DWLBC REPORT

Surface Water Assessment of the Upper Angas Sub-catchment

2006/09

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

Surface Water Assessment of the Upper Angas Sub-catchment

Kumar Savadamuthu

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

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Report DWLBC 2006/09

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

Knowledge and Information Division
Department of Water, Land and Biodiversity Conservation
25 Grenfell Street, Adelaide
GPO Box 2834, Adelaide SA 5001

Telephone	National	(08) 8463 6946
	International	+61 8 8463 6946
Fax	National	(08) 8463 6999
	International	+61 8 8463 6999
Website	www.dwlbc.sa.gov.au	

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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 continue to improve this knowledge through undertaking investigations, technical reviews and resource modelling.

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

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EXECUTIVE SUMMARY

This technical report describes the methodology and outcomes of the detailed hydrological study of the Upper Angas sub-catchment. It is one of the series of detailed hydrological studies undertaken for the individual catchments in the *Eastern Mount Lofty Ranges Prescribed Area*. The study quantifies the surface water resources within the sub-catchment, examines the impact of farm dams on the resources using rainfall-run-off modelling and provides guidance regarding future water resources management policies. The model setup for the Upper Angas sub-catchment was also extended to evaluate the resources in neighbouring sub-catchments within the Angas River Catchment.

This report will be used as a technical foundation for the state government's consideration of water resources management measures required for this sub-catchment. The main findings of the study are summarised below and further detailed in the 'Conclusions' section of the report.

Catchment Hydrology — The Angas River Catchment is located on the southern side of the Eastern Mount Lofty Ranges (EMLR). The Upper Angas is its high-yielding sub-catchment, with mean annual rainfall of 700 mm. Long-term rainfall records indicate an overall decreasing trend in annual rainfall, with the decline being more pronounced during the last two decades.

Streamflow from the sub-catchment has a high annual variability and on average 95% of it occurs during the winter months. Long-term modelled data indicate that the mean annual streamflow from the sub-catchment is 6000 ML, with the median being 5200 ML. The average annual run-off coefficient is 0.15 (15% of rainfall leaves the sub-catchment as streamflow), which is relatively higher than the catchments to its north.

Farm Dams — Farm dam development across the Angas River Catchment is comparable to other catchments in the EMLR. There are ~880 dams in the catchment with an estimated storage capacity of 2700 ML. The development levels in the Upper Angas and Middle-Creek sub-catchments are higher than in the other sub-catchments. Development levels in all the sub-catchments within the Angas River Catchment are below their allowable limits, as defined in the Catchment Water Management Plan for the River Murray (RMCWMP) in South Australia[1].

Impacts of Farm Dams on Catchment Run-off — The rainfall-run-off model constructed and calibrated for the Upper Angas sub-catchment was used to simulate three farm dam development scenarios:

(i) pre-farm dam development — current farm dams (2001) removed from sub-catchment model,

(ii) farm dams developed to RMCWMP limits, and

(iii) farm dams developed to RMCWMP limits, with diversion rules.

[1] The allowable limits set in the RMCWMP were estimated with a run-off coefficient of 0.10. While this run-off coefficient is an average estimate for the entire EMLR, and was used as an initial basis for planning on a regional scale, it varies on a catchment scale. Streamflow records and modelled data for the Upper Angas sub-catchment indicate a higher run-off coefficient of 0.14. Hence, the development limits are higher than those set in the RMCWMP and none of the sub-catchments in the Angas River catchment have exceeded their limit.

Comparison of catchment run-off from the three scenarios indicate that:

- *Annual impacts* — The current (2001) level of farm dam development in the Upper Angas sub-catchment has potentially reduced the mean annual adjusted run-off (run-off simulated with the impact of farm dams removed) from the catchment by 14%. This reduction is estimated to have been higher (39%) during drier years and marginal (6%) during wetter years. A further reduction of 7% and 6% to the current mean annual run-off was estimated when current farm dam capacities were increased to the development limits set in the RMCWMP, the first without and the latter with diversion rules.
- *Seasonal impacts* — Flows during summer months have potentially been more impacted (50% reduction) by the current dams than winter flows, which have potentially been reduced by 9%. While summer flows constitute only a small (5%) proportion of the annual flows, they are at least as crucial to the health of the water-dependent ecosystems as winter flows. Increasing farm dam capacities to RMCWMP limits would further impact on summer flows. However, incorporating diversion rules to the new dams would minimise further impacts on summer flows. However, incorporating diversion rules would delay the 'break-of-season' due to delays caused in the filling and spilling of new dams resulting in delay of 'high flow' events.
- *Daily impacts* — Medium and low flows (<10 ML/d), particularly during late winter and late autumn – early winter have potentially been impacted by an estimated 50% by the dams. The impact on low flows may mainly be on a local scale (lower order streams) than at the end of the catchment, as low flows at the outlet of the catchment are more baseflow dependent. Increasing farm dam capacity to the RMCWMP limits without incorporating diversion rules would deteriorate the situation further by reducing the frequency of the low and medium flow ranges. This is due to the fact that diversion rules ensure that new dams capture only the high flows.

Recommendations

To minimise future impacts on low and medium flows, and ensure sustainability of existing local water-dependent ecosystems, some of the key principles to be considered in future planning are:

- definition of ecologically sensitive stream locations, pools and wetlands and defining extraction rules for them
- ensuring that existing free-to-flow areas are maintained, as they possibly contribute to most of the current low flows occurring within the sub-catchments
- definition of conditions for permissible diversions to new dams located in other areas of the catchment.

This will ensure that the current low flows that are crucial to the existing local water-dependent ecosystems are maintained, while further development is allowed to continue to sustainable limits.

The state of existing water-dependent ecosystems and their flow requirements need to be identified and assessed. This would enable verification of the assessed impacts of farm dams on flow regimes and ecosystems and, more importantly, provide vital information to plan for future monitoring requirements and environmental water provisions.

It is recommended that streamflow and/or water level monitoring be carried out (i) downstream of the confluence of the major tributaries for more accurate streamflow estimates from the entire 'hills zone' of the catchment, and (ii) in the plains (downstream of Strathalbyn) to quantify the resources in the zone. Study on surface-groundwater interaction is an essential requirement to better understand and quantify the water resources in the ‘plains zone’ of the catchment.

This study has been based on very limited (spatial and temporal) streamflow data, and hence numerous assumptions have been necessary in the modelling and assessment exercise. Further data and information are required to reduce and/or refine the assumptions. A monitoring program that includes long-term ambient monitoring and short-term project monitoring needs to be established. This will ensure that appropriate surface water, groundwater and ecological data are collected for better quantifying the catchment’s water resources.

1. INTRODUCTION

1.1 PURPOSE AND SCOPE OF THE STUDY

This technical report describes the methodology and outcomes of the detailed hydrological study of the Upper Angas sub-catchment. It is one of a series of detailed hydrological studies undertaken for the individual catchments in the *Eastern Mount Lofty Ranges Prescribed Area*. The study was undertaken under the Eastern Mount Lofty Ranges Water Resources Management Program of the Department of Water, Land and Biodiversity Conservation (DWLBC) and the South Australian Murray-Darling Basin Natural Resources Management Board (SAMDNRM Board).

The study quantifies the surface water resources within the catchment, examines the impact of farm dams on the resources using rainfall-run-off modelling, and provides guidance regarding future water resources management policies. The model setup for the Upper Angas sub-catchment was also extended to evaluate the resources in neighbouring sub-catchments within the Angas River Catchment.

The scope of this study covers the following:

- quantification of the surface water resources within the Upper Angas sub-catchment
- construction and calibration of a computer rainfall-run-off model for the catchment
- assessment of the impact of current levels of farm dam development on streamflow
- assessment of model case scenarios to study future impacts, for facilitation of future catchment management decisions
- identification of data deficiencies and recommendations of future monitoring requirements.

1.2 BACKGROUND

Surface water use in the highlands and groundwater use in the plains are vital to the economics of the Eastern Mount Lofty Ranges (EMLR) region. However, the rapid development of farm dams over the last two decades in the EMLR has raised considerable concern on the sustainability of water resources and the impacts seen on the dependent ecosystems. Preliminary investigations indicate that farm dam development in the high rainfall areas of a number of catchments in the EMLR has either reached or exceeded allowable levels of development as defined in the Catchment Water Management Plan for the River Murray in South Australia (RMCWMP).

To prevent further resource decline and to provide security to all water users, the South Australian Government, on 16 October 2003, declared two Notices of Prohibition, one on the taking of surface water and water from watercourses and the other on the taking of water from wells in the EMLR catchments. A Notice of Intent to Prescribe the surface water, watercourses and wells of the EMLR catchments was also issued under section 8 of the *Water Resources Act 1997*. Following the consultation period, the state government prescribed the surface water, watercourses and wells in the EMLR on 8 September 2005.

The SAMDNRM Board, established under the *Natural Resources Management Act 2004*, is responsible for protection of the water resources and associated ecosystems in the River Murray Catchment in South Australia. The Catchment Water Management Plan, in its policy on development, has set limits for development on a regional basis for the entire EMLR (RMCWMB 2003).

DWLBC, under its initiative 'The Mt Lofty Ranges Water Resources Assessment Program', has been carrying out detailed technical studies to quantify and assess the condition of surface and groundwater resources of the Mount Lofty Ranges. Surface and groundwater assessments of the Marne Catchment (Savadamuthu 2002), Surface Water Assessment of the Upper Finniss Catchment (Savadamuthu 2003) and Surface Water Assessment of the Tookayerta Catchment (Savadamuthu 2004) are some of the studies that have been completed under the program in the recent past. SAMDNRM is currently in the process of preparing Water Allocation Plans for catchments in EMLR.

The Angas River catchment is one of the high-yielding catchments in the EMLR (Map 1). The river and its catchment are a major source of water for irrigation (through water stored in farm dams), and for the ecosystems within the catchment. Intensive farm dam development directly affects natural flow regime of the catchment and hence the ecosystems dependent on that flow regime.

This study, along with those to be carried out for other catchments in the EMLR, will form an important technical foundation and hence basis for consideration for policy decisions to be made on future management of water resources in the region.

1.3 STUDY APPROACH

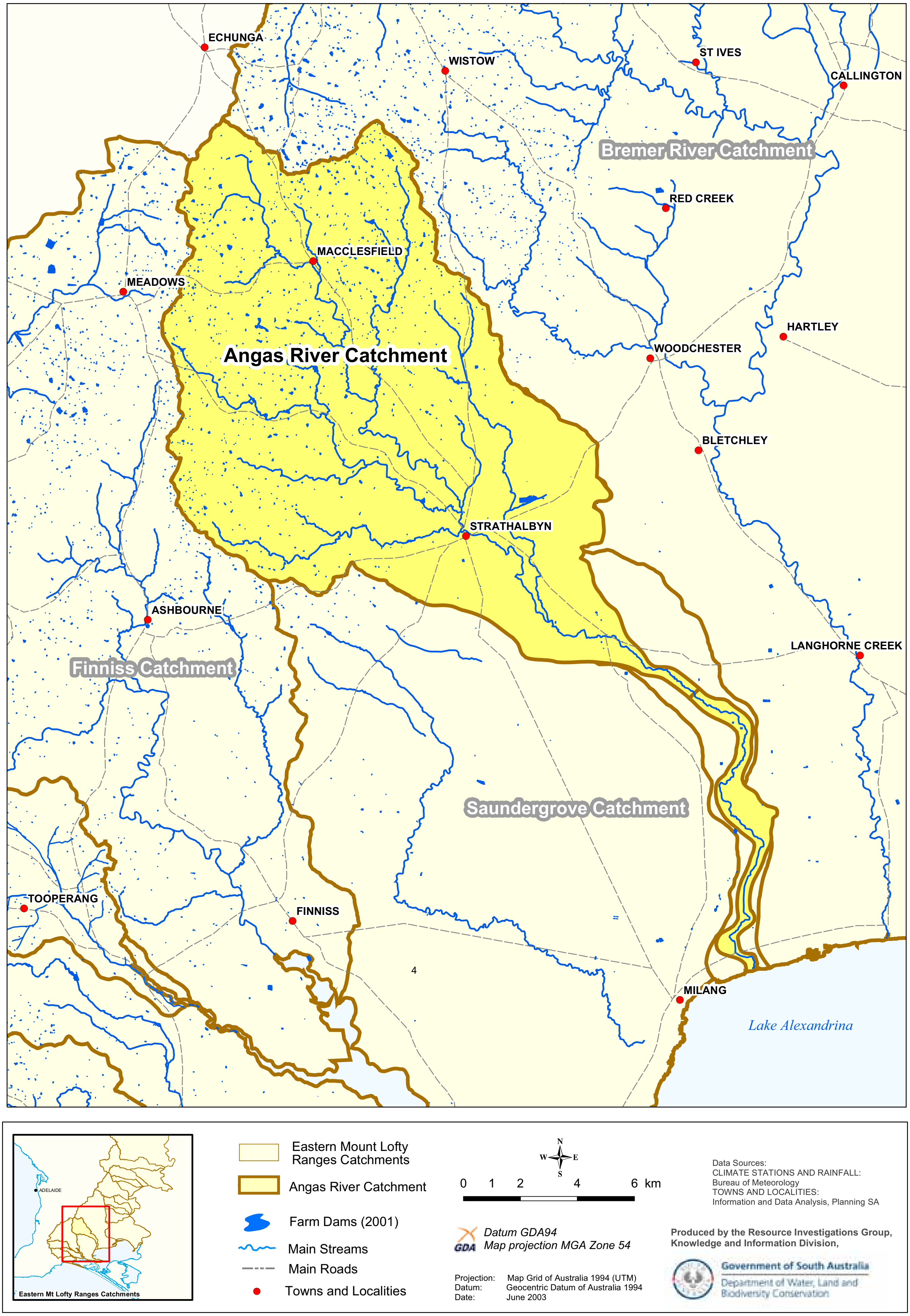
The concept of this study and the results presented in this report are based on a rainfall-run-off model constructed by using the surface water management platform WaterCress (Cresswell 2000). The catchment area above gauging station AW426503 (Angas River @ Angas Weir), termed the 'Upper Angas sub-catchment' in this study, was the main area of analysis. The Upper Angas sub-catchment was subdivided (using GIS package ArcMap) into surface water zones based on the major (3rd order) tributaries feeding the main streams (Map 5). These were further subdivided into farm dam catchments based on size, location and intensity of farm dams (Map 6). Further details on catchment subdivision are presented in Section 2.2 of this report. A catchment model was constructed as a series of farm dam catchment nodes draining into farm dam nodes to represent the entire Upper Angas sub-catchment (Section 4.3).

The catchment model constructed was then calibrated for the period 1996–99 ('current dams scenario') using observed daily rainfall data, observed streamflow data and 2001 levels of estimated farm dam capacities. The calibrated model was then used to simulate:

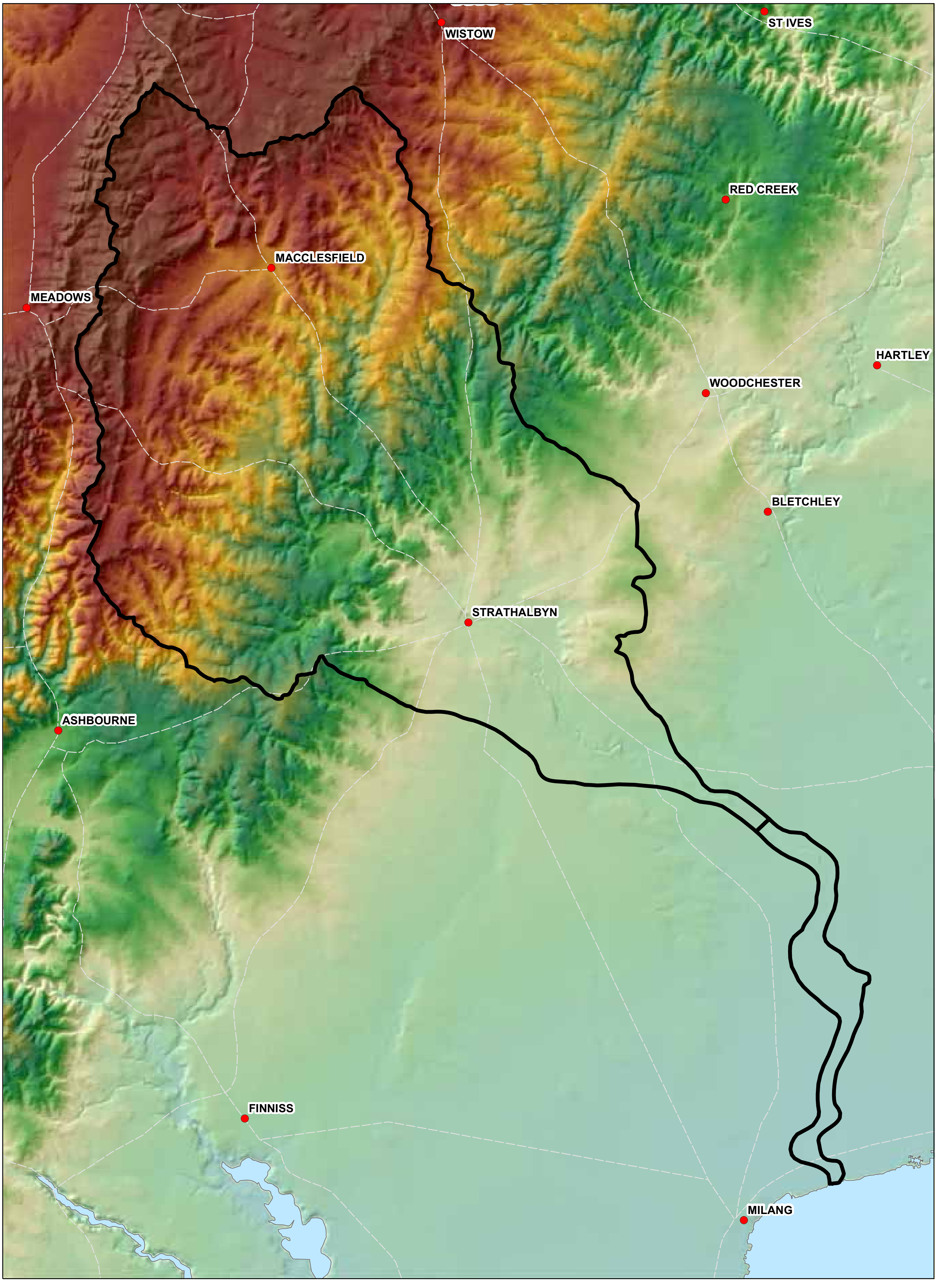
- streamflow data from rainfall records for the Upper Angas sub-catchment for the period 1885–2003
- streamflow data for three neighbouring ungauged sub-catchments — Middle Creek, Dawson Creek and Burnside Creek
- farm dam development scenarios to assess the impact of dams on catchment run-off.

The results of the scenarios modelled are presented in this report on a sub-catchment level, and an annual, monthly and daily basis. This provides better understanding of not only the impacts of dams on catchment yields, but also the impacts on flow regimes that are critical for environmental flows assessment. This leads to assessment of the potential risks to the sustainability of the overall surface water resources and the water-dependent ecosystems, which provides a basis for consideration for future water management options.

