	113	114	949.5		2	495	0.4	0.0	SPRE	689	663	638	0.96	663	0.1
10	LC_10	3	115	116	619.8		4	14 801	32.0	5.2	SPRE	689	663	580	0.87	603	0.95
11	LC_11	3	108	109	644.1		6	2 133	2.0	0.3	PWRP	646	633	545	0.86	556	0.1
12	LC_12	3	117	118	67.0		7	3 037	3.2	4.8	SPRE	689	663	538	0.81	559	1
13	LC_12b	3	153	134	770.0				0.0	0.0	SPRE	689	663	538	0.81	559	0
14	LC_13	3	132	133	354.7		18	4 638	4.2	1.2	SPRE	689	663	570	0.86	592	0.35
15	LC_14	3	119	120	52.2		2	4 559	8.0	15.2	WTPO	684	661	646	0.98	668	1
16	LC_14b	3	154	125	670.0				0.0	0.0	WTPO	684	661	646	0.98	668	0
17	LC_15	3	121	122	493.8		27	23 773	30.3	6.1	WTPO	684	661	649	0.98	672	0.75
18	LC_16	3	123	124	104.9		10	10 441	14.5	13.8	WTPO	684	661	614	0.93	635	0.75

No	Subcat	Cat Set	Rural Node	Dam Node	Subcat Area (ha)	Urban (ha)	No of Dams	Dam Area M^2	VOL_ PIK99	Dam Density ML/km^2	*Location*	Rainfall station *mean*	*isohyet*	*At Centroid of catch*	*Rainfall factor*	*Adj rainfall at centroid*	Diversion Fraction To Dam
19	LC_17	3	126	127	62.9		6	11 036	18.1	28.8	WTPO	684	661	597	0.90	618	0.6
20	LC_18	3	128	129	314.2		15	15 921	22.1	7.0	WTPO	684	661	595	0.90	616	0.7
21	LC_19	3	130	131	1 057.2		18	19 874	32.6	3.1	WTPO	684	661	564	0.85	584	0.25
22	LC_20	3	135	136	532.7		3	6 677	10.8	2.0	WTPO	684	661	505	0.76	523	0.1
23	LC_21	3	137	138	177.5		0		0.0	0.0	WTPO	684	661	481	0.73	498	0
24	LC_22	3	142	143	321.3		12	20 693	30.6	9.5	WTPO	684	661	525	0.79	543	0.75
25	LC_23	3	144	145	467.7		6	4 322	5.0	1.1	WTPO	684	661	491	0.74	508	0.65
26	LC_24	3	140	141	524.7		1	817	0.9	0.2	WTPO	684	661	444	0.67	459	0.05
27	MC_01	4	47	48	433.7		13	13 843	17.4	4.0	WTGG	686	706	728	1.03	707	0.6
28	MC_02	4	49	50	299.9		9	11 468	18.1	6.0	WTGG	686	706	751	1.06	730	0.6
29	MC_03	4	148	51	259.1		9	21 039	35.9	13.9	WTGG	686	706	754	1.07	733	0.7
30	MC_04	4	52	53	1 055.9	15	21	35 486	64.1	6.1	WTGG	686	706	726	1.03	705	0.4
31	MC_05	2	54	55	421.1		17	39 794	65.9	15.7	WTPO	684	661	693	1.05	717	0.85
32	MC_06	2	60	61	2 435.4		14	12 131	14.9	0.6	SPRE	689	663	700	1.06	727	0.1
33	MC_07	2	56	57	321.6		0		0.0	0.0	KB	736	725	734	1.01	745	0
34	MC_08	2	74	75	288.2		15	11 837	15.0	5.2	KB	736	725	734	1.01	745	0.95
35	MC_09	2	76	77	486.1		8	16 037	29.1	6.0	KB	736	725	730	1.01	741	0.6
36	MC_10	2	78	79	246.9		33	43 695	68.1	27.6	KB	736	725	732	1.01	743	0.95
37	MC_11	2	81	82	169.8		10	40 344	89.3	52.6	KB	736	725	720	0.99	731	1
38	MC_12	2	89	90	758.6		21	50 353	88.2	11.6	KB	736	725	710	0.98	721	0.75
39	MC_13	2	62	63	344.3		0		0.0	0.0	KB	736	725	722	1.00	733	0
40	MC_14	2	64	65	344.6		15	18 573	25.6	7.4	KB	736	725	735	1.01	746	0.8
41	MC_15	2	66	67	217.1		9	21 082	35.0	16.1	KB	736	725	734	1.01	745	1
42	MC_16	2	68	69	594.6		41	62 231	93.7	15.8	KB	736	725	747	1.03	758	0.9