Map 1. Angas River Catchment - Location Map



Map 2. Angas River Catchment - Topography



Elevation (m)

High : 700 metres

Low : 0 metres

Angas River Catchment

Towns and Localities

Roads

N
W E
S

0 1 2 3 Km

Datum GDA 94
Map projection MGA Zone 54

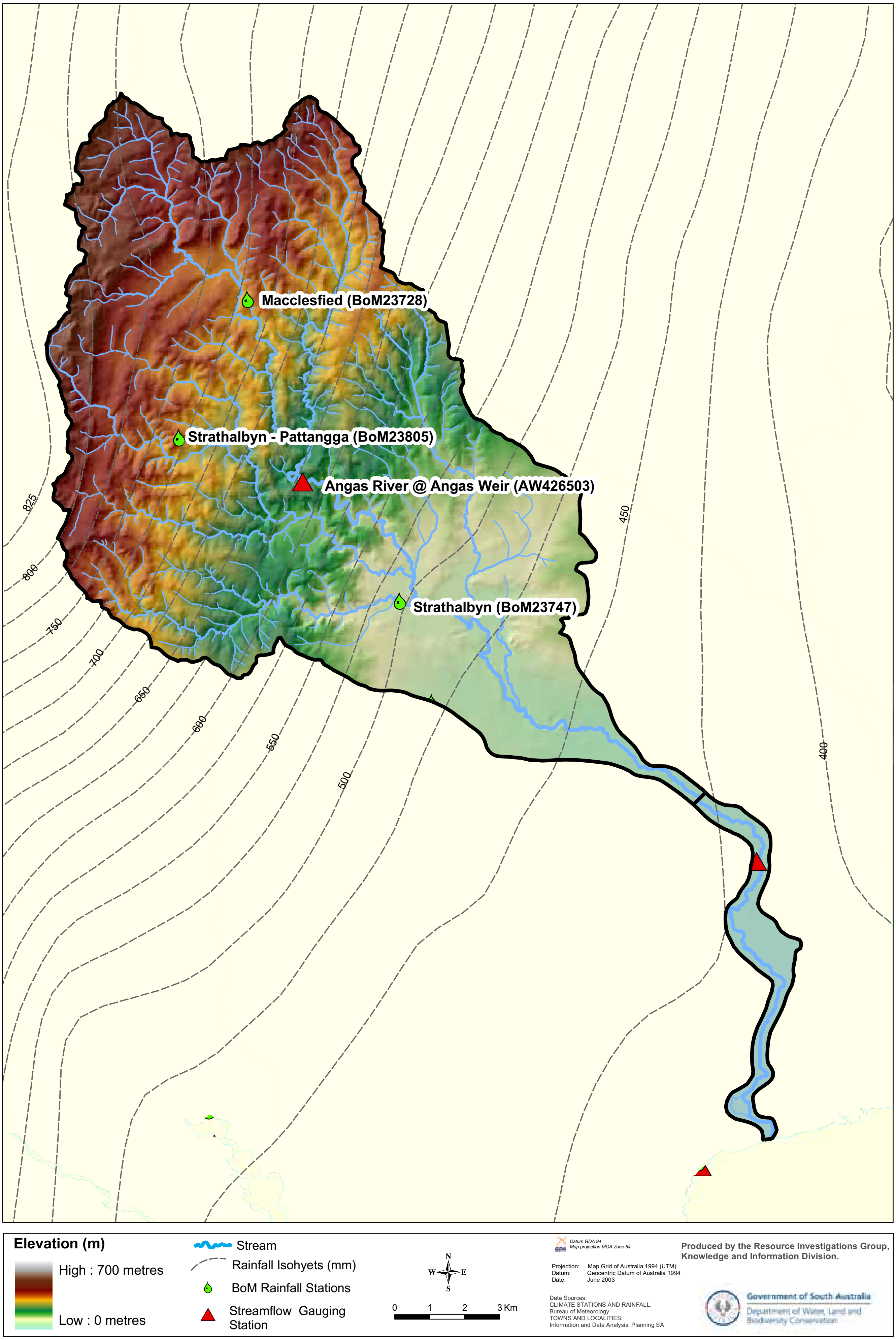
Projection: Map Grid of Australia 1994 (UTM)
Datum: Geocentric Datum of Australia 1994
Date: June 2003

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

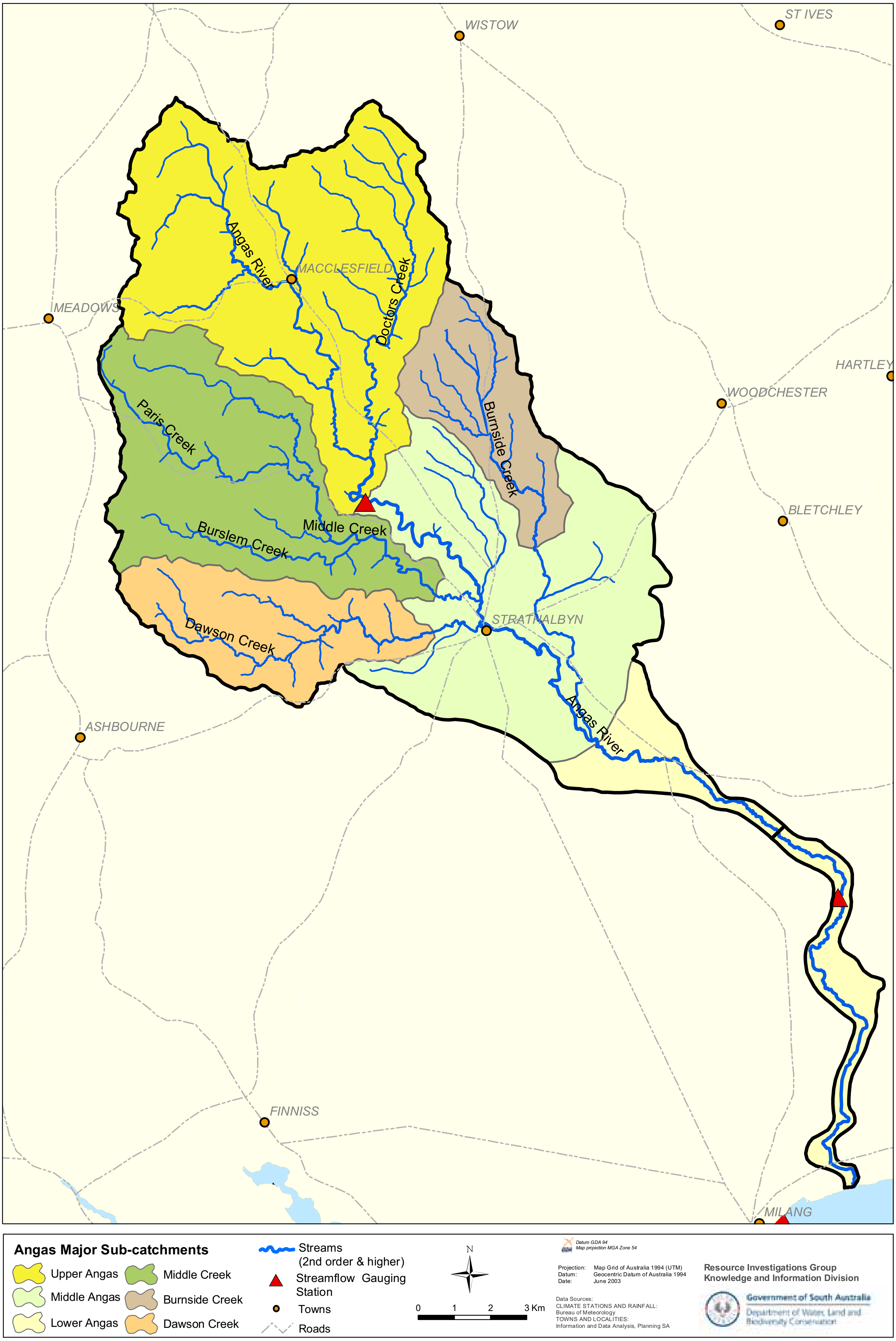
Produced by the Resource Investigations Group, Knowledge and Information Division.

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

Map 3. Angas River Catchment - Topography & Surface Water Features



Map 4. Angas River Catchment - Major Streams & Sub-catchments



2. CATCHMENT DESCRIPTION

2.1 OVERVIEW

The Angas River Catchment is located in the EMLR ~50 km southeast of Adelaide (Map 1). The headwaters of the main river are located near Flaxley and the river flows in a southeasterly direction through the towns of Macclesfield and Strathalbyn to its confluence with Lake Alexandrina near Milang. The major tributaries feeding the river include the Doctors, Paris, Burslem, Middle, Dawson and Burnside Creeks (Map 4).

The catchment covers an area of ~190 km^2, with the area upstream of Strathalbyn being the 'hills zone', the area surrounding Strathalbyn being the 'transition zone' and the area further downstream being the 'plains zone' (Map 2). The detailed geomorphic classification of the catchment's watercourses and their conditions are presented in the report 'Watercourse Risk Assessment – Geomorphology and Vegetation, Angas and Tookayerta catchments' (RMCWMB 2003).

Annual rainfall in the catchment varies from ~800 mm in the western ridges to ~400 mm on the plains (Map 3). Run-off coefficient for the 'hills zone' of the catchment is estimated to be ~0.15 (15% of rainfall runs off), which is higher than most the EMLR catchments to its north. Surface water is a major resource for irrigation, stock and domestic use in the 'hills zone'. Water from the gauging station was diverted to the Strathalbyn Reservoir for town water supply until 1995, when its use ceased due to increasing salinity. Groundwater is predominantly used in the 'plains zone', particularly in the *Angas-Bremer Prescribed Wells Area*. Land use in the 'hills zone' is mainly grazing and dairy farming, while it is vines, lucerne and vegetables on the plains.

2.2 CATCHMENT SUBDIVISION

Characteristics such as topography, rainfall, run-off and land use vary within a catchment area. Catchments are therefore divided into sub-catchments to represent areas with homogenous characteristics. This increases the efficiency of catchment assessment and enables planning on a localised scale rather than on a 'whole-of-catchment' scale.

Catchment sub-division in this study was carried out to three different scales:

- **Major sub-catchments** — areas within the whole catchment that represent catchment areas of the main (4th order and higher) streams; as defined in the RMCWMP.
- **Surface water zones** — areas within the major sub-catchments that represent catchment areas of the major tributaries (3rd order) that feed the main streams; useful during water allocation planning process, as variable and localised development is accounted for.
- **Farm dam catchments** — areas within the surface water zones that represent catchment areas of controlling dams; used for modelling the impact of dams on run-off.

Details on subdivision of the Angas River Catchment are presented in the following sections.

2.2.1 MAJOR SUB-CATCHMENTS

The Angas River Catchment was subdivided into six major sub-catchments (Map 4, Table 1) based on topography:

- the 'hills zone' catchment areas of the major streams upstream of Strathalbyn with higher elevation and steeper slopes
- the 'transition zone', where the topography changes from a hilly terrain to an area of comparatively less slopes (areas surrounding Strathalbyn)
- the 'plains zone', basically the 'flood plains' of the catchment (area downstream of Strathalbyn).

This subdivision is consistent with the RMCWMP's Surface Water Zones A1 to A6 (RMCWMB 2003, p.243).

Table 1. Major sub-catchments in the Angas River Catchment

No.	**Major sub-catchment name** (catchment ID as in RMCWMP)	**Area**[1] (km^2)	**Average annual rainfall**[2] (mm)
1	Upper Angas (A1)	60	717
2	Middle Creek (A2)	40	722
3	Dawson Creek (A3)	20	650
4	Burnside Creek (A4)	16	564
5	Middle Angas (A5)	48	507
6	Lower Angas (A6)	16	435

1 Area rounded to the nearest decimal.

2 Calculated using gridded isohyet data in GIS.

Sub-catchments A1 to A4 represent the hilly terrain with higher elevation and slopes. Sub-catchments A5 and A6 are downstream of the ridge and could primarily be classified as the 'transition zone' and 'plains zone', respectively. Catchment characteristics such as topography, geomorphology, rainfall-run-off characteristics, surface – groundwater interactions and land use vary with the zones.

Since streamflow monitoring is carried out only in the Upper Angas (A1) sub-catchment, catchment modelling and further assessment was primarily carried out for this sub-catchment. The model was further extended to neighbouring sub-catchments, but only to those in the 'hills zone' — Middle Creek sub-catchment (A2), Dawson Creek sub-catchment (A3) and Burnside creek sub-catchment (A4).

Hence, data analysis and results presented in the following sections of this report include only sub-catchments A1–A4 of the Angas River Catchment.

2.2.2 SURFACE WATER ZONES

Analysis of farm dam distribution indicated that within the major sub-catchments there are local zones with varying levels of dam development. To account for this variation, it was considered appropriate for future planning purposes that surface water zones be used rather than major sub-catchments. Catchment areas of the tributaries (1^{st} to 3^{rd} order streams) feeding the main streams and 'free-to-flow' sections of the main streams (3^{rd} order and higher) were then digitised in GIS as 'surface water zones'. This results in each major sub-catchment comprising a series of surface water zones.

The surface water zones within the four major sub-catchments analysed are shown in Map 5, and the total number within each major sub-catchment is listed in Table 2.

Table 2. Surface water zones in the Angas River Catchment

No.	Major sub-catchment	Number of surface water zones
1	Upper Angas (A1)	16
2	Middle Creek (A2)	5
3	Dawson Creek (A3)	5
4	Burnside Creek (A4)	7

While the determination of surface water zones in this section of the report was based on stream order, some of them could possibly be combined based on similar development levels. This would reduce the number of surface water zones to be used for future planning process. This is addressed in the later sections of this report that present the results of modelling.

2.2.3 FARM DAM CATCHMENTS

The next stage was to define and digitise smaller catchments based on the location of farm dams. The purpose of this exercise was to assess the impact of farm dams on run-off on a localised and spatially explicit manner within a catchment. The primary criterion for this sub-division was therefore the presence of a significant on-stream dam ('controlling dam'), which is deemed to control or block the flow from the upstream catchment area. Other factors were used in the sub-division of catchments in the absence of major on-stream dams. In general, based on all the factors used, each farm dam catchment is one of the following:

- a catchment area of a controlling dam with other smaller dams upstream, if any
- a catchment area of a series of controlling dams with other smaller dams upstream, if any
- a catchment area of a well-defined stream with off-stream dams
- a catchment area of a well-defined stream with no dams.

The subdivision process was initially done manually on a map, followed by digitising of the farm dam catchments in ArcMap (Map 6). The area of each of these farm dam catchments and the cumulative farm dam capacity in each of those catchments were then calculated. Information such as area, farm dam capacity and rainfall of the farm dam catchments is listed in Appendix F.

2.3 LAND USE

Land use data provide information on the nature of the use of land, for example, forestry, livestock grazing, horticulture and residential. This, in addition to the land and water management information (e.g. irrigated or unirrigated, usage of water from bore wells or from farm dams), provides a better understanding of resource availability and resource usage within the catchment.

Land use data for the catchment area were obtained from the land status data set that was an outcome of the land status mapping exercise for the Mount Lofty Ranges Watershed carried out by the Department for Environment and Heritage in 2001 (Bradley & Billington 2002). The exercise involved interpretation of 1:20 000 aerial photographs with field verification and the provision of access through a spatial data format that can be interpreted through geographical information systems.

The land-cover categories available from the data set were grouped into seven main types. The categories and their distribution in the different sub-catchments are shown in Map 7 and Table 3.

Table 3. Land use data for the Angas River Catchment; sub-catchment areas are shown below each sub-catchment name

Land use category	Land use category as percentage of total area						
	Upper Angas *60 km^2*	*Middle Creek* *40 km^2*	*Dawson Creek* *20 km^2*	*Burnside Creek* *16 km^2*	*Middle Angas* *48 km^2*	*Lower Angas* *16 km^2*	*Total* *200 km^2*
Livestock — broadscale grazing	87	85	96	67	54	47	75
Dairy cattle — intensive grazing	6	6	0	20	1.3	4	5
Vines	2	2	0	0	0.2	23	3
Horticulture	0.1	0.5	0	0.3	1.5	1	1
Field crops	0	0	2.4	7	27	25	9
Forestry, protected area	1.4	3	0.7	0.2	0	0.2	1
Residential, industrial	2	3	0.5	6.2	15.4	0.9	6

Data presented above indicate that land use in the ‘hills zone’ (Upper Angas, Middle Creek, Dawson Creek and Burnside Creek) is mainly grazing and dairy farming. In the ‘plains zone’ (Lower and Middle Angas) the land use changes to more of field crops and vines.

2.4 FARM DAMS

Farm dams are water storage structures generally constructed in regional areas (rural areas) for capturing the run-off generated from the catchment area above them (Fig. 1). The stored water is used for domestic, stock and irrigation purposes. While farm dams provide a source of water (in addition to rainfall and water pumped from groundwater bores) for agriculture, they also act as barriers for the run-off generated from the catchment area upstream of the dam, until the dam spills. This directly impacts the availability of water to users (including the environment) downstream of the dam, particularly when the dam is large. The other negative impact of this is the change in the flow regime of the stream, which directly affects the riverine and other water-dependent ecosystems. One of the main purposes of this study is to estimate this impact of farm dam development of the flow regime in the catchment.

The constant increase of more land being brought into intensive agricultural use in the Mount Lofty Ranges has necessitated the construction of more water storage facilities, and hence the inevitable situation of construction of a large number (and higher storage capacity) of farm dams. This increase in construction of farm dams has been more predominant and

Figure 1. Farm Dam in the Angas River Catchment

rapid in the highlands of the Mount Lofty Ranges with intense vineyard development. Assessment of catchments across the region has been carried out by DWLBC, including the Barossa Valley (Cresswell 1991), Onkaparinga River (Teoh 2002), Upper River Torrens (Heneker 2003), Upper Marne River (Savadamuthu 2002), Upper Finniss River (Savadamuthu 2003) and Tookayerta (Savadamuthu 2004) Catchments.

2.4.1 NUMBER AND STORAGE CAPACITY OF DAMS

Farm dam information for this study was obtained from the 2001 aerial survey, which was then digitised by the Department for Environment and Heritage and stored in a format to be used by GIS packages. Surface areas of these dams were then used to estimate dam capacities. A few farm dam surveys have been carried out in the Mount Lofty Ranges in the past and dam surface area to dam capacity relationships developed. There is considerable difference in the dam capacity estimation by these different relationships, particularly for the larger dams. Physical surveys of farm dams (the larger dams at least) are required for better estimation of the actual depths and dam capacities and, hence, a better dam capacity to surface area relationship.

In this study, farm dam capacities were estimated using the most recent following dam surface area to volume relationship (McMurray 2003):

For surface area <15 000 m^2 — dam capacity (ML) = 0.0002 x surface area $^{1.25}$

For surface area ≥15 000 m^2 — dam capacity (ML) = 0.0022 x surface area.

Based on the 2001 farm dam survey, the total number of farm dams in the Angas River Catchment was 884 (Map 8). Using the formulae shown above, the total estimated storage capacity of those farm dams is 2695 ML. The number of dams and their storage capacity based on size classification are shown in Table 4.

Table 4. Farm dam size classification, Angas River Catchment (2001)

Dam size category (ML)	**Number of dams**	**% of total dams**	**Total storage capacity** (ML)	**% of total capacity**
<0.5	271	31	76	3
0.5–2	375	42	372	14
2–5	124	14	392	15
5–10	50	6	356	13
10–20	40	4	552	20
20–50	22	3	758	28
>50	2	–	189	7
Total	**884**	**–**	**2 694**	**–**

Data presented in the table indicate that almost 90% of the dams in the catchment are of 5 ML or less capacity and contribute to ~30% of the total dam capacity. The larger dams (>10 ML) constitute ~10% of the total number of dams in the catchment but account for ~70% of the total dam capacity.

2.4.2 DAM DENSITY

Farm dam density, in comparison to the number and capacity of farm dams, is a more important parameter in indicating the intensity or the level of farm dam development, as it includes catchment area in its calculation, as shown below:

Farm dam density (ML/km^2) = total farm dam capacity (ML) / catchment area (km^2).

The farm dam density of the Angas River Catchment based on 2001 data is 13.6 ML/km^2. This is in the same range as other catchments in EMLR.

A better understanding of the extent and variation of farm dam development within a catchment is obtained when analysed on a sub-catchment level. Farm dam details of the major sub-catchments in the Angas are listed in Table 5.

While the farm dam density of the whole catchment is 13.6 ML/km^2, it varies widely on a sub-catchment level as shown in Table 5. The Upper Angas and Middle Creek sub-catchments, with dam densities of 23.3 and 18 ML/km^2 respectively, are highly developed in comparison to the other sub-catchments. Most of the larger dams (capacity >10 ML) are also located in those two sub-catchments.

Further analysis of farm dam development on a ‘surface water zone’ scale (Map 9) within the two highly developed major sub-catchments indicates that:

- Within the Upper Angas sub-catchment, the Doctors Creek catchment is more developed than the catchment area of the main Angas River section.