No	Subcat	Cat Set	Rural Node	Dam Node	Subcat Area (ha)	Urban (ha)	No of Dams	Dam Area M^2	VOL_ PIK99	Dam Density ML/km^2	Rainfall station *Location*	*mean*	*isohyet*	*At Centroid of catch*	*Rainfall factor*	*Adj rainfall at centroid*	Diversion Fraction To Dam
43	MC_17	2	70	71	375.6		43	69 587	113.0	30.1	KB	736	725	753	1.04	764	1
44	MC_18	2	72	73	467.9		26	77 868	142.2	30.4	KB	736	725	737	1.02	748	1
45	MC_19	2	85	86	542.7		44	55 060	83.8	15.4	KB	736	725	734	1.01	745	0.9
46	MC_20	2	87	88	270.8		5	12 929	24.4	9.0	KB	736	725	727	1.00	738	0.45
47	MC_21	2	83	84	251.8		0		0.0	0.0	KB	736	725	726	1.00	737	0
48	MC_22	2	58	59	215.1		3	6 526	9.7	4.5	KB	736	725	699	0.96	710	0.3
49	UC_01	1	1	2	72.0		4	28 869	68.1	94.5	WTGG	686	706	794	1.12	772	1
50	UC_02	1	3	4	90.3		4	54 444	149.7	165.8	WTGG	686	706	785	1.11	763	1
51	UC_03	1	5	6	429.4		8	22 745	39.8	9.3	WTGG	686	706	795	1.13	772	0.35
52	UC_04	1	7	8	216.4		16	43 118	86.3	39.9	WTGG	686	706	780	1.10	758	1
53	UC_05	1	9	10	234.1		13	27 266	45.7	19.5	WTGG	686	706	770	1.09	748	0.75
54	UC_06	1	11	12	925.3		60	64 525	100.7	10.9	WTGG	686	706	777	1.10	755	0.55
55	UC_07	1	13	14	255.4		16	78 462	246.4	96.4	WTGG	686	706	759	1.08	737	1
56	UC_08	1	15	16	694.3		20	26 929	39.3	5.7	WTGG	686	706	775	1.10	753	0.15
57	UC_09	1	18	19	307.3		10	7 922	9.2	3.0	WTCF	725	746	750	1.01	729	0.15
58	UC_10	1	20	21	532.7		10	16 707	28.5	5.3	WTCF	725	746	723	0.97	703	0.15
59	UC_11	1	22	23	155.6		3	3 822	4.9	3.2	WTCF	725	746	671	0.90	652	0.35
60	UC_12	1	24	25	120.4		2	2 454	3.1	2.6	WTCF	725	746	682	0.91	663	0.4
61	UC_13	1	29	30	98.3		2	5 913	9.6	9.7	WTCF	725	746	690	0.92	671	0.45
62	UC_14	1	26	27	87.2		3	2 783	3.4	3.9	WTCF	725	746	706	0.95	686	1
63	UC_14b	1	150	28	500.0				0.0	0.0	WTCF	725	746	706	0.95	686	0
64	UC_15	1	33	34	275.6		27	29 507	38.5	14.0	WTCF	725	746	724	0.97	704	1
65	UC_15b	1	151	35	1 350.0				0.0	0.0	WTCF	725	746	724	0.97	704	0
66	UC_16	1	36	37	559.2		21	77 466	160.7	28.7	WTCF	725	746	756	1.01	735	0.8

No	Subcat	Cat Set	Rural Node	Dam Node	Subcat Area (ha)	Urban (ha)	No of Dams	Dam Area M^2	VOL_ PIK99	Dam Density ML/km^2	Rainfall station: *Location*	*mean*	*isohyet*	*At Centroid of catch*	*Rainfall factor*	*Adj rainfall at centroid*	Diversion Fraction To Dam
67	UC_17	1	31	32	199.6		9	29 457	53.2	26.6	WTCF	725	746	698	0.94	678	0.8
68	UC_18	1	38	39	878.1		78	130 311	200.0	22.8	WTCF	725	746	723	0.97	703	1
69	UC_19	1	40	41	156.9		11	10 778	14.1	9.0	WTCF	725	746	738	0.99	717	1
70	UC_19b	1	152	152	1 400.0				0.0	0.0	WTCF	725	746	738	0.99	717	0
71	UC_20	1	42	43	561.3		15	18 895	28.1	5.0	WTCF	725	746	745	1.00	724	0.4
72	UC_21	1	44	45	1 758.4		25	52 786	101.8	5.8	WTCF	725	746	747	1.00	726	0.35
	GRAND TOTAL				33 704.0		979	1 678 205	2961.1	8.8							

D. WATERCRESS WC–1 RUNOFF ROUTINE PARAMETERS

WaterCress program incorporates a number of runoff routines for modelling. For this study where the pervious catchments were represented as rural catchment nodes, the WC–1 runoff model was used. For impervious catchment of urban catchment node, the Initial Loss and Continuing Loss model (ILCL) was used. WC–1 model requires 10 input parameters, namely:

- median soil moisture
- interception store
- catchment distribution
- groundwater discharge
- soil moisture discharge
- pan factor soil
- fraction groundwater loss
- store wetness multiplier
- groundwater recharge fraction
- creek losses.

By adjusting these parameters using WC–1 runoff model, catchment runoff can be calibrated against streamflow records. To reduce the number of variables required for adjustment, the pan factor soil and store wetness multiplier were fixed at 0.65 and 0.85 respectively. Other parameters values were adjusted until the calibration for the individual catchments, namely Victoria Creek, Upper, Middle and Lower catchments was satisfactory. Hence four sets of catchment characteristic sets were obtained from the calibration as shown in Table 26.

The current farm dams development scenario being used for model calibration was based on.1999 farm dam data with 30% annual storage used. Irrigation was assumed to occur during the summer months.

Table 26. The statistics of calibrated Major Subcatchments

(1) Parameter	Upper catchment	Middle catchment	Lower catchment	Victoria Ck
Revision No.	# 33	# 30	# 44	# 49
Start (Year)	1968	1968	1968	1977
Over (Year)	26	25	26	13
Daily (Year)	N/A	N/A	1968	1980
Over (Year)	N/A	N/A	26	8
Node #	46	125	139	155
Catchment characteristic set	1	2	3	4
Model type	WC–1	WC–1	WC–1	WC–1
Parameters required	10	10	10	10
Median soil moisture (MSM)	180	180	187	217
Interception store (IS)	11.5	13	14	14
Catchment distribution (CD)	40	42	40	40
Groundwater discharge (GWD)	0.005	0.0006	0.002	0.04
Soil moisture discharge (SMD)	0.00003	0.00035	0.0002	0.00007
Pan factor soil (PF)	0.65	0.65	0.65	0.65
Fraction groundwater loss (FGL)	0.002	0.002	0.0005	0.004
Store wetness multiplier (SWM)	0.85	0.85	0.85	0.85
Goundwater recharge fraction (GW)	0.11	0.3	0.2	0.3
Creekloss (CL)	0.002	0.002	0.005	0.0
(2) Dam information	**Upper catchment**	**Middle catchment**	**Lower catchment**	**Victoria Ck**
input annual as fraction of storage	0.3	0.3	0.3	0.3
input distribution	3	3	3	3

E. RAINFALL-RUNOFF RELATIONSHIP TANH CURVE

Rainfall runoff relationship can be expressed in terms of Tanh curve equation. Establishing this relationship for individual catchments would provide a quick assessment of the hydrological runoff characteristics of the catchment. They would be useful for Water Allocation Planning (WAP) studies to identify limits to farm dam development.

This section attempts to establish the rainfall runoff relationship for the Upper, Middle and Lower catchments using Scenarios 1 (WFD) and 2 (WOFD) for runoff simulations between 1884–1998. Rainfall (X-axis) versus runoff (Y-axis) for the scenarios are then plotted together to show their trendlines, each represented by a Tanh curve equation. In general, Tanh curve equation is provided below, Teoh (2002):

Tanh curve runoff $Q = a \times [P - L] - b \times F \times Tanh \frac{(P - L)}{F}$

Where:

a, b are constants and equal to 0.72 and 0.75 respectively

Q, discharge (mm)

P, precipitation (mm)

L, notional loss (mm)

F, notional infiltration (mm)

The equation was modified from the Tanh curve proposed by Grayson et al. (1996) with an addition of two constants a, and b, which apparently more suited to the study areas.

The variables for L and F were derived by trial and error so that a best-fit curve could be plotted by eye through the plotted points. The resulting L and F values thus derived for the Upper, Middle and Lower catchments are shown in Table 27. As the notional infiltration for the respective catchment under WFD and WOFD scenarios is the same for the equation, the impact of farm dams to catchment flow is seen as causing an increase in the notional loss factor L.