Table 5. Farm dam details of Angas River sub-catchments

Sub-catchment	**Catch-ment area** (km^2)	**Dam size classification** *Number of dams (total dam capacity in ML)* *<0.5*	*0.5–2*	*2–5*	*5–10*	*10–20*	*20–50*	*>50*	**Total number of dams**	**Total dam capacity** (ML)	**Dam density** (ML/km^2)
Upper Angas (A1)	60	136 (37)	196 (195)	48 (141)	33 (237)	23 (318	11 (377)	1 (72)	448	1377	23.3
Middle Creek (A2)	40	77 (23)	106 (102)	40 (133)	12 (87)	11 (155)	6 (205)	0 (–)	252	704	18.0
Dawson Creek (A3)	20	23 (7)	35 (36)	17 (55)	2 (15)	2 (31)	1 (29)	0 (–)	80	173	8.7
Burnside Creek (A4)	16	17 (5)	20 (18)	12 (42)	0 (–)	2 (27)	1 (31)	0 (–)	52	123	7.7
Middle Angas (A5)	48	15 (3)	14 (16)	5 (13)	2 (11)	2 (20)	3 (116)	1 (117)	42	297	6.2
Lower Angas (A6)	16	3 (1)	4 (5)	2 (8)	1 (6)	0 (–)	0 (–)	0 (–)	10	19	1.2
Total catchment	200	271 (76)	375 (372)	124 (392)	50 (356)	40 (552)	22 (758)	2 (189)	884	2694	13.6

- Within the Middle Creek sub-catchment, the Paris Creek catchment is more developed than catchment areas of Burslem Creek and Middle Creek.

Farm dam information for surface water zones is presented in Appendix E.

2.4.3 DAM DEVELOPMENT LIMITS

Rapid development of farm dams over the last two decades in the EMLR has raised considerable concern regarding the sustainability of water resources and the impacts seen on the ecosystems dependent on them. Preliminary investigations indicated that farm dam development in the high rainfall areas of a number of catchments in the EMLR have either reached or exceeded allowable levels of development as defined in the RMCWMP.

To prevent further resource decline and to provide security to all water users, a 'Notice of Prohibition on Taking Surface Water and Water from Watercourses' was placed in the EMLR. Pursuant to section 16(1) of the *Water Resources Act 1997*, the prohibition was placed by the Minister for Environment and Conservation, South Australia, on 16 October 2003 for a period of two years, due to the opinion that:

> '*The rate at which surface water is taken in the area is such that the surface water available can no longer meet the demand*;' and
>
> '*The rate at which water is taken from watercourses is such that the available water will not be sufficient to meet future demand*,'

thereby prohibiting the taking of surface water and water from watercourses in the area (except for circumstances specified in the notice). A similar notice of prohibition was also placed for groundwater, and a 'Notice of Intent to Prescribe the Watercourses, Wells and Surface water in the EMLR' was also issued on the same day as the notice of prohibition.

The prohibition period of two years enables assessment of the resource and accurate determination of its capacity to support existing use and provide for future growth. Part of this process will be to establish development limits on a catchment scale and assess the current level of development in the individual catchments. Following the consultation period, the state government prescribed the surface water, watercourses and wells in the EMLR on 8 September 2005.

One of the main reasons leading to the EMLR being placed under a Notice of Prohibition was due to some of the major catchments in the region exceeding the sustainable development limits set in the RMCWMP (RMCWMB 2003, p.244). The plan defines farm dam development limits in a catchment as:

> '*The surface water sub-catchment zone limit of all dams (megalitres) = 0.3 (30% of) X area of the surface water sub-catchment zone (sq km) X long term average rainfall between the months of May and November (mm) X run-off coefficient; where the run-off coefficient is 0.1 (10%), unless otherwise specified in a relevant Water Allocation Plan*' (RMCWMB 2003, p.182).

The 2001 levels of farm dam development in the Upper Angas sub-catchment (A1) and Middle Creek sub-catchment (A2) have exceeded development limits set in the RMCWMP (Table 6). Farm dam development in the Dawson Creek (A3) and Burnside Creek (A4) sub-catchments are below those limits.

Table 6. Development limits for the Angas River Catchment

Sub-catchment	**Catchment area** (km^2)	**Run-off coeffcient[1] with dams (without dams)**	**Current farm dam development[2]** (ML)	**Development limit set in RMCWMP[3]** (ML)	**Development limit based on observed and modelled streamflow data[4]** (ML)
Upper Angas (A1)	60	0.14 (0.17)	1377	1039	1853
Middle Creek (A2)	40	0.15 (0.16)	707	658	1237
Dawson Creek (A3)	20	0.12 (0.14)	173	303	441
Burnside Creek (A4)	16	0.08 (0.09)	123	212	205

1 Run-off coefficient = mean annual observed rainfall / mean annual modelled run-off (for the period 1974–2003).

2 Farm dam capacity estimates based on 2001 level of development.

3 As defined in RMCWMB (2003, p.244).

4 Modelled winter run-off (without farm dams) data for the period 1974–2003.

However, results of this study indicate that:

- the development limits set in the RMCWMP are lower than those calculated from the observed and modelled rainfall and streamflow data for the catchment and, hence,
- none of the four sub-catchments (A1–A4) have exceeded the development limits calculated in this study.

Development limits set in the RMCWMP vary from the ones calculated in this study because:

- The RMCWMP uses a constant run-off coefficient of 0.10 (10% of rainfall runs off) for all sub-catchments in the EMLR to calculate run-off and hence their development limits.
- In this study, the development limit for each sub-catchment was calculated using the observed average winter rainfall for the sub-catchment and the modelled average winter run-off for the sub-catchment, for the period 1974–2003.

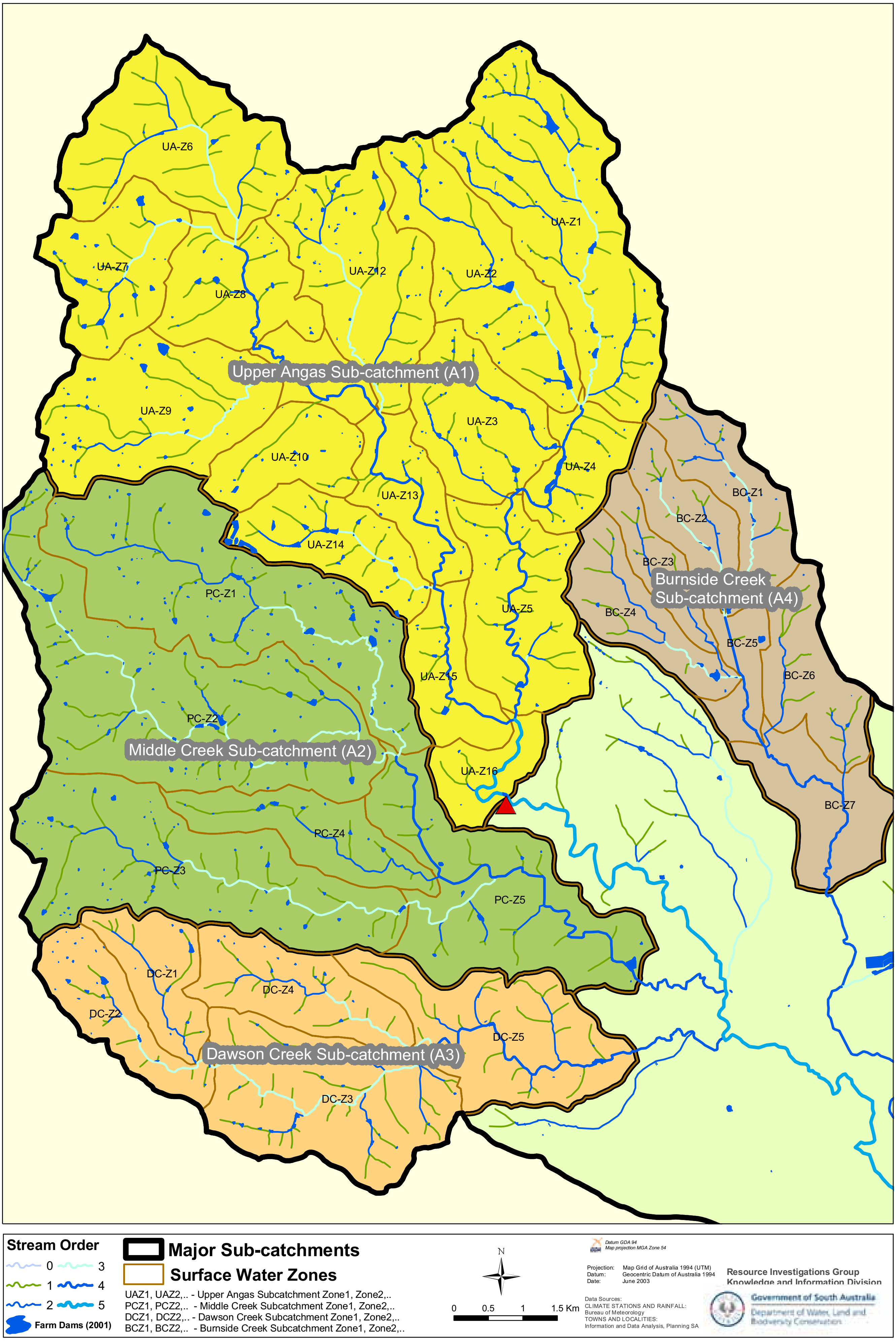
Moreover, as shown in Table 6, the run-off coefficients calculated in this study for sub-catchments A1, A2 and A3 are higher than those used in the RMCWMP. This results in development limits being higher for those sub-catchments than the ones set in the RMCWMP. Burnside Creek (A4) is the only sub-catchment that has a run-off coefficient and hence the development limit is similar in those stated in the plan (results of this study and the values in the RMCWMP).

In the RMCWMP, a run-off coefficient of 0.10 (10% of rainfall runoff) was used in the calculation of development limits for all catchments in the EMLR as:

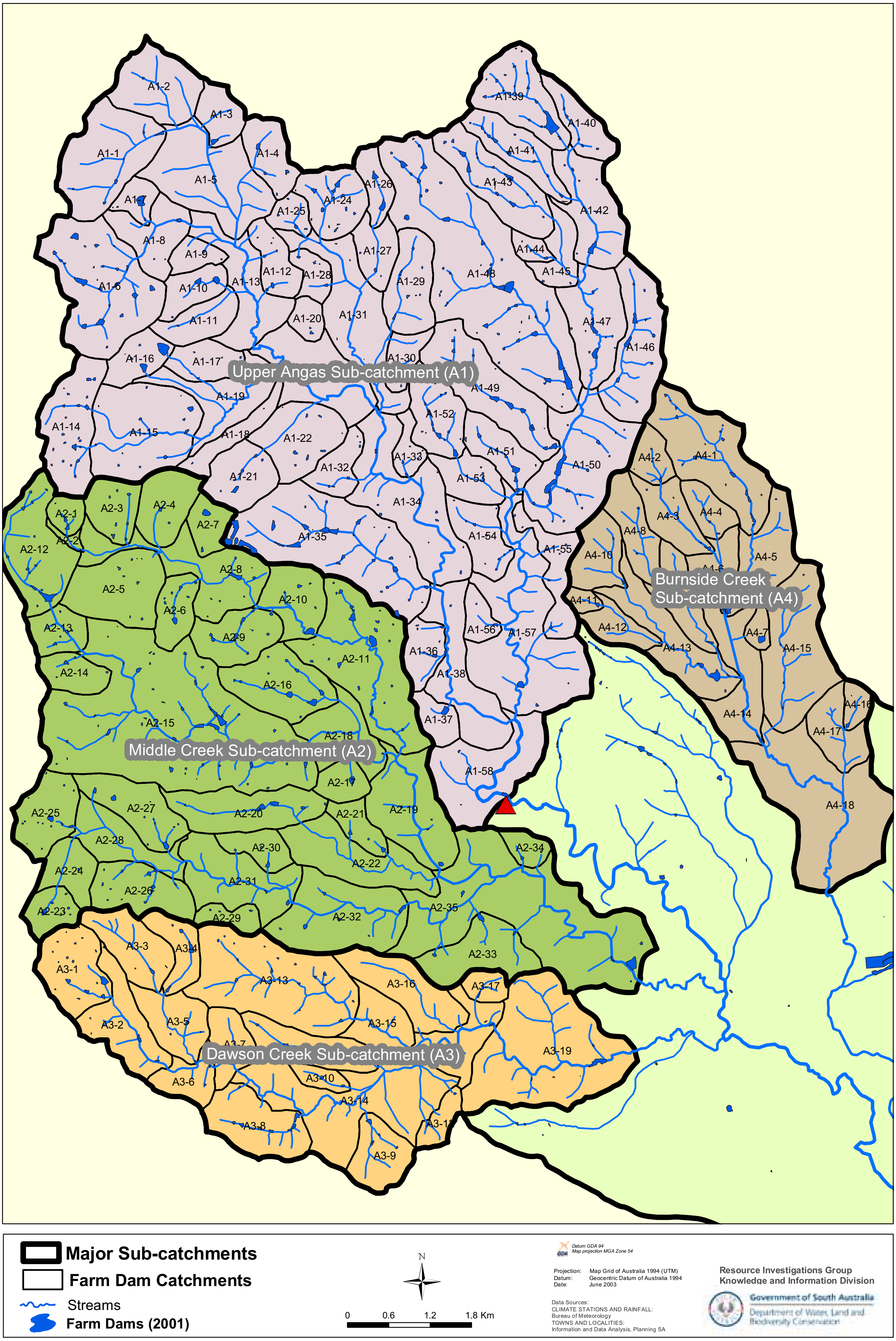
- detailed hydrological analysis of the individual catchments in the EMLR had not been carried out at the time the catchment plan was developed
- the estimated average run-off coefficient across the entire EMLR region is 0.10 (ranging from 0.05 for the Upper Marne Catchment in the north to 0.25 for the Tookayerta Catchment in the south).

While the development limits in the RMCWMP formed an initial basis for setting development limits for the entire EMLR, the data (rainfall, run-off, run-off coefficients and development limits) presented in this report should to be used in future planning as they better represent actual catchment data.

Map 5. Angas River Catchment - Surface Water Zones



Map 6. Angas River Catchment - Farm Dam Catchments



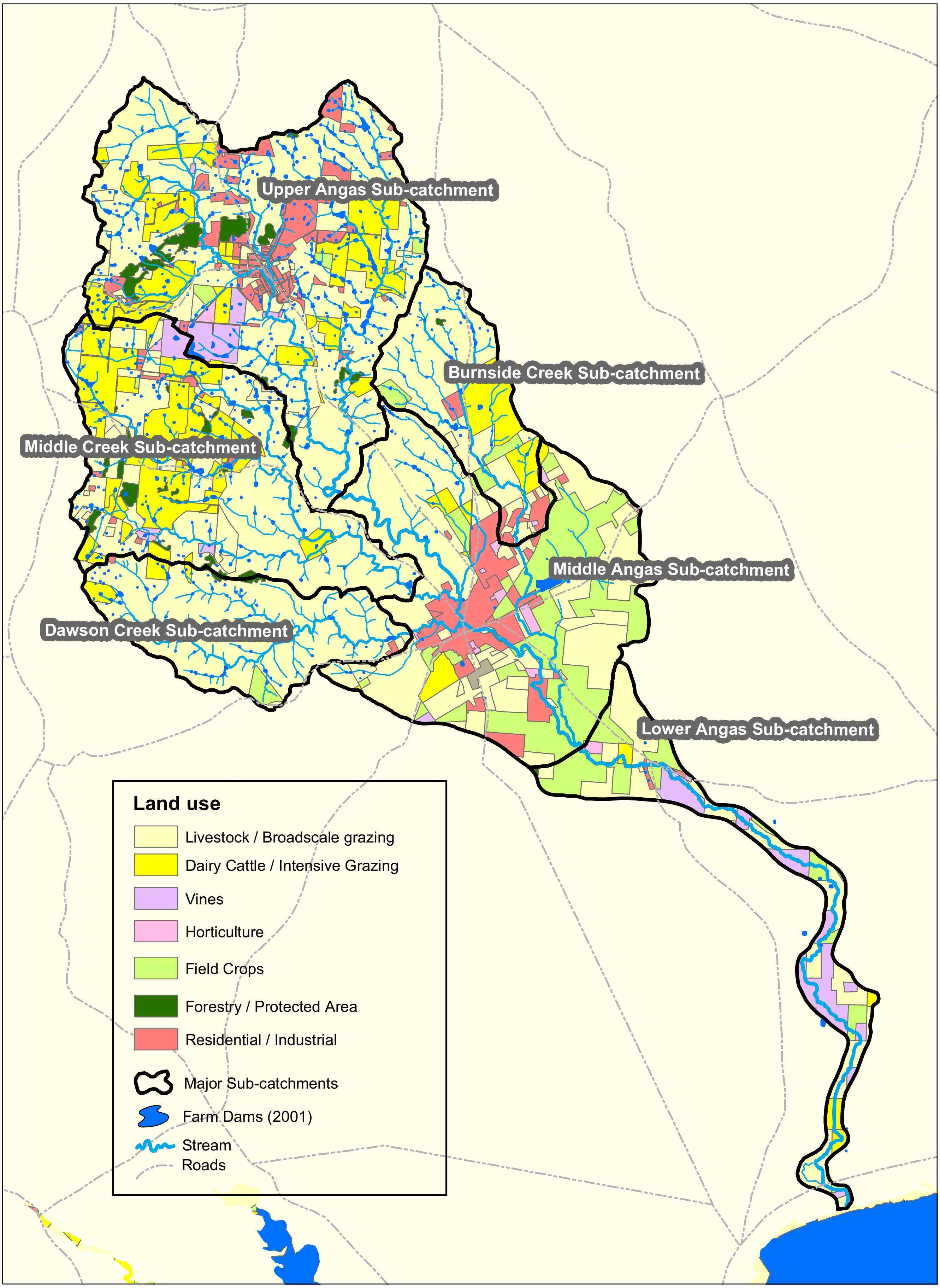
Datum GDA 94
Map projection MGA Zone 54

Projection: Map Grid of Australia 1994 (UTM)
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

Resource Investigations Group
Knowledge and Information Division
Government of South Australia
Department of Water, Land and Biodiversity Conservation

Map 7. Angas River Catchment - Land use



Projection: Map Grid of Australia 1994 (UTM)
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

N

0 1 2 3 Km

Datum GDA 94
Map projection MGA Zone 54

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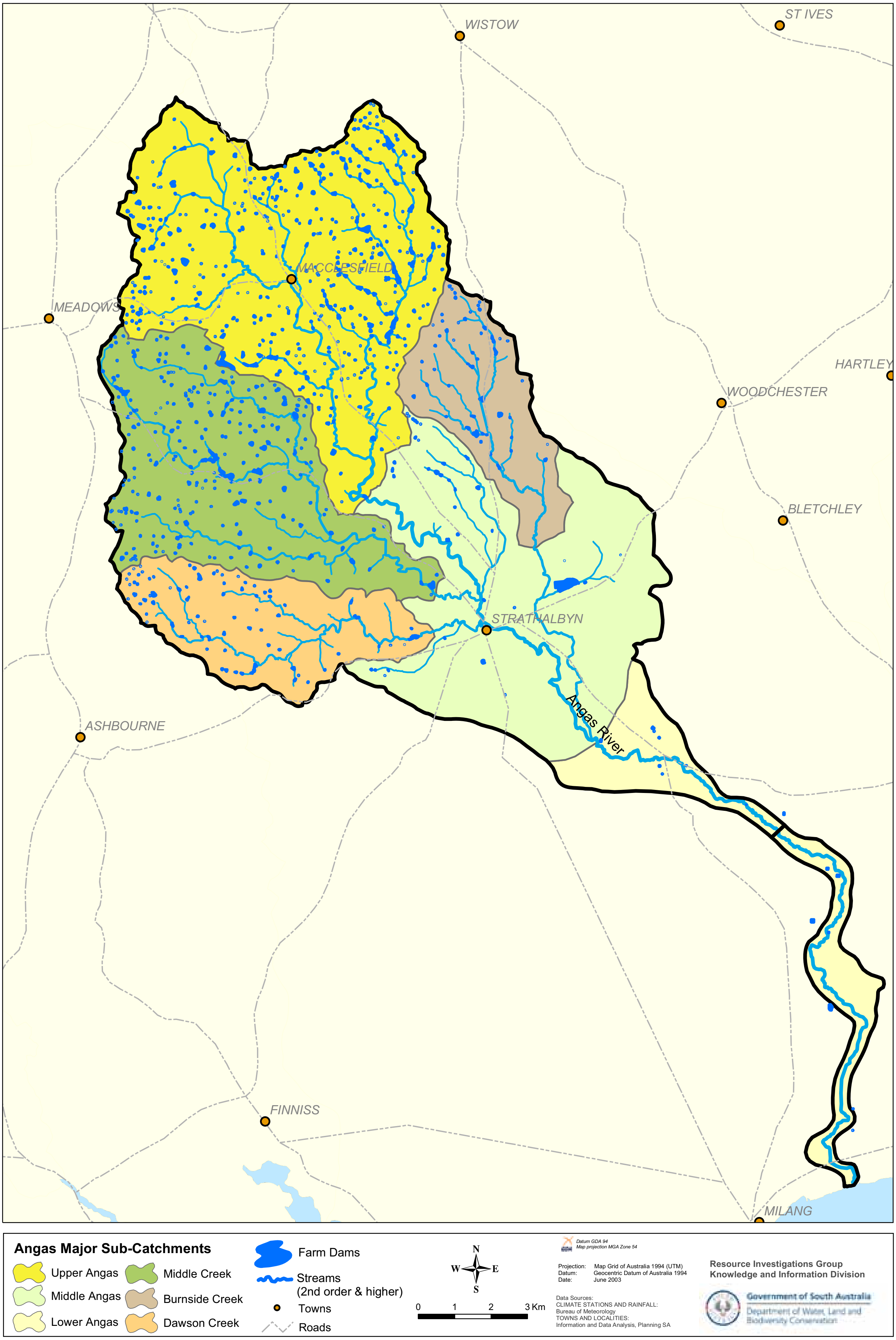
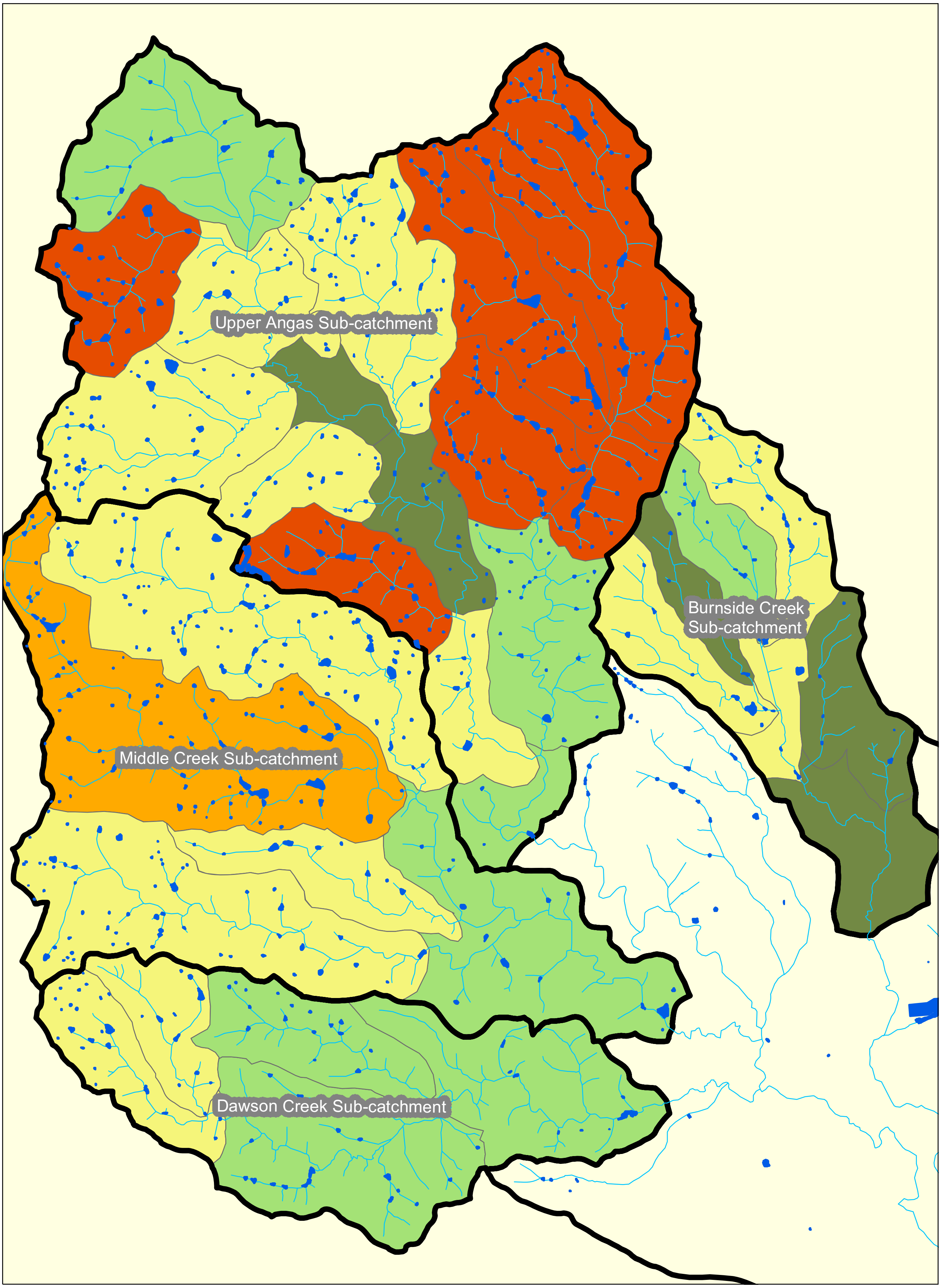
Map 8. Angas River Catchment - Farm Dams (2001)



Map 9. Surface Water Zones - Farm Dam Density



Dam Density (ML/km2)

- < 5
- 5 - 10
- 10 - 20
- 20 - 30
- > 30

Major Sub-catchments

Farm Dams (2001)

N

0 0.5 1 1.5 Km

Datum GDA 94
Map projection MGA Zone 54

Projection: Map Grid of Australia 1994 (UTM)
Datum: Geocentric Datum of Australia 1994
Date: June 2003

Data Sources:
CLIMATE STATIONS AND RAINFALL:
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Resource Investigations Group
Knowledge and Information Division

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

3. CATCHMENT HYDROLOGY

3.1 RAINFALL

Rainfall is one of the primary drivers of the hydrological cycle, with its volume and intensity directly affecting the volume of water available within a catchment and hence its productivity. Rainfall within a catchment generally varies spatially with topography, for example areas in higher elevations generally receive more rainfall than areas in lower elevations within the catchment. This necessitates determination of the varying rainfall pattern for estimation of effective run-off from different areas or sub-catchments within the catchment. This is achieved by using rainfall records from the Bureau of Meteorology (BoM) stations in the region and rainfall isohyets developed from those records.

3.1.1 DATA AVAILABILITY AND PROCESSING

Daily rainfall records within the Upper Angas sub-catchment are available from four BoM stations. Daily-read rainfall records usually have periods when rainfall during weekends and public holidays are accumulated and recorded on the next working day. Periods of missing records due to various reasons such as instrument malfunction are also common. Disaggregation of accumulated data and infilling of data for periods of missing records were carried out by Sinclair Knight Merz (SKM 2000) for DLWBC (App. H) to obtain complete data sets.

3.1.2 DATA ANALYSIS

Analysis of daily rainfall records was undertaken at monthly, annual and decadal time scales in this study. Trend analysis of annual rainfall was also carried out using different methodologies.

Annual Rainfall

Since the BoM station at Macclesfield (BoM23738) has the longest period of record within the catchment, data from this station were primarily used for further analysis. However, the station is located on the northern upper reaches of the catchment (Map 3) and does not represent the average rainfall for the catchment. The average annual rainfall for the catchment was therefore calculated in GIS (ArcMap) using the rainfall isohyets and the area of the catchments between them. Based on rainfall isohyets, annual rainfall within the catchment varies from 800 mm in the northern highlands to ~400 mm in the south. While the values of the rainfall isohyets are not exact and are currently under review, it is considered that they do provide a good representation of the spatial distribution of rainfall within the catchment. Hence, they were used to calculate the average annual rainfall for the individual major sub-catchments, surface water zones and the farm dam catchments using the digital elevation model (DEM) methodology in GIS. The average annual rainfall for the four major sub-catchments included in this study is listed in Table 7.

Table 7. Average annual rainfall of major Angas River sub-catchments

Major sub-catchment	**Average annual rainfall** (mm)
Upper Angas	717
Middle Creek	722
Dawson Creek	650
Burnside Creek	564

Average annual rainfall data calculated for the surface water zones within the major sub-catchments and for the farm dam catchments within the surface water zones are listed in Appendix E.

The long-term (1885–2003) mean and median annual rainfall at Macclesfield are 733 and 715 mm, respectively. Comparison of mean rainfall on a decadal basis (Fig. 2) also confirms the decreasing trend, with the late 1800s and early 1900s being wetter in comparison to the later decades. The data also indicate a decreasing trend in annual rainfall as shown by the trend line in Figure 3.

The decadal data also indicate that in the last seven decades only two had average (1960s) or above average (1970s) rainfall. The annual data plotted in Figure 3 also indicate that after 1992 all the years had below average rainfall until 2003. To verify this decreasing trend, further analysis was carried out using the 'Residual Mass Curve Analysis' method and two other trend analysis methodologies.

A residual mass curve is a plot of the cumulative deviation of a set of data from its mean value. In a residual mass curve plotted for annual rainfall data, a distinctive upward slope indicates an increasing trend in annual rainfall and vice versa. The residual mass curve for the Macclesfield rainfall data is plotted in Figure 3. Some of the periods with distinctive increasing trend are 1885–1910 and 1967–75. Some of the periods with distinctive decreasing trend are 1935–66 and 1993–2002.

Trend analysis methodologies were further used to confirm the existence of a trend in a long-term data set and also the level of statistical significance of the trend. Results of the trend analysis of annual rainfall data from Macclesfield for the period 1885–2003 indicate a definitive decreasing trend, with a statistical significance of 98% using the Mann's test (Grayson 1996; App. I) and a statistical significance of 96% using the 't' and 'F' tests (Draper 1998).

A similar decreasing trend in long-term rainfall data has also been observed in other catchments in the Mount Lofty Ranges — the Finniss River (Savadamuthu 2003), River Torrens (Heneker 2003), Onkaparinga River (Teoh 2002), Marne River (Savadamuthu 2002) and Barossa Valley (Cresswell 1991) Catchments.

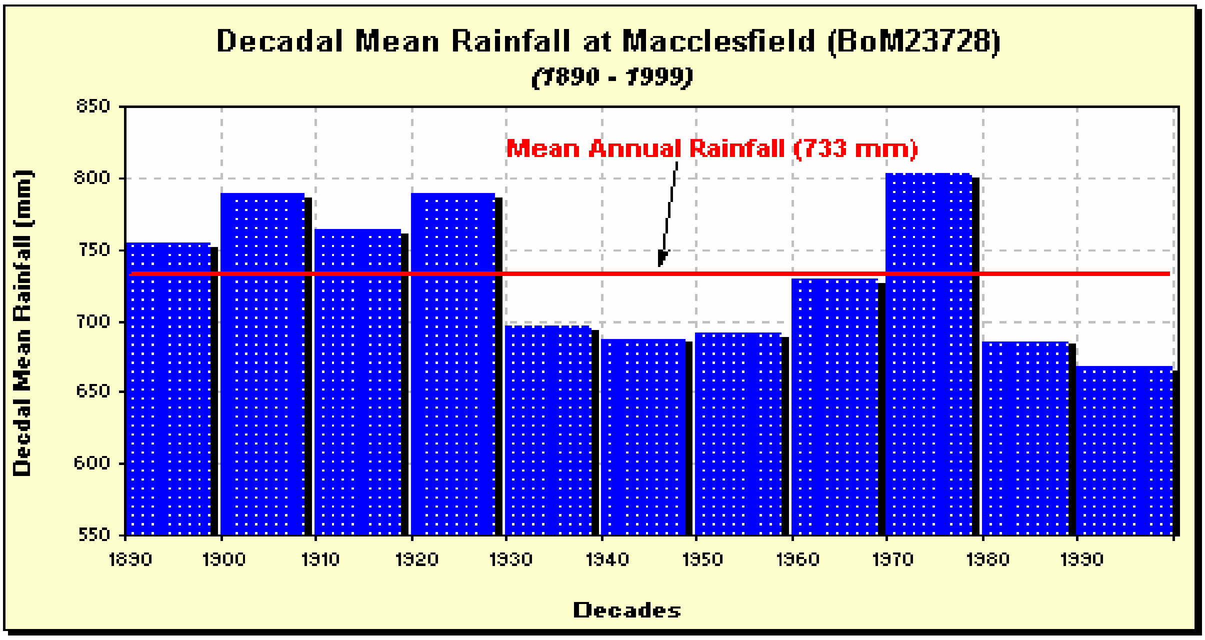


Figure 2. Decadal rainfall at Macclesfield

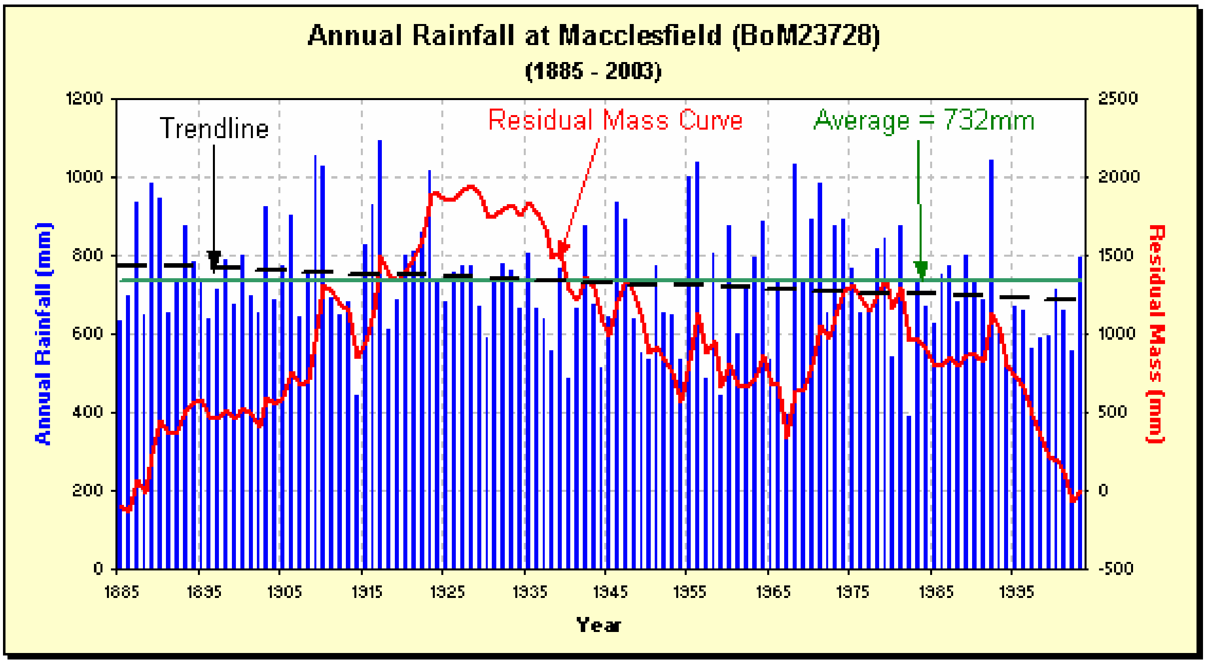


Figure 3. Annual rainfall at Macclesfield

Monthly Rainfall

The average monthly rainfall for the period 1885–2003 indicates that on average 76% of the annual rainfall occurs in winter (between May and November). Residual mass curves for winter and summer were then plotted along with the annual residual mass curve to identify possible variations between winter and summer trends (Fig. 4).

As shown in Figure 4, winter rainfall trend closely follows the annual rainfall trend except for a short period between 1969 and 1974, during which the increasing trend in annual rainfall is

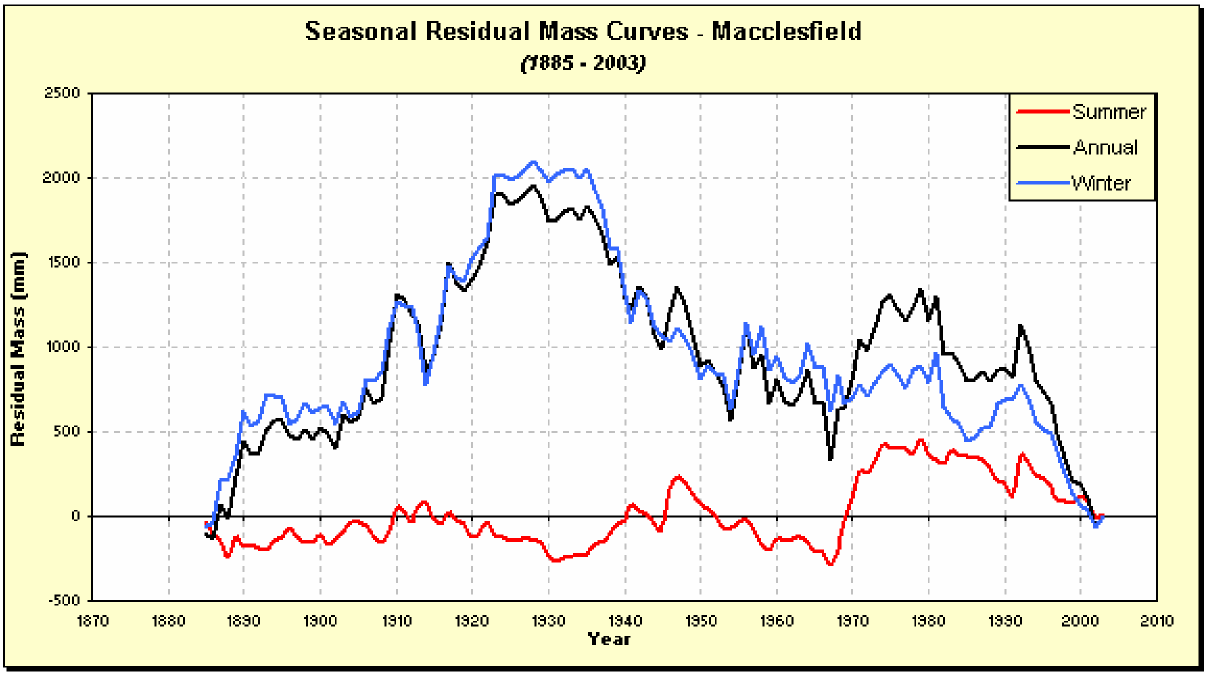


Figure 4. Seasonal residual mass curves for Macclesfield

attributed to an increasing trend in summer rainfall rather than the winter rainfall. Summer rainfall during this period, as a percentage of annual rainfall, was 46%, 34%, 35%, 25%, 27% and 30%, compared to the long-term average of 24%.

3.2 STREAMFLOW

Streamflow is one of the major components of the hydrological cycle. To measure the amount of water leaving a catchment, streamflow is generally measured near its outlet. Streamflow data is one of the major inputs in the assessment of catchment hydrology as it is a good indicator of catchment characteristics and health.

The Angas River has three other tributaries — Middle Creek, Dawson Creek and Burnside Creek (Map 4) — which flow through the plains before discharging into Lake Alexandrina. Streamflow measurement ('gauging') in catchments in South Australia is generally carried out by DWLBC). Streamflow gauging station AW426503 (Angas River @ Angas Weir) (Fig. 5) is located upstream of the confluence of the tributaries and hence gauges flows from only a portion the main stem of the Angas River, termed the 'Upper Angas' in this report.

3.2.1 DATA AVAILIABILITY AND QUALITY

Streamflow gauging station AW426503 includes a diversion structure upstream of the gauging weir, which was used from 1969 (when the station was commissioned) to 1995 to divert water to the Strathalbyn Reservoir. The volume of water diverted to the reservoir was not metered at the gauging station or at the reservoir. The actual streamflow or the volume of water passing through the gauging station is therefore unknown for the period 1969–95. This led to data for that period not being used for analysis, and data from 1996 onwards being used for further analysis and modelling purposes.

Figure 5. Streamflow gauging station AW426503 (Angas River @ Angas Weir)

Streamflow is calculated from water level data measured at the gauging station and a water level – discharge relationship ('rating') established for the site. The geometry of the approach section of a stream changes with time, changing the approach velocity and hence changing the rating at the site. Due to this unstable nature of streams, the ratings need to be updated on a regular basis to maintain an accurate calculation of streamflow. This is achieved by gaugings being undertaken at different flow ranges and verifying or updating the rating.

The quality of streamflow data is highly dependent on the accuracy and currency of the rating equation curve used to convert water level data to streamflow data. The quality of streamflow data for the Upper Angas sub-catchment would be considered low as:

- an empirical rating curve is used to calculate streamflow as against a rating curve being established from field measurements, and
- only one gauging has been undertaken during the whole period (from 1969) that the station has been operational.

Establishment and periodical verification of an appropriate rating for the site should be considered an absolute necessity to ensure that minimum standards of monitoring are achieved.

3.2.2 DATA ANALYSIS

Streamflow data analysis and results presented in this section are based on observed data from the streamflow gauging station AW426503 for the period 1996–2003. It is recognised that rainfall and streamflow during this period were much lower than their long-term averages. Therefore, for any water resources planning purposes, it is recommended that long-term modelled data from the ‘5.1.2 Modelled Streamflow Data’ section of this report be used.

The mean and median annual streamflow for the Upper Angas sub-catchment for the period 1996–2003 are 3425 and 2672 ML, respectively. The data indicate high variability, ranging from a maximum streamflow of 7666 ML in 1996 to a minimum of 1208 ML in 2002.

Figure 6 illustrates the mean monthly streamflows and corresponding rainfall data for the period 1996–2003. Most of the streamflow occurs during the months of July, August and September, with the highest streamflow during August. On average, 95% of annual streamflow occurs during winter (May to November) and 74% of annual rainfall is received during this period.

Analysis of daily flow for the period 1996–2003 indicates that the median daily flow is 1.8 ML, which is much lower than the long-term median. As mentioned earlier in this section, detailed daily flow analysis of long-term modelled data is presented in the later sections of this report.

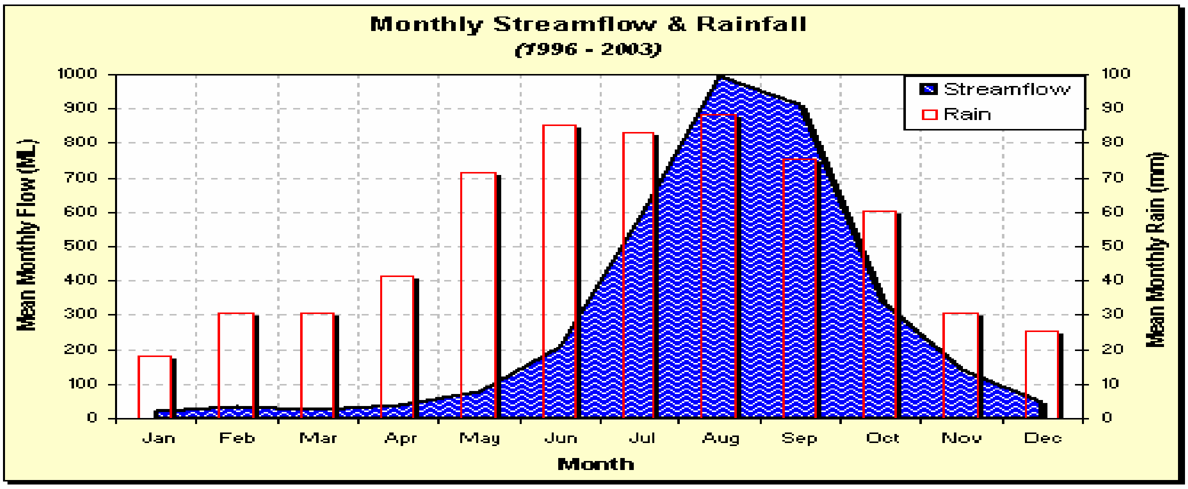


Figure 6. Monthly streamflow from Upper Angas

Rainfall-Run-off Relationship

Annual rainfall-run-off relationship analysis provides a simple means of estimating the volume of run-off that can be expected from a catchment for a given amount of rainfall. Run-off generated from a catchment generally varies annually for the same amount of rainfall. This variation is due to a number of factors, with variation in temporal distribution of rainfall being an important one. Rainfall-run-off relationships are often used for comparing the characteristics of different catchments and for providing initial run-off estimates from ungauged catchments. The run-off coefficient and the Tanh function are two commonly used tools in rainfall-run-off analysis.

Run-off coefficient for a catchment is derived by dividing its average annual run-off by its average annual rainfall. The run-off coefficient obtained from observed data for the period 1996–2003 is 0.09 (in simpler terms, on an average, 9 mm of run-off leaves the catchment for every 100 mm of rainfall). The run-off coefficient obtained from modelled data for the period 1974–2003 is 0.15. This value was used in further assessment as it represents long-term data. The run-off coefficient for the Upper Angas sub-catchment is comparable to other catchments in the EMLR, with catchments in the south of the region having higher coefficients and catchments to the north of the Angas having lower run-off coefficients.

Run-off coefficients for other catchments in the EMLR are listed in Table 8.

Table 8. Run-off coefficients for catchments in the EMLR

Catchment	Period of record	**Mean annual rain** (mm)	**Mean annual run-off** (mm)	Run-off coefficient
Tookayerta Creek Catchment	1922–2000	770	191	0.25
Finniss Catchment U/S of AW426504	1970–98	854	144	0.17
Currency Creek U/S of AW426530	1973–96	726	108	0.15
Bremer River U/S of AW426533	1974–96	492	42	0.09
Angas River U/S of AW426503	1996–2003	641	57	0.09* (0.15)#
Marne Catchment U/S of AW426529	1973–96	535	33	0.06

* Results of observed data for the period 1996–2003. Refer to first paragraph in section 3.2.2 of this report for further details.

\# Results of long-term (1974–2003) modelled data.

A rainfall-run-off curve, and hence a rainfall-run-off relationship for a catchment, can be developed by plotting the annual rainfall versus the annual run-off values. Tanh (Grayson 1996) is a standard hyperbolic function that can provide a simple rainfall-run-off relationship. A Tanh curve for the observed streamflow data was not plotted due to the few number of data points. Tanh curves are plotted from modelled run-off data in section 5 of this report. The Tanh function and its parameters are described in Appendix A.

4. SURFACE WATER MODELLING

4.1 OVERVIEW

Hydrologic models are conceptual models that represent the various components of the hydrologic cycle (rainfall, interception, evaporation, infiltration, surface run-off, groundwater recharge and baseflow) and the links between them. The components and links of the cycle are represented by mathematical functions that are built into a model by using computer-programming languages. The models are built to simulate catchment conditions, to generate long-term data and to enhance further understanding of the hydrological behaviour of catchments. They are further used for assessment of the impacts of various changes and activities within the catchment.

In this study, the hydrological model that was used was a rainfall-run-off water balance model. Observed daily streamflow records, rainfall records, farm dam capacities and estimated catchment parameters were used to construct and calibrate a catchment model for the Upper Angas (A1) sub-catchment. The model was then used to simulate long-term streamflow data from long-term rainfall records. It was further used to model different catchment scenarios to study their impacts on catchment run-off. Catchment models for the Middle Creek (A2), Dawson Creek (A3) and Burnside Creek (A4) sub-catchments were also constructed and streamflow data were simulated using the same set of catchment parameters derived for the Upper Angas sub-catchment.

Hydrologic modelling involves the following processes:

Model construction — The process of formulation of a series of mathematical equations that represent the relationships between the various processes involved in the hydrological cycle (rainfall, interception storage, evaporation, transpiration, infiltration, percolation, baseflow, etc.).

Model calibration — The iterative process of solving the abovementioned set of mathematical equations. Some of the main steps involved in this process are:

- Input data to the model — one or more measured sets of hydrological parameters (e.g. daily rainfall data set).
- Iteratively vary the other unobserved hydrological and catchment characteristics parameter sets (e.g. interception storage, ground water discharge, etc.) to mathematically simulate (generally) one hydrological parameter that has been measured (e.g. simulation of catchment run-off).
- Compare the simulated data set to the measured data set and continue the iteration process until a 'good correlation' is obtained between the simulated and measured data sets. The model is thus calibrated at this stage.
- Use the calibrated model to generate long-term data and to model different catchment scenarios.

The level of efficiency of the calibration process depends on the availability and accuracy of the number of hydrological parameter data sets. Since the hydrological cycle involves a large number of parameters that are not measured, efficient calibration of hydrological models requires good knowledge of the catchment conditions, in addition to input data sets.

Modelling scenarios — The process of running the calibrated model with measured long-term hydrological data set(s) to obtain long-term estimates of the other hydrological data set(s) that were not measured (e.g. to generate long-term streamflow from 100 years of measured rainfall data) to:

- provide an historical insight of the hydrological condition of the catchment
- assess the probable impacts of various changes (natural and human influenced), that had occurred in the past, on the catchment hydrology
- assess the impacts of possible future developments and changes on catchment hydrology and in this case
- simulate run-off for the ungauged sub-catchments A2, A3 and A4.

4.2 METHODOLOGY

WaterCress (Cresswell 2002), a PC-based water balance modelling platform was used for construction of the model in this study. This modelling platform incorporates some of the most widely used models in Australia (AWBM, SFB, HYDROLOG, and WC1). WC1 (App. G) is a water balance model that was used to construct and calibrate models for various catchments in South Australia and hence was used in this study. WaterCress allows the incorporation of different components in its water balance models. Some of components that can be incorporated are:

- Demand Components — includes town and rural demands
- Catchment Components — includes rural and urban catchments
- Storage Components — includes reservoir, aquifer, tank, and off-stream dam
- Treatment components — includes sewage treatment works and wetlands
- Transfer Components — includes weir and routing component.

A model is then constructed as a series of ‘nodes’, each node being one of the components mentioned above. The nodes are then linked based on the drainage direction to form one major catchment.

4.3 MODEL CONSTRUCTION

4.3.1 MODEL NODES

The Upper Angas (A1) sub-catchment was divided (as explained in the earlier section on catchment subdivision) into 58 farm dam sub-catchments. The model was then set up as a series of rural catchment nodes followed by off-stream dam nodes, with a routing node added to the end of the catchment. Each rural catchment node in the model represents a farm dam sub-catchment within the whole of Upper Angas sub-catchment (Map 10). Each off-stream dam node in the model represents an individual dam or accumulation of dams within that farm dam sub-catchment.

4.3.2 CATCHMENT NODE INPUTS

The input data for each rural catchment node were:

- Area of the minor sub-catchment representing that node.
- Corresponding observed daily rainfall data set, rainfall factor and monthly evaporation data set.
- Model to be used, which was WC1 in this case and the initial estimated values for the catchment parameter set (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).
- Calibration file, which contains the observed daily rainfall data set and corresponding observed streamflow data set for the node that has the gauging station. Since streamflow data from only one gauging site was used is this study, the calibration file was included in only one node in the Upper Angas sub-catchment model.

4.3.3 DAM NODE INPUTS

Each catchment node with farm dams was then linked to an off-stream dam node (Map 10). The input data for each off-stream dam node were:

- Dam storage volume, which in this case was the cumulative storage capacity of all the dams in the minor sub-catchment.
- Corresponding measured daily rainfall data set, rainfall factor and monthly evaporation data set.
- Dam capacity to dam surface area relationship.
- Maximum daily diversion to the dam, which in this case was the maximum capacity of the dam.
- Fraction of total catchment run-off diverted to the dam. This is dependent on the location of the dam(s) and the probable catchment run-off captured by the dam(s). For example, this fraction was 1.0 if there was a large on-stream dam located on the downstream end of the catchment, as it would be a controlling dam that is deemed to control or block the run-off from the entire sub-catchment. This fraction was reduced when the total catchment storage was made up of numerous smaller dams spread throughout the catchment or when the dams were truly off-stream.
- Water usage from the dams which, due to lack of further information, was assumed to be 30% of the total dam capacity, on an annual basis. This rate of water usage was found to allow for some carry over of storage to following years in previously calibrated models for other catchments in the Mount Lofty Ranges. A recent study of over 700 dams across the ranges supports this figure of 30% as an average water use from farm dams. (McMurray 2003).

The whole of the Upper Angas sub-catchment was therefore represented as a series of rural catchment nodes and off-stream dam nodes, followed in the end by a routing node, that were all connected based on the catchment's drainage pattern. Refer to Appendix F for details on the catchment and off-stream dam nodes in the model.

4.3.4 RAINFALL SPATIAL VARIABILITY

Since rainfall varies spatially within a catchment, its variability has to be accounted for in the input data of each node. Spatial variability of rainfall in the Upper Angas sub-catchment was accounted for by using a rainfall factor for each node derived from daily rainfall data set from the BoM station at Macclesfield and the average annual rainfall for each farm dam catchment calculated using GIS. The rainfall factor for each node was calculated as the ratio of the average annual rainfall for each farm dam catchment representing that node to the average annual rainfall at the Macclesfield BoM station. The rainfall factors used for all the sub-catchments are listed in Appendix F.

4.4 MODEL CALIBRATION

Long-term data generally provide a good basis for calibration of any model as the data set would reflect a wider range of data, and in particular the extremities. In case of catchment rainfall-run-off modelling, long-term (10–20 years at the least) rainfall and streamflow data provide this basis as they probably would represent a wider range of catchment conditions including high rainfall years, flood events, a series of drought years, change in land use pattern and change in other catchment conditions. But, as with many other catchments, long-term and good-quality streamflow records are not available for the Upper Angas sub-catchment. The catchment model was therefore calibrated to streamflow data available for just four years (1996–99). This is not ideal and, as a result, caution should be used when interpreting or assessing the results of the model and the results of the management scenarios presented in this study.

4.4.1 CALIBRATION METHOD

The calibration process involves keeping recorded data (daily rainfall, daily streamflow, monthly evaporation, dam capacities) as constants and iteratively varying the other catchment parameters until a ‘good correlation’ is obtained between the measured and simulated data sets, which in this study was daily streamflow data.

‘Good correlation’ in this study involved visual and statistical comparison of observed and modelled streamflow data sets on daily, monthly and annual time scales, as well as comparison of daily flow frequency data. Statistical examination involved examining the correlation statistics (i.e. Co-efficient of Determination (R^2) and the Co-efficient of Efficiency (Ce)) for each iteration. While R^2 indicates the extent of correlation between two data sets, it does not indicate the extent of closeness between the data sets. Ce is sensitive to actual differences in values of the two data sets and, hence, the extent of closeness of the two data sets. Ce is therefore considered a better comparison tool.

4.4.2 CALIBRATION RESULTS

The Upper Angas sub-catchment model was calibrated to the daily streamflow data for the period between 1/1/1996 and 31/12/1999. The values used for the parameters in the catchment model are listed in Appendix G. The correlation statistics of calibration are shown in Table 9.

Table 9. Model calibration results

Time scale	R^2	Coefficient of efficiency	Mean flow (ML)		% Volume difference
			Measured	*Modelled*	
Annual	0.98	0.77	3092	2820	8.8
Monthly	0.90	0.75	257	238	8.8
Daily	0.78	0.61	4.51	4.11	9.2

The R^2 and Ce statistics for three different time scales shown in Table 9 indicate a good correlation between the observed and modelled data, given that only four years of streamflow data were available for calibration.

As shown in Table 9, correlation at daily time scale is low in comparison to annual and monthly correlations due to the usual difficulties faced in simulating individual streamflow events during particular seasons:

- Summer events, which are more rainfall-intensity driven while the data input is only in daily time scale.
- Late spring events, which are mostly baseflow driven, that are primarily ground water dependent. The events are generally difficult to be modelled to a great degree of accuracy due to the complex nature of surface – groundwater interactions.
- Late autumn – early winter events, which are the 'break-of-season' events. This is the period when the initial wetting-up followed by saturation of soil happens, and the first run-off events from various parts of the catchment start to occur.

These difficulties are reflected in the next two plots (Figs 7, 8) and discussed in the following sections.

Figure 7 shows the plot of daily flow durations of observed and modelled streamflow data. The plot indicates that the model simulates most of the flow range satisfactorily except for flows below 0.5 ML/d. As discussed earlier, these are the late spring baseflow events that are usually difficult to be modelled accurately.

Figure 8 shows the plot of the mean observed and modelled monthly flows, and the correlation between them for the period 1996–99. As discussed earlier in this section, the plot indicates that the model simulates winter flows much better than the summer, late spring and autumn events. The correlations (R^2) for the winter months (July to November) are in the high 0.9s, while the lowest are for the late autumn – early winter months of May and June.

Hence, caution is required when using modelled low flows from this and later sections of the report.

4.4.3 CALIBRATION IMPROVEMENT

As with most hydrological models, simulation of late autumn 'break-of-season' events, summer events and late season baseflows could probably be improved by using:

- rainfall intensity data rather than daily rainfall data
- long-term and good quality gauged streamflow data in preference to the four years of gauged streamflow data used in this study, and

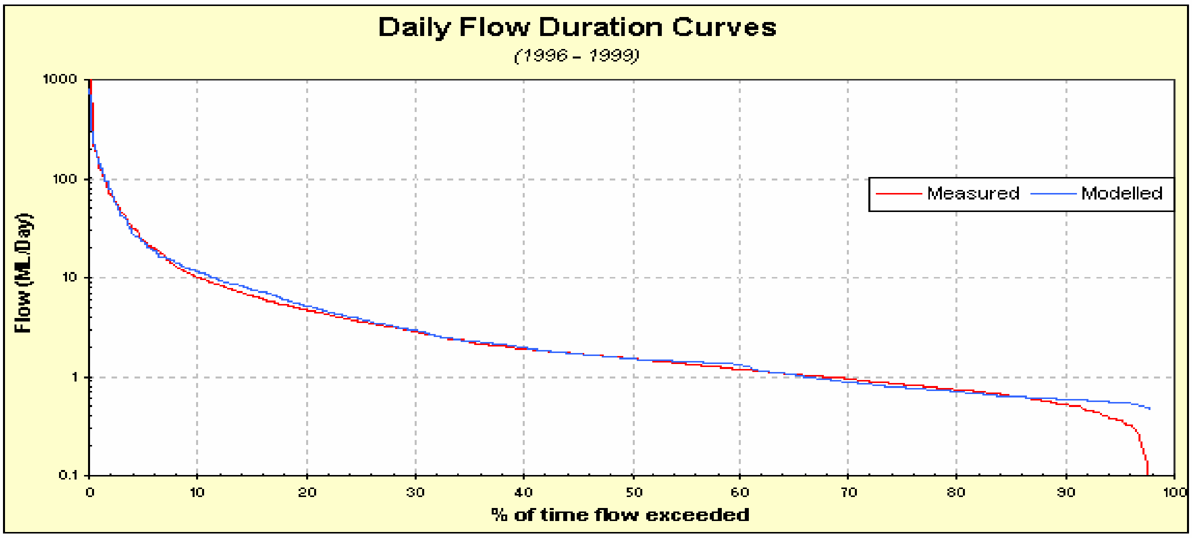


Figure 7. Observed and modelled daily flow frequency curves for Upper Angas sub-catchment

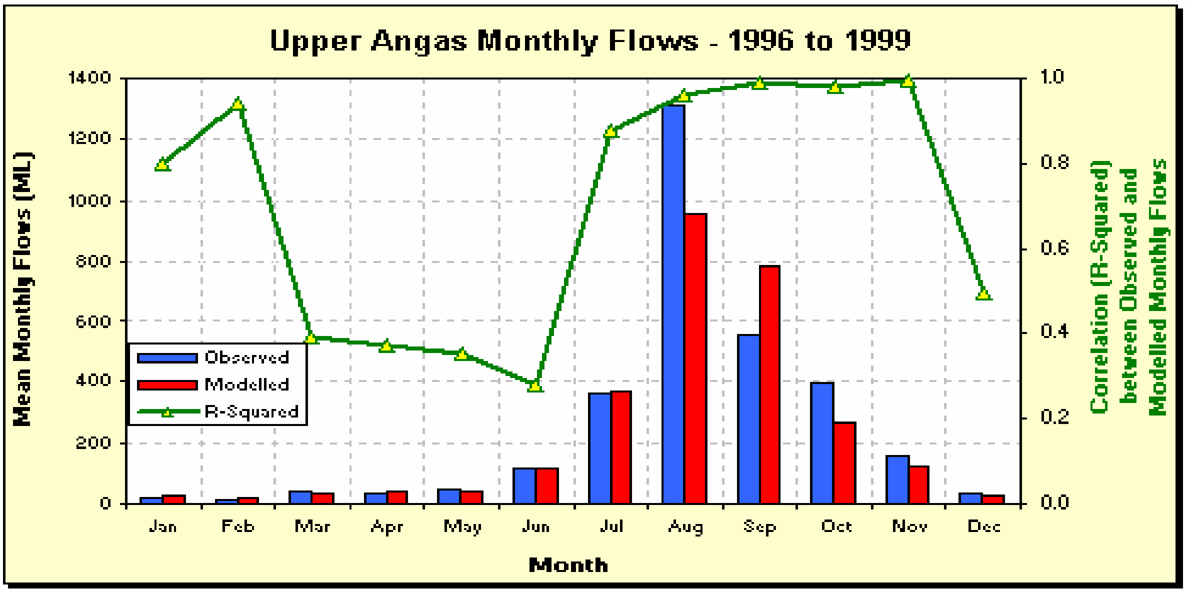


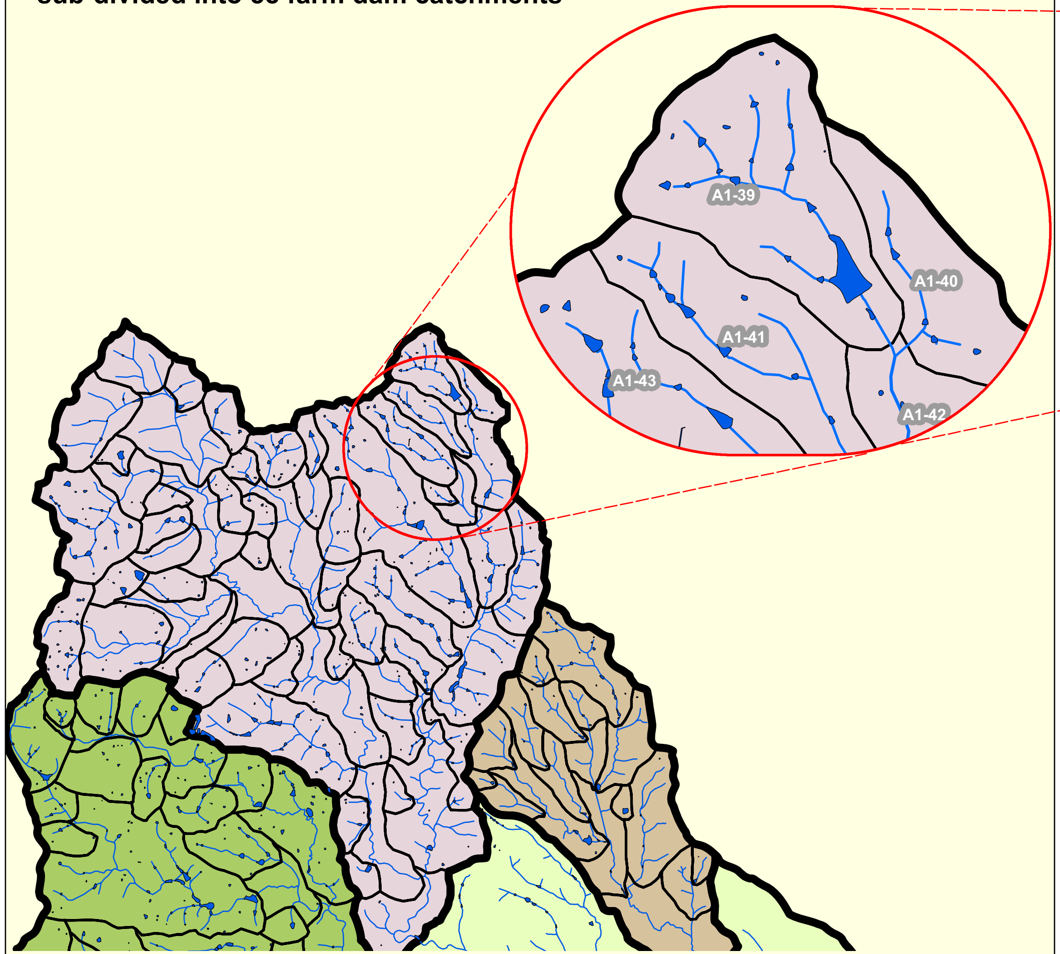
Figure 8. Monthly flows — correlation between observed and modelled data

- a better understanding of the hydrogeology of the catchment and the surface – groundwater interaction within the catchment.

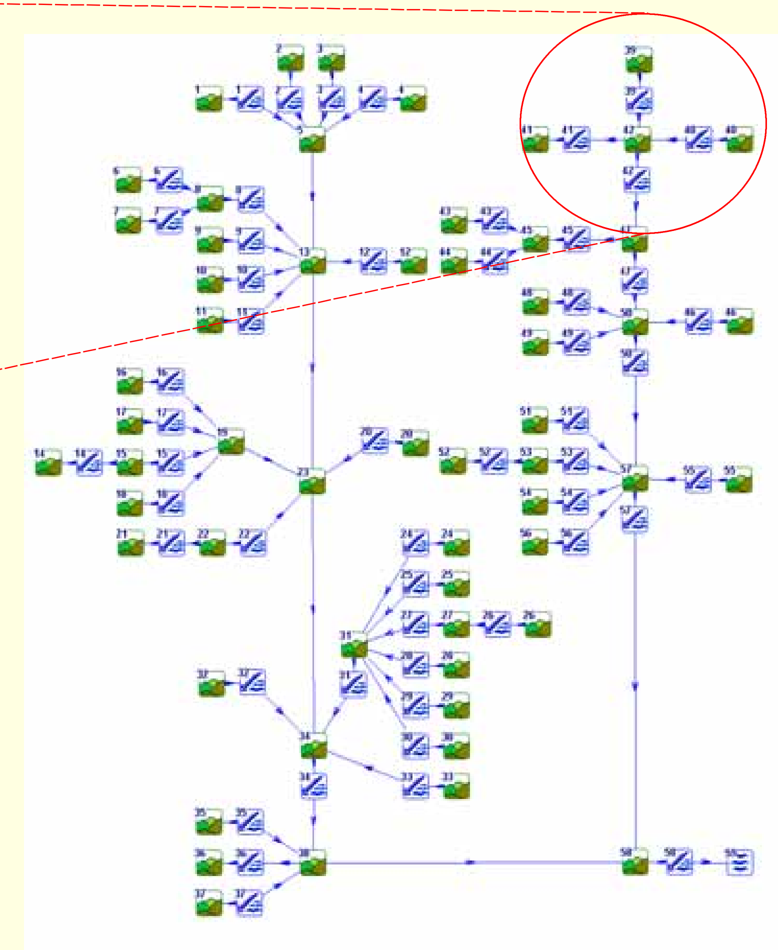
These factors would lead to better input data and possibly better calibration of the run-off events. But such data, particularly rainfall and evaporation, are limited in availability, which in turn limits the ability to accurately assess the long-term sustainability of all catchment resources. However, as the primary objective of this study was to quantify and assess the overall surface water resources within the catchment, the potential errors at the extremes of the flow range are not seen as critical. The calibrated catchment model was therefore considered suitable for further modelling of scenarios in this study, the results of which are presented in the next section.

Map 10. Upper Angas Sub-catchment - Model Layout

The Upper Angas sub-catchment was sub-divided into 58 farm dam catchments



Representation of farm dam catchments and farm dams as nodes in the model



A1-1, A1-2, ...A1-58 - Farm dam catchments within the Upper Angas sub-catchment

Farm Dams (2001)

Streams

N
W E
S

0 1 2 3 Km

Datum GDA 94
Map projection MGA Zone 54

Projection: Map Grid of Australia 1994 (UTM)
Datum: Geocentric Datum of Australia 1994
Date: June 2006

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

Produced by the Resource Investigations Group, Knowledge and Information Division.

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

5. SCENARIO MODELLING

The calibrated hydrological model of the Upper Angas sub-catchment was used to simulate:

- run-off from three neighbouring ungauged sub-catchments — Middle Creek, Dawson Creek and Burnside Creek
- different farm dam development scenarios in the four sub-catchments.

The purpose of simulating the dam development scenarios was to quantify their impacts (current and possible future) on catchment run-off. The dam development scenarios modelled were:

- Current scenario — generation of long-term streamflow data with the current levels of farm dam development for the gauged sub-catchment and the three hydrologically similar ungauged sub-catchments.
- Pre-farm dam development scenario — estimation of the impact of current farm dams on catchment hydrology.
- Future scenarios — (1) farm dam development to RMCWMP limits, without diversion limits. (2) farm dam development to RMCWMP limits, with diversion limits.

Estimation of impact of farm dams on catchment hydrology in this study was carried out differently to studies done in the past for other catchments in the region. In the previous studies, the impact of farm dams was determined for the period of observed streamflow records, as relatively good quality long-term (10–20 years) streamflow records were available for those catchments. Since long-term observed streamflow records are not available for the Upper Angas sub-catchment, the impacts in this study were determined using long-term modelled streamflow data.

Since rainfall data are available from 1885 onwards, the calibrated model was used to generate stream flow data from 1885. But for further analysis purposes, modelled streamflow data only for the period 1974–2003 were used in this study because:

- The longest observed streamflow data sets available for gauged catchments in the EMLR are generally for the last three decades. Hence, for consistency of assessment and defining development limits across catchments in the region, it was considered appropriate to use modelled data for the last three decades rather than data from 1885.
- Decadal rainfall data for this catchment and others in the EMLR suggest that the last few decades in the 1800s and the first few decades in the 1900s were wetter than the later periods. Using development limits based on streamflow data generated from long-term rainfall data would possibly lead to over allocation of the resources.

Hence, 'long-term data' from this section onwards refers to modelled data for the period 1974–2003.

5.1 CURRENT SCENARIO

As discussed in the earlier section on streamflow, streamflow data are available for only one (Upper Angas) of the six sub-catchments in the Angas River Catchment. Moreover, further verification of the quality of the data resulted in only four years of data being usable for assessment. Hence, long-term streamflow data for the Upper Angas sub-catchment was generated using the calibrated model for further analysis.

5.1.1 METHODLOGY

The Middle Creek, Dawson Creek and Burnside Creek sub-catchments are located in the 'hills zone' of the Angas River Catchment. It is recognised that each sub-catchment is hydro-geologically unique. But for rainfall-run-off modelling, those three sub-catchments were considered to be more similar to the Upper Angas sub-catchment in comparison to the other two sub-catchments in the 'transition zone' and 'plains zone'. The model parameters used for calibrating the Upper Angas sub-catchment were therefore used to generate streamflow data for those three ungauged sub-catchments. Since the Middle Angas (in the 'transition zone') and Lower Angas (in the 'plains zone') sub-catchments were not considered to be hydrologically similar to the Upper Angas, the Upper Angas model parameters were not used to generate streamflow data for them.

Farm dam capacities based on 2001 data were used for modelling the catchments current scenario. Hence, streamflow data generated for the period 1974–2003 include the impact of dams present during the year 2001. It is recognised that farm dam development during the period 1974–2003 would have been varied but, since farm dam data are not available for other years during that period, 2001 data were used. This, while a simplification, was adopted solely because it provides a consistent method of assessment across studies done in other catchments in the region. While the study acknowledges the fact that catchment hydrology is influenced by various catchment parameters, data related to many of these parameters are largely unknown at this stage.

5.1.2 MODELLED STREAMFLOW DATA

Streamflow data generated for the four sub-catchments in the 'hills zone' and further analysis of the data are presented in this section of the report.

Annual Flows

The short-term observed and long-term modelled annual run-off data for the Upper Angas (A1) sub-catchment are listed in Table 10.

Table 10. Annual streamflow data for the Upper Angas (A1) sub-catchment

Hydrological parameters	Modelled long-term data *(for the period 1974–2003)*	Observed data *(for the period 1996–2003)*
Mean annual flow (ML (mm))	6082 (101)	3425 (57)
Median annual flow (ML (mm))	5271 (88)	2672 (45)
Run-off coefficient	0.14	0.09
Mean annual rainfall (mm)[1]	680	627

1 Mean annual rainfall calculated from observed (and not modelled) data in both cases.

As listed in Table 10, the 'long-term' observed annual average rainfall and the modelled annual run-off are much higher than the 'short-term' observed data. Although the long-term streamflow data are 'simulated', they were considered to better represent the catchment conditions than the short-term 'observed' data. Hence, they were used for further assessment purposes in this study.

Streamflow data for the Middle Creek, Dawson Creek and Burnside Creek sub-catchments were then simulated using:

- the corresponding annual rainfall values for the individual farm dam sub-catchments
- farm dam data for the farm dam catchments
- the same set of model parameters used for the Upper Angas sub-catchment.

Table 11 lists the modelled annual flows, rainfall and run-off coefficient for the four major sub-catchments.

Table 11. Modelled annual streamflow data for Angas River sub-catchments

Hydrological parameters	Upper Angas (A1)	Middle Creek (A2)	Dawson Creek (A3)	Burnside Creek (A4)
Mean annual flow* (ML (mm))	6082 (101)	4194 (105)	1532 (77)	667 (42)
Median annual flow* (ML (mm))	5271 (88)	3653 (91)	1278 (64)	513 (32)
Run-off coefficient	0.14	0.15	0.12	0.07
Catchment area (km^2)	60	40	20	16
Mean annual rain (mm)	680	684	617	536

* Modelled data for the period 1974–2003.

The Upper Angas and Middle Creek sub-catchments are comparatively high rainfall sub-catchments, generating similar annual run-offs (100 mm). Burnside Creek receives the lowest rainfall among the four sub-catchments and generates the lowest annual run-off (42 mm).

As discussed in Section 2.4.3, the run-off coefficients for the sub-catchments A1, A2 and A3 are much higher than 0.10, which was used in determining the development limits in the RMCWMP. This results in the development limits being higher than the ones in the RMCWMP and is discussed further in the next section of this report.

The rainfall-run-off curve (Fig. 9) shows the annual rainfall values plotted against the modelled annual run-off for the four major sub-catchments for the period 1974–2003. While a distinct curve for each sub-catchment would be ideal, streamflow data are available for only one sub-catchment. The same set of catchment model parameters were therefore used for all the four sub-catchments. Hence, one rainfall-run-off curve was fitted to all four sub-catchments. The higher and middle portions of the curve represent the high rainfall sub-catchments of Upper Angas and Middle Creek (red and blue dot points). The middle and lower portions of the curve represent the lower rainfall sub-catchments of Dawson Creek and Burnside Creek (green and yellow dot points). The lowest section of curve mostly represents Burnside Creek (green data points), and also the low rainfall years of the other catchments.

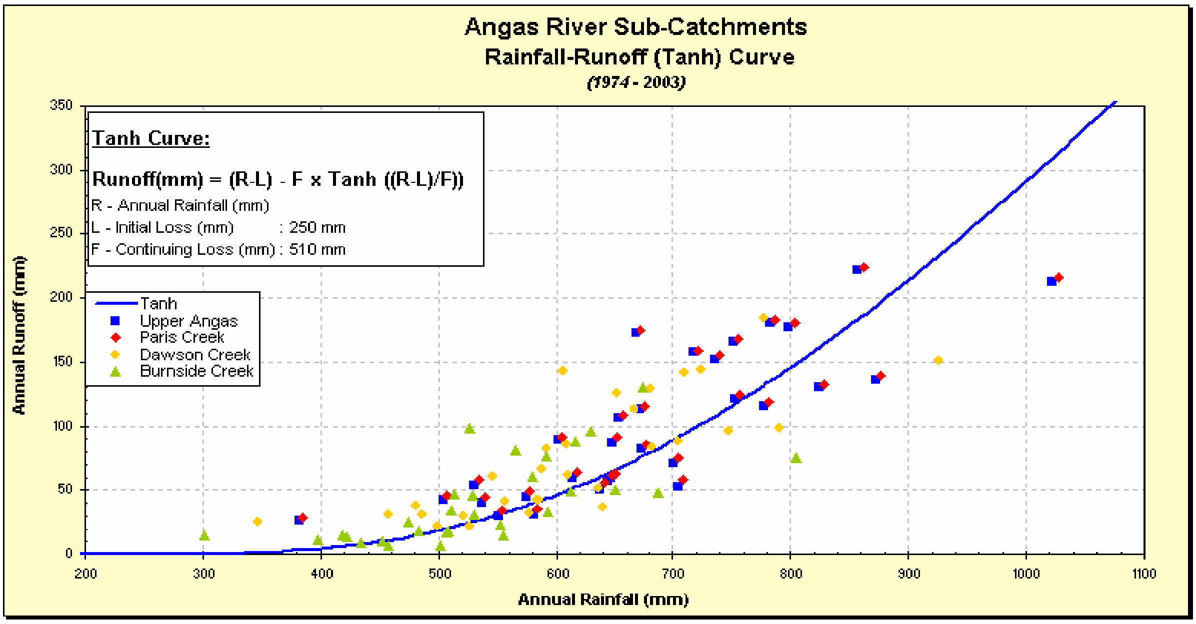


Figure 9. Annual rainfall-run-off curve

Winter Flows

Winter flows (May to November) were calculated from modelled data for the four major sub-catchments (Table 12), as the RMCWMP's development policies are based on winter rather than annual flows.

Table 12. Modelled winter streamflow data for Angas River sub-catchments

Catchment characteristics	Upper Angas (A1)	Middle Creek (A2)	Dawson Creek (A3)	Burnside Creek (A4)
Mean winter flow (ML (mm))*	5620 (94)	3955 (99)	1418 (71)	632 (40)
Median winter flow (ML (mm))*	4894 (82)	3544 (89)	1190 (60)	446 (31)
Run-off coefficient	0.18	0.19	0.15	0.10
Catchment area (km^2)	60	40	20	16
Mean winter rain (mm)	520	523	472	410

* Modelled flows for the period 1974–2003.

Comparison of annual and winter flows (Tables 11, 12) for the sub-catchments indicates that more than 90% of the annual run-off occurs in winter. In comparison, only ~75% of the annual rainfall occurs in winter. This indicates the higher losses during summer, which is demonstrated in the annual and winter rainfall-run-off curves (Figs 9, 10) and further discussed below.

The rainfall-run-off curve for the winter season (May to November) is shown in Figure 10. Comparison of the parameters used in determining the annual and winter rainfall-run-off relationships indicates:

- The initial loss parameter is 175 mm for winter in comparison to 250 mm for annual run-off. This indicates the higher losses during summer that could be attributed to the 'wetting-up' period followed by the filling-up of dams, before run-off occurs in the catchment.

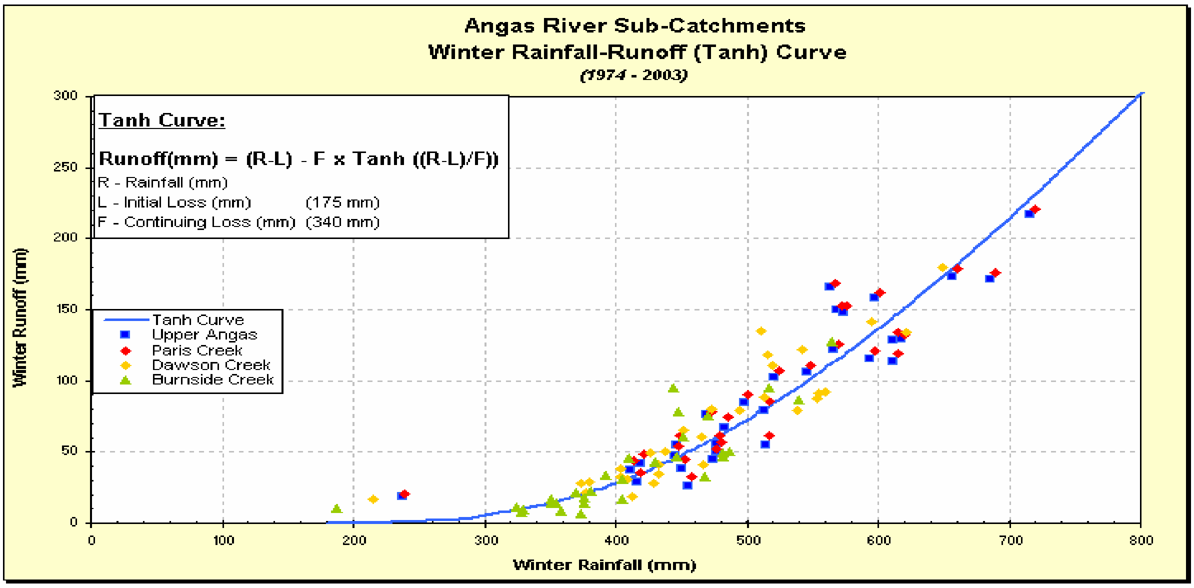


Figure 10. Winter rainfall-run-off curve

- The continuing loss is also less for winter in comparison to annual data due to the higher rainfall, run-off and run-off coefficient during winter.

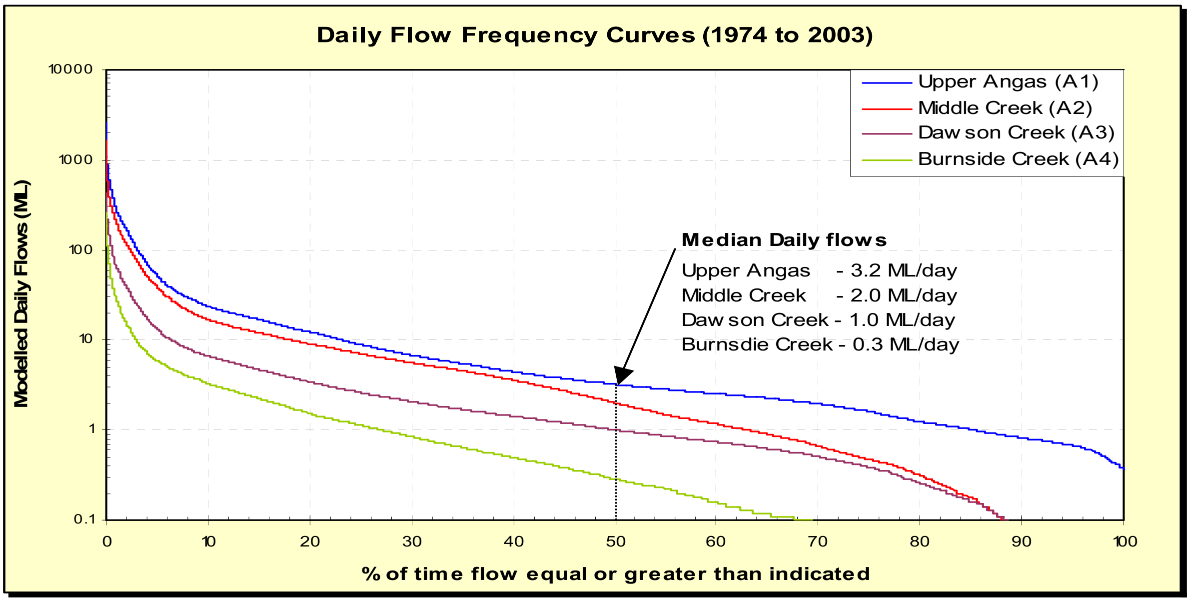
Daily Flows

Daily flow frequency analysis is a simple but effective method of analysing daily flows and, hence, the flow regimes within a catchment. Figure 11 shows the daily flow frequency curves for the four Angas River sub-catchments. This was plotted with modelled daily flow data for the period 1974–2003.

Flow frequencies are defined as the percentages of time during the period of record the flows equalled or exceeded various rates. It can also be interpreted as, the percentage of time in an average year, during which different daily flows would occur. For example, as can be interpreted from Figure 11, daily flows of 10 ML or higher in the Upper Angas sub-catchment would occur for ~23% of the time (around 85 days) in an average year. This decreases across the other three sub-catchments, with modelled data for Burnside Creek indicating that such flows would occur for only 3% of the time (around 11 days) in an average year. The chart also shows a median daily flow of 3.2 ML for the Upper Angas sub-catchment (i.e. a flow of 3.2 ML/d would occur at least 50% of the time during an average year). This value also decreases across the other three sub-catchments, with data for Burnside Creek indicating a low value of 0.3 ML/d.

The flow frequencies of different flow ranges in the four Angas River sub-catchments are provided in Table 13. Data presented in the table indicate that in an average year:

- the Upper Angas sub-catchment flows throughout the year, while Burnside Creek sub-catchment would flow for only 69% of the year (253 days)
- while the Upper Angas and Middle Creek sub-catchments have similar medium and high flows, the Upper Angas has a higher low flow (80th and 90th percentiles) regime



* modelled low flows to be used with caution. Refer text below for details

Figure 11. Daily flow frequency curves for Angas River sub-catchments

Table 13. Daily flow frequencies for Angas River sub-catchments

Sub-catchment	Frequencies of daily flows (% of year (no. of days))				
	*≥0.1 ML/d**	*≥1 ML/d*	*≥10 ML/d*	*≥100 ML/d*	*≥1000 ML/d*
Upper Angas (A1)	100 (365)	85 (312)	23 (84)	3 (11)	0.09 (8 hours)
Middle Creek (A2)	88 (323)	63 (230)	18 (66)	2 (9)	0.03 (2 hours)
Dawson Creek (A3)	88 (323)	50 (183)	6 (24)	0.6 (2.1)	0 (0)
Burnside Creek (A4)	69 (253)	27 (99)	3 (11)	0.2 (14 hours)	0 (0)

* Modelled low flows to be used with caution. Refer to text below for details.

- while the Middle Creek and Dawson Creek sub-catchments have similar low flow regimes, Middle Creek has much higher flows (up to 10th percentile)
- the Upper Angas and Middle Creek generate much higher flows (>100 ML/d) in comparison to the Dawson and Burnside Creek sub-catchments.

Caution is required when using the results of low or baseflow (from 80th percentile onwards) analysis indicated in Figure 11 and Table 13 due to the limitations in modelling the low flows. Further discussion of modelled low flows is presented in the next section.

5.1.3 SUMMER BASEFLOWS

The modelled data presented in the previous section indicate that streamflows in the Middle Creek, Dawson Creek and Burnside Creek occur for around 90%, 90% and 70%, respectively, of the time during a normal year. This could be an overestimate due to the following reasons:

- The rainfall-run-off model calibrated for the Upper Angas sub-catchment overestimates low flows (<0.5 ML/d), as indicated in Section 4.2.2. The same set of parameters used for calibrating the Upper Angas model was used to model run-off from the Middle Creek, Dawson Creek and Burnside Creek sub-catchments. Hence, it can be assumed that the low flows and summer baseflows for those three sub-catchments are also probably overestimated.

- To verify the status of summer baseflows in the different sub-catchments, a visit to the catchment was made on 19 April 2005. Some of the observations during the visit were:
  - Within the Upper Angas sub-catchment, streamflow (summer baseflow) was observed only in the section of the main Angas River extending downstream of Macclesfield and flowing into Strathalbyn (Fig. 12). No flow was observed in Doctors Creek, which flows into the main Angas River.
  - No flow was observed at the outlet of the Middle Creek (A2), Dawson Creek (A3) and Burnside Creek (A4) sub-catchments.

These observations, and information obtained from landholders during the field visit, indicate that the Middle Creek, Dawson Creek and Burnside Creek sub-catchments have a very low summer baseflow component. Hence, the streams in those three major sub-catchments could be flowing for a lesser duration than indicated earlier by the results of modelling.

Further investigations are required to identify the actual source (spring and/or groundwater) and location from where the summer baseflows are generated within the Upper Angas sub-catchment.

Steamflow monitoring in the Middle Creek, Dawson Creek and Burnside Creek sub-catchments would validate the model and enhance confidence in its results.

Figure 12. Baseflow in the Main Angas River (19 April 2005)

5.2 PRE-FARM DAM DEVELOPMENT SCENARIO

This section looks at the possible impacts of the current (2001) level of farm dam development on catchment run-off.

5.2.1 METHODOLOGY

To assess the impact of dams on catchment run-off, the run-off generated in the absence of dams was estimated. This involved:

- Removing the farm dams from the models set up for the four major sub-catchments and generating long-term run-off data. The run-off generated under this scenario is termed as the ‘pre-farm dam development run-off’ or ‘without dams’ or ‘no dams’ scenario run-off.
- Determining the difference between the run-offs generated from this scenario and the ‘current’ or ‘with dams’ scenario. The difference is the potential run-off captured or trapped by the dams.

5.2.2 RESULTS AND DISCUSSION

The flow data generated under this scenario were then analysed on annual, monthly, seasonal and daily time scales, the results of which are presented in the following sections.

Annual Flows

The average annual run-off generated by the model the Upper Angas sub-catchment without the dams for the period 1974–2003 is 7087 ML. This is ~1000 ML more then the average annual run-off modelled with the dams. This equates to a 14% reduction of the average annual run-off by farm dams. As shown in Figure 13, the impact varies annually with rainfall, impacting higher during drier years while having a minimal impact during wetter years. For example, a dry year like 1982 (with 380 mm of rain) would potentially have annual flows reduced by 39%, while a wet year like 1992 (with 1020 mm of rain) would potentially have annual flows reduced by just 6%.

The potential impacts of farm dams in other sub-catchments were analysed similarly and the results are presented in Table 14.

Table 14. Potential reduction of annual flows by farm dams (1974–2003)

Sub-catchment	Mean annual rainfall (mm)	Dam density (ML/km^2)	Modelled mean annual run-off (ML)		Reduction in mean annual run-off (%)
			With dams	*Without dams*	
Upper Angas (A1)	680	23.3	6082	7087	14
Middle Creek (A2)	684	18.0	4194	4736	11
Dawson Creek (A3)	616	8.7	1532	1672	8
Burnside Creek (A4)	536	7.7	667	764	13

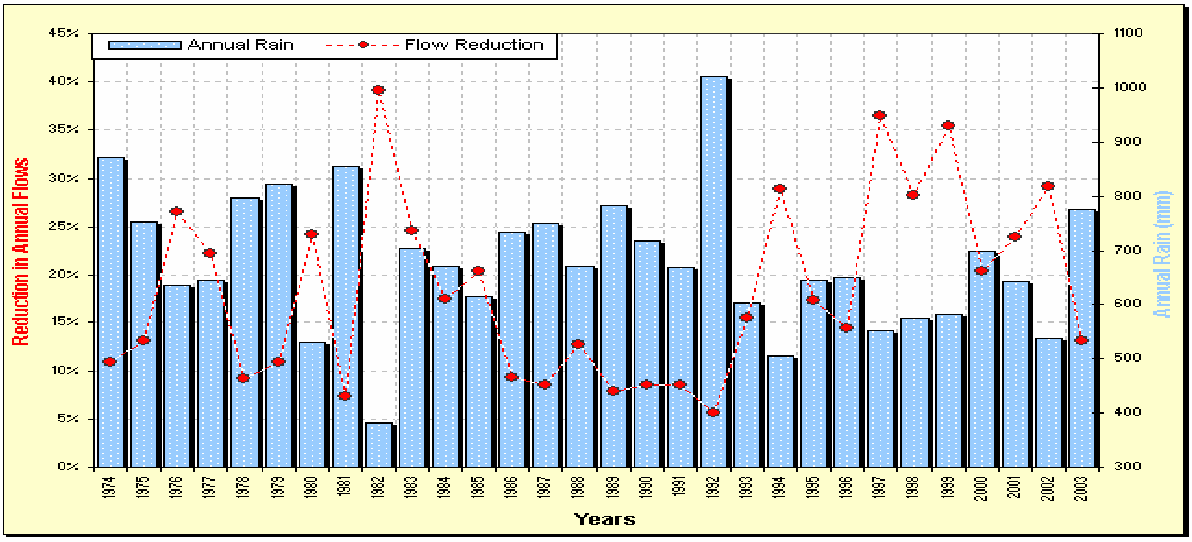


Figure 13. Reduction of annual flows by farm dams in the Upper Angas sub-catchment

As shown in Table 14, the impact of dams on catchment flows is directly related to farm dam density and rainfall. For example:

- while the annual rainfall for Upper Angas and Middle Creek are similar, flow reduction by dams in the Upper Angas is much higher due its higher farm dam density
- while the farm dam densities of Dawson Creek and Burnside Creek are similar, the impact of dams in Burnside Creek is much higher due to its lower annual rainfall.

The annual rainfalls and corresponding modelled run-offs without the dams for the four major sub-catchments were plotted and a rainfall-run-off (Tanh) curve was fitted (Fig. 14). The Tanh curve 'with dams' was also plotted in the same chart to indicate the difference in flows generated under the two scenarios.

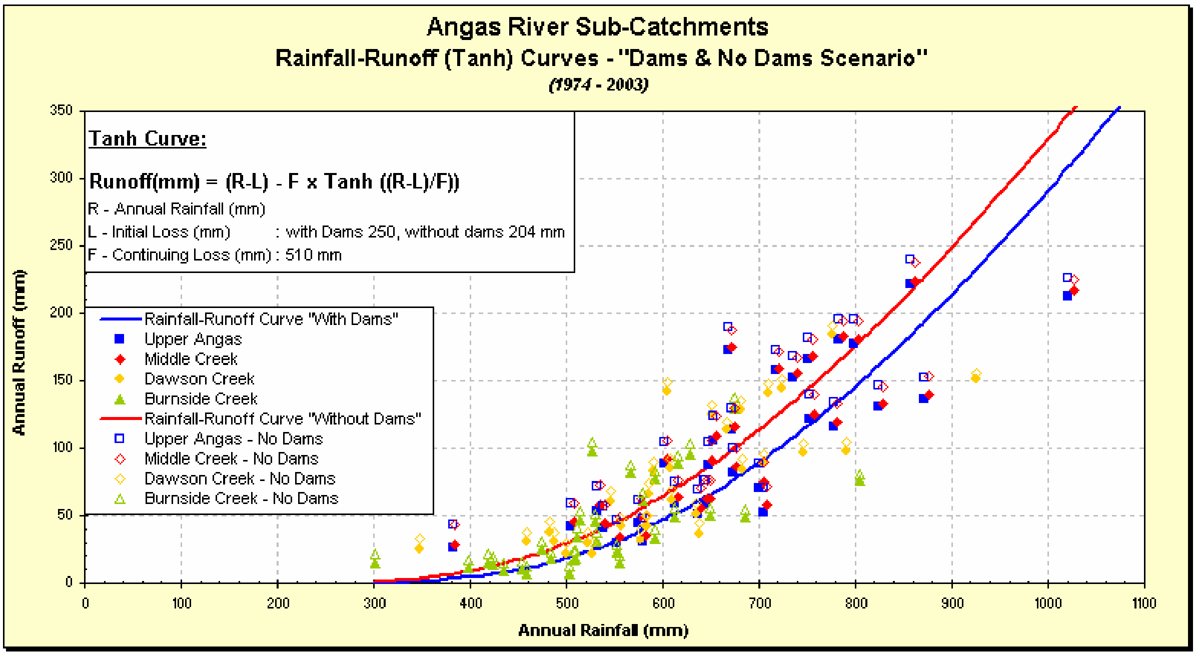


Figure 14. Annual rainfall-run-off curves — 'with and without dams'

Some of the main observations from the two rainfall-run-off relationships shown in Figure 14 are:

- The initial loss parameter for the ‘with dams’ scenario is 46 mm higher than that for the ‘without dams’ scenario. This indicates that, for a given annual rainfall, run-off will start earlier if the dams did not exist. The higher initial loss in the ‘with dams’ scenario is attributed to the water captured by the dams before run-off starts to occur.
- On initial observation, the gap between the two curves in Figure 14 appears to be wider for higher rainfall values. But, the actual percentage difference between flows decreases as rainfall increases. For example, the difference in run-offs from the two scenarios for 400 mm rainfall is 54%, while it is only 17% for 800 mm rainfall. The data generated from the two scenarios indicate that the difference in run-off decreases progressively with increasing rainfall. This re-emphasises the fact that the impact of dams is higher in drier catchments and also higher during drier years in wetter catchments.

Monthly Flows

Analysis of flows on a monthly time scale provides a better understanding of the varying impacts of dams on a seasonal basis. Figure 15 shows the mean run-offs modelled with and without the dams, the potential percentage reduction in flows, and the observed mean rainfall data on a monthly basis for the Upper Angas sub-catchment.

As shown in Figure 15, farm dams have minimal impact on catchment flows during winter (July to September). The impact gradually increases from October onwards and the maximum impact is observed in the months of January and February. The impact decreases slowly in the next few months until reaching a minimum in September.

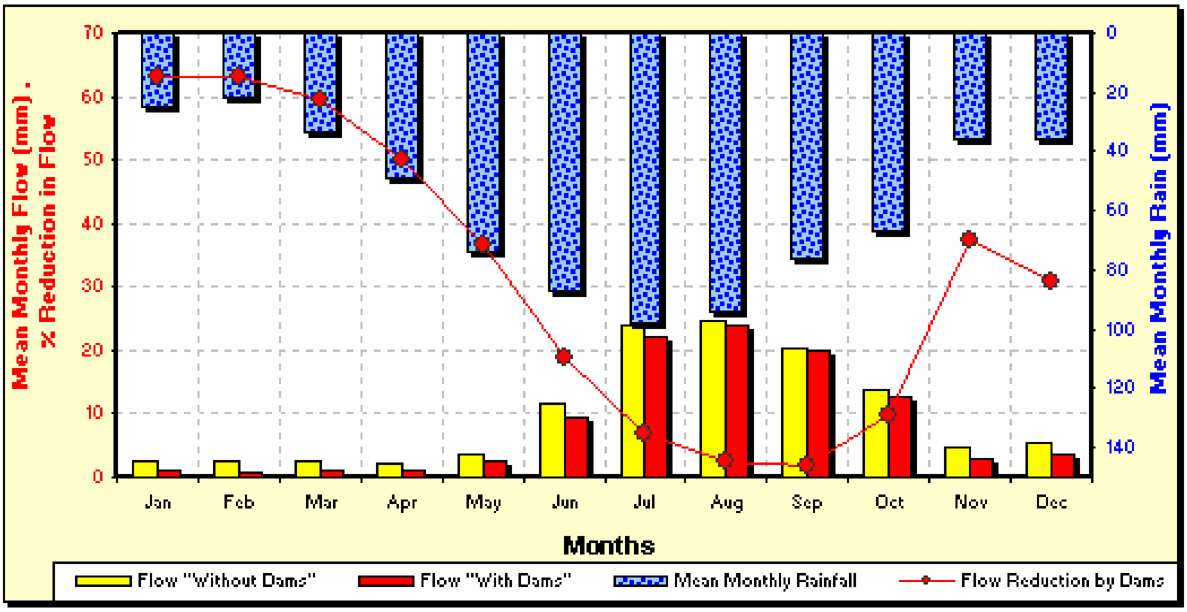


Figure 15. Impact of dams on monthly flows in the Upper Angas sub-catchment

The reasons for the impact of farm dams on a monthly basis can be interpreted as:

- Mid- and late winter (July, August, September and beginning of October) — this is the season when the dams are probably full and spilling. There is also no water pumped from the dams for irrigation during this period. This leads to the catchments being in a 'free-to-flow' state. At this stage, flow from the catchments is not captured by the dams as they spill over. Hence, the impact of dams is minimal during this season.

- Spring and summer (late October to March) — this is the period when rainfall decreases, evaporation increases and pumping from the dams for irrigation gradually increases. This leads to water levels in dams going down, consequently leading to flows passing through them being captured. Hence, the impact of dams on catchment run-off gradually increases from October onwards.
- Autumn and early winter (April to June) — this is the period when the amount of rainfall starts to increase. Combined with lower evaporation and areas of catchment wetted-up, this results in higher run-offs being generated. The whole catchment gradually wets-up and starts contributing to the run-off. While the impacts of dams are higher earlier in this season, it gradually reduces as the dams (starting with the smaller dams and progressively increasing with size) start to fill up and catchments gradually become free-to-flow. This is reflected by the impact of dams gradually reducing to a very minimal in winter.

Seasonal Flows

As mentioned in the earlier section on annual flows, farm dams reduce the average annual run-off in the Upper Angas sub-catchment by 1000 ML. On a seasonal basis, this equates to 555 ML reduction during winter and 445 ML during summer. While the reductions in flows during the two seasons are quantitatively similar, they are completely different when compared to the average flows during the seasons. They account to a low 9% reduction to mean winter flows and to a high 50% reduction to mean summer flows.

While summer flows constitute <10% of the annual flows, they are crucial to the catchment's water-dependent ecosystems. Reduction in summer flows results in the catchment drying up earlier. This leads to delays in the occurrence of the first ('break-of-season') flow events, which is when the ecosystems need the flows most, following the dry summer months. Hence, a potential 50% reduction in summer flows by farm dams would have a high impact on the survival of those ecosystems.

The potential impact of dams on winter flows on a sub-catchment basis is shown in Table 15. Data presented confirm the results presented in Table 14. They indicate that the impact of dams on winter flows is:

- Highest in the Upper Angas sub-catchment due to its high farm dam density (23.3 ML/km^2).
- Lower in the Middle Creek sub-catchment due to its lower farm dam density (18.0 ML/km^2) in comparison to the Upper Angas.
- Lower in the Dawson Creek sub-catchment due its much lower farm dam density (8.7 ML/km^2).
- Highest in the Burnside Creek sub-catchment — while its farm dam density is the lowest (7.7 ML/km^2) of the four sub-catchments, the impact of dams is highest due to the low rainfall it receives.

Table 15. Potential reduction in winter flows by farm dams (1974–2003)

Sub-catchment	Mean winter rainfall (mm)	Modelled mean winter run-off (ML)		Reduction in mean winter run-off (%)
		With dams	*Without dams*	
Upper Angas (A1)	520	5620	6178	9
Middle Creek (A2)	523	3955	4123	4
Dawson Creek (A3)	472	1418	1470	4
Burnside Creek (A4)	410	632	685	8

The winter rainfalls for the period 1974–2003 and the corresponding modelled run-offs generated 'with dams' and 'without the dams' were plotted, and rainfall-run-off (Tanh) curves were fitted as shown in Figure 16. The plot indicates that the two curves are closer in comparison to the annual rainfall curves plotted in Figure 14. This indicates that the impact of dams on winter flows is lower than their impact on an annual basis. This is attributed to the higher percentage of run-off captured by dams during summer than in winter.

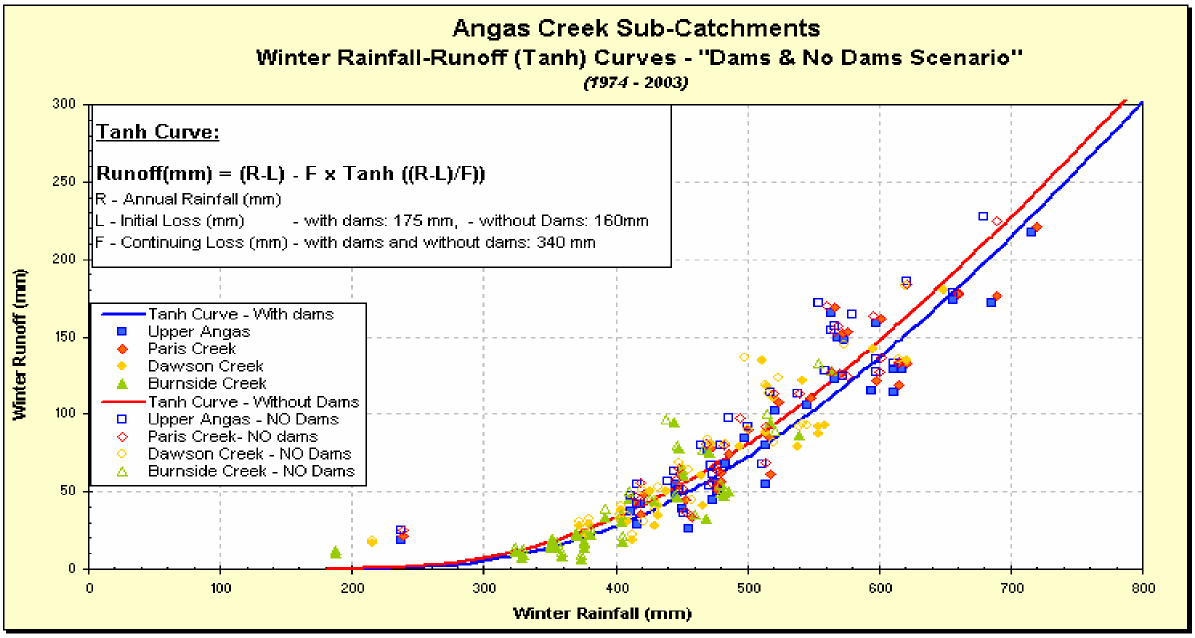
Daily Flows

While changes in monthly flows are useful for examination of seasonal impacts, changes in daily flows provide a better understanding on the impact on the catchment's flow regime. Changes in flow regimes that are relevant to the ecology are generally on a daily basis, and hence analysis of daily flows is crucial for ecological assessment. The impact of farm dams on daily flows can be assessed by comparing the exceedance frequencies of flows 'with' and 'without dams'.

Comparison of daily flows from the two scenarios for the Upper Angas sub-catchment (Fig. 17) indicates a significant increase in the duration of flows ranging from 1–10 ML/d, if the dams did not exist. The difference in durations (or the impact of dams) gradually decreases as the daily flow volume increases. For example, as shown in Table 16, a flow of 5 ML/d would occur for around 100 days more in an average year if the dams were not there. This reduces to 27 and 6 days for flows of 10 and 20 ML/d, respectively.

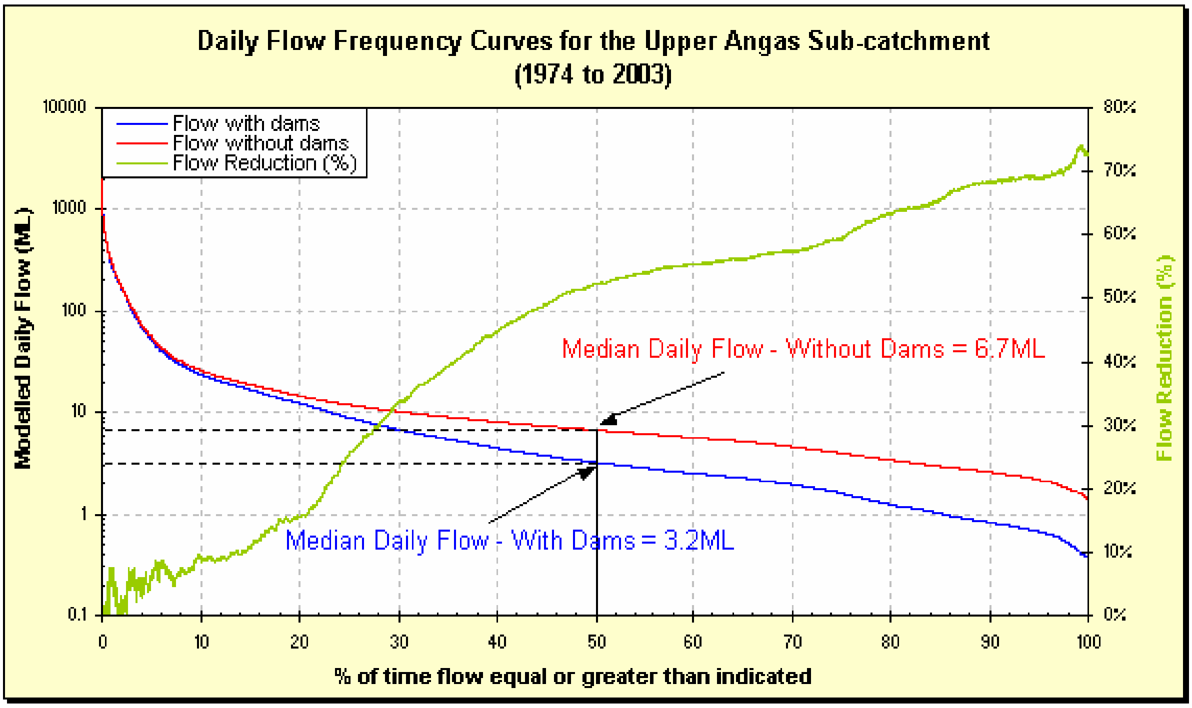
Table 16. Daily flow frequencies for the Upper Angas — 'with and without dams' scenarios

Flow (ML/d)	Number of days in a year that flows are equalled or exceeded		Difference in flow exceedance days
	'With dams'	*'Without dams'*	
≥5	136	243	107
≥10	84	112	28
≥50	19	19.8	0.8
≥100	11.3	11.8	0.5
≥500	1.6	1.5	0.1



*Modelled low flows to be used with caution. Refer Section 5.1.2 for details.

Figure 16. Winter rainfall-run-off curves — 'with and without dams'



* modelled low flows to be used with caution. Refer Section 5.1.2 for details

Figure 17. Comparison of Upper Angas sub-catchment daily flows — 'with and without dams'

This indicates that high flows (>10 ML/d) are not affected much by dams, as the dams gradually fill up when flows increase. This leads to catchments progressively becoming free-to-flow, resulting in negligible impact of dams on flow.

Table 17 lists the daily flows for different flow percentiles for both scenarios. As discussed earlier, the impact of dams decreases as the flow increases, with only 9% impact on higher flows and >50% impact on medium and low flows. The median daily flow (50th percentile) would be more than double if the dams did not exist.

Table 17. Daily flow percentiles for the Upper Angas — 'with and without dams' scenarios

Flow percentile	**Daily flow** (ML)		**Difference in flow** (%)
	'With dams'	*'Without dams'*	
10%	23.7	26.1	9
20%	12.3	14.6	16
50%	3.2	6.7	52
80%	1.2	3.4	63
90%	0.8	2.6	68

The reasons for the reduction in medium and low flows during the last few decades of progressive farm dam development are:

- progressive reduction in the free-to-flow areas within the entire catchment due to streams being blocked by dams, and hence
- progressive reduction in the low and medium flow events, as those would be used to fill up the dams.

The highest impact would be during late autumn – early winter when the rainy season starts and the low and medium flow events start to occur after the initial wetting-up period. This is also the period when the ecosystems would require the flows most, following the earlier drier periods.

Further construction of farm dams could, in future, result in slow but progressive degradation of water-dependent ecosystems. This would start from the downstream areas and progress to the upstream areas of the catchment.

Results of analysis of daily flows under 'with dams' and 'without dams' scenarios for the Middle Creek, Dawson Creek and Burnside Creek sub-catchments are presented in Appendices B, C and D.

5.3 FUTURE SCENARIO 1: FARM DAM DEVELOPMENT TO RMCWMP LIMITS, WITHOUT DIVERSION LIMITS

This scenario refers to increasing the farm dam capacities in the major sub-catchments to the RMCWMP (RMCWMB 2003) allowable development limits, without incorporating diversion rules and assessing their possible impacts on catchment run-off.

The RMCWMP has set allowable limits for surface water development for all the major catchments and sub-catchments in the EMLR. The allowable development limits set in the catchment plan were developed using a run-off coefficient of 0.10 (10% of rainfall runs off) for the entire EMLR. While the run-off coefficient of 0.10 used in the catchment plan represents the estimated average run-off coefficient across the entire EMLR, it varies widely with individual catchments, as does rainfall.

Run-off coefficients for the Upper Angas (A1), Middle Creek (A2), Dawson Creek (A3) and Burnside Creek (A4) sub-catchments were calculated in this study from long-term modelled data. As shown earlier in Table 6, the run-off coefficients for sub-catchments A1, A2 and A3 are higher than the estimated value of 0.10 used in the RMCWMP.

Development limits based on long-term modelled winter run-off were calculated in this study and are listed in Table 18. These were considered more appropriate in comparison to the development limits set in the catchment plan (that were estimated using a run-off coefficient of 0.10). Hence, the term ‘allowable development limits’ in the following sections of this report means the ‘allowable development limits calculated as defined in the RMCWMP, but using modelled winter run-off without the dams for the period 1974–2003’.

Table 18. Extent of current dam development in the Angas River sub-catchments

Sub-catchment	**Average winter run-off[1] without dams** (ML)	**Allowable dam development[2]** (ML)	**Current dam development[3]** (ML)	**Extent of current development[4]** (%)
Upper Angas (A1)	6178	1853	1377	74%
Middle Creek (A2)	4123	1237	705	57%
Dawson Creek (A3)	1470	441	173	40%
Burnside Creek (A4)	684	205	123	60%

1 average winter run-off modelled without dams, for the period 1974–2003

2 30% of long-term winter run-off as defined in the RMCWMP

3 farm dam capacities estimated form 2001 farm dam surveys

4 equals current farm dam capacity divided by allowable development limit

As shown in Table 18, the current farm dam developments in all the four major sub-catchments are below their allowable development limits. Hence, as a future scenario, the Upper Angas (A1) sub-catchment was modelled with farm dam capacities increased to its new development limit and the impact on catchment run-off assessed. Due to limited project timeframes, analyses under this scenario were not undertaken for the other sub-catchments.

5.3.1 METHODOLOGY

The methodology for estimating the impacts of possible future farm dam development involved the following six major steps:

1. Determination of the additional allowable level of development for the Upper Angas (A1) sub-catchment by comparing the current level of dam development to its allowable limit.
    - allowable development limit — 1853 ML.
    - current dam development — 1377 ML.
    - additional allowable development — 476 ML.
2. Proportional distribution of the additional allowable development among different surface water zones[1] (Table 19) within the Upper Angas sub-catchment. This was undertaken as follows:

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[1]Details on the process involved in the subdivision of major sub-catchments into surface water zones are discussed in section 2.2.2 of this report.

Table 19. Surface water zone details for the Upper Angas sub-catchment

Additional Allowable Development: **476** ML

Cumulative runoff1 from unsaturated surface water zones: **5139** ML

NO.	Surface Water Zone	Area (km^2)	Average Annual Rain (mm)	Number of Dams	Cumulative Dam Capacity 2001 (ML)	Dam Density (ML/ km^2)	Winter Rain (mm)	Winter runoff withoutdams[1] (mm)	Winter runoff without dams (ML)	Allowable Development Limit[2] (ML)	Current level of development	% of runoff from unsaturated zones	Additional allowable development[3] (ML)
1	UA-Z1	8.4	668	81	256.1	30.6	528	98.0	820.5	246.1	104.0%	–	0.0
2	UA-Z2	5.0	696	45	209.3	42.2	550	112.3	556.8	167.0	125.3%	–	0.0
3	UA-Z3	3.7	690	46	123.6	33.2	545	109.0	406.0	121.8	101.5%	–	0.0
4	UA-Z4	2.0	644	15	96.1	48.0	509	86.4	172.7	51.8	185.5%	–	0.0
5	UA-Z5	4.6	647	24	27.7	6.0	511	87.6	402.1	120.6	23.0%	7.8%	37.2
6	UA-Z6	5.7	771	15	33.2	5.8	609	154.2	880.8	264.2	12.6%	17.1%	81.6
7	UA-Z7	3.5	787	32	127.6	36.7	622	164.1	570.9	171.3	74.5%	11.1%	52.9
8	UA-Z8	3.3	766	16	35.1	10.7	605	151.2	495.7	148.7	23.6%	9.6%	45.9
9	UA-Z9	5.7	786	48	114.3	19.9	621	163.4	936.4	280.9	40.7%	18.2%	86.7
10	UA-Z10	2.3	752	20	29.5	12.7	594	143.1	332.4	99.7	29.6%	6.5%	30.8
11	UA-Z11	1.4	750	0	0.0	0.0	592	141.7	195.0	58.5	0.0%	3.8%	18.1
12	UA-Z12	5.3	737	47	80.1	15.2	582	134.4	706.2	211.9	37.8%	13.7%	65.4
13	UA-Z13	2.3	707	15	10.9	4.7	559	118.4	275.3	82.6	13.2%	5.4%	25.5
14	UA-Z14	3.0	727	33	199.8	65.9	574	128.8	390.5	117.1	170.6%	0.0%	0.0
15	UA-Z15	2.2	664	8	25.7	11.6	525	96.1	212.2	63.7	40.4%	4.1%	19.7
16	UA-Z16	1.6	634	3	8.4	5.2	501	81.6	132.5	39.8	21.1%	2.6%	12.3

1 calculated using Rainfall-Runoff (Tanh) curve for winter for "without dams" scenario

2 30% of Winter Runoff without the dams (as defined in the River Murray Catchment Water Management Plan)

3 % of runoff generated from unsaturated zone multiplied by additional allowable development for the Upper Angas Sub-catchment (476 ML)

a. Determining for each surface water zone the allowable development limit (ML) = area of surface water zone (km^2) x mean winter run-off[1] for the zone (mm) x 0.30[2].

b. Comparing the allowable development limit to the cumulative capacity of the existing dams in each surface water zone. This resulted in either of the two cases:

   (i) Surface water zones equalling or exceeding their allowable limits. The zone was then considered 'fully allocated' or 'saturated'. In such cases, new dams were not added for further analysis.

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[1]Mean winter run-off was calculated using mean winter rainfall for the zone and the rainfall-run-off relationship for winter for 'no dams' scenario.

[2]30% of winter run-off as defined in the RMCWMP.

(ii) Surface water zones below their allowable development limits and termed as 'under allocated' in this report.

c. Increasing the farm dam capacity of each unsaturated zone to a proportion of the entire sub-catchments additional allowable development. This was calculated as:

Additional allowable development for unsaturated surface water zone (ML) = Additional allowable development for the entire major sub-catchment (ML) (476 ML in the case Upper Angas sub-catchment) x surface water zone run-off factor.

Surface water zone run-off factor = run-off generated from the surface water zone \ cumulative run-off generated from the unsaturated surface water zones within the major sub-catchment.

3. Adding a new off-stream dam node in the model at the end of each unsaturated zone. It is recognised that new dam development might occur anywhere within the catchment. Since this is difficult to predict, the worst-case scenario of new dam development at the downstream end of each surface water zone was assumed. This was also done to maintain consistency in modelling procedure across catchments in the region.
4. Setting the capacity of the new dams to the value calculated in step 2(c) above.
5. Diverting all flows from the zone through the new dam.
6. Running the model with the abovementioned changes and generating long-term streamflow data.

Streamflow data generated from the abovementioned steps were then compared to data generated under the 'current dams' and 'without dams' scenarios for predicting future impacts if farm dam development was allowed to happen in future.

Table 19, Appendix E and Map 11 show the status of the surface water zones with respect to their development levels. Surface water zones UA-Z1 to UA-Z5 represent Doctors Creek catchment area within the Upper Angas sub-catchment. Four out of the five zones (UA-Z1 to UA-Z4) have exceeded their allowable limits, making the Doctors Creek catchment area overdeveloped, based on the RMCWMP development limits.

Map 11 also indicates a high level of development in the surface water zones within the Burnside Creek sub-catchment. As discussed in the earlier sections, though the farm dam density in the Burnside Creek sub-catchment is comparatively low, its development level is high due it being in a low rainfall catchment.

5.3.2 RESULTS AND DISCUSSION

The results of increasing the farm dam capacities in the surface water zones of the Upper Angas sub-catchment to the development limit, and their impacts on run-off, are presented in this section (refer to section 5.3.1 for details on methodology). Analysis was undertaken on annual, seasonal, monthly and daily time scales, results of which are presented in the following sections.

Annual Flows

The average annual run-off generated for the Upper Angas sub-catchment by the model for the period 1974–2003 under this scenario is 5636 ML. This equates to 7% and 20% less annual flows