Table 27. Factors for the Tanh Curve Equations (flows modelled between 1884–1998)

Catchment Location	With Farm Dams (WFD)		Without Farm Dams (WOFD)	
	L (mm)	**F** (mm)	**L** (mm)	**F** (mm)
Upper catchment	285	340	255	340
Middle catchment	130	530	100	530
Lower catchment	265	380	245	380

UNITS OF MEASUREMENT

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

Name of unit	Symbol	Definition in terms of other metric units	Quantity
dam density	ML/km^2		
Day	d	24 h	time interval
gigalitre	GL	10^6 m^3	volume
gigalitre per year	GL/a		
hectare	ha	10^4 m^2	area
kilolitre	kL	1 m^3	volume
kilometre	km	10^3 m	length
litre	L	10^{-3} m^3	volume
megalitre	ML	10^3 m^3	volume
megalitres per day	ML/d		
megalitres per year	ML/a		
metre	m	base unit	length
millimeter per year	mm/a		
millimetre	mm	10^{-3} m	length
minute	min	60 s	time interval
second	s	base unit	time interval
Square kilometre	km^2	10^6 m	area

GLOSSARY

Adjusted flow: The adjusted catchment yield.

Adjusted natural flow: The catchment yield modelled with farm dams removed from the model after it was calibrated against gauged streamflow using current farm dams development.

AMLR: Adelaide Mount Lofty Ranges

AMLRNRMB: Adelaide and Mount Lofty Ranges Natural Resource Management Board

ANZLUC: Australian New Zealand Land Use Codes

Appl: Application.

BDW: Barossa Diversion Weir

BIL: Barossa Infrastructure Limited

Board: Northern Adelaide and Barossa Catchment Water Management Board (Now the Adelaide and Mount Lofty Ranges Natural Resources Management Board)

BoM: Bureau of Meteorology

BR: Barossa Reservoir

Cat: Catchment

CD: Catchment standard distribution

CL: Creek loss

Current farm dams development: The surveyed 1999 farm dams data.

Cv: coefficient of variability

CWMP: Catchment Water Management Plan

d/s: downstream

Defined dry period: The 3-year period between 1957–1959.

Defined wet period: The 3-year period between 1915–1917.

DIV: diversion

DWLBC: Department of Water, Land and Biodiversity Conservation

FGL: fractional groundwater loss

GWD: groundwater discharge

GWR: groundwater recharge

IL: initial loss

ILCL: Initial Loss and Continuing Loss model

IS: interception store

MAP: Mannum Adelaide Pipeline

Median flow: The median flow simulated for the period between 1884–1998. SWP2000 uses 50% of the value as the permissible water extraction quantity from the resource in order to maintain the sustainability of the catchment yield. It is not the average flow value.

ML: Megalitres

MSM: median soil moisture

Mt: Mount

NABCWMB: Northern Adelaide and Barossa Catchment Water Management Board (now the Adelaide and Mount Lofty Ranges Natural Resource Management Board)

NABCWMP 2001-2006: Northern Adelaide and Barossa Catchment Water Management Plan 2001–2006

NABCWMP: Northern Adelaide Barossa Catchment Water Management Plan

NAB: Northern Adelaide and Barossa

NEC: Not else where classified

NRM: Natural Resource Management

O/S: off-stream

PF: pan factor

PO: Post Office

Predevp: predevelopment

QC: quality code

Reduct: reduction

RF: rainfall

RL: rule

RMCWMB: River Murray Catchment Water Management Board (Now the SA Murray Darling Basin NRM Board)

RMCWMP 2003–2008: River Murray Catchment Water Management Plan 2003–2008

RM: River Murray

RO: runoff

SA Water: South Australian Water Corporation

S&D: stock and domestic

SE: South East

SKM: Sinclair Knight Merz

SMD: soil moisture discharge

SPR: South Para Reservoir

SRSP: Swan Reach Stockwell Pipeline

Subcat: subcatchment

Surface water resource: The available surface water resource of a catchment is taken as the median adjusted natural flow of the catchment. The value is derived from runoff simulation for the period 1884–1998 with farm dams removed from the model, after it is calibrated using current farm dams development with the level of dam water use as 30% of its storage capacity.

SWM: store wetness multiplier

SWP: State Water Plan

u/s: upstream

Vol: Volume

WAP: Water Allocation Planning

WFD: with farm dam

WOFD: without farm dam

WR: Warren Reservoir

WTM: Warren Trunk Main

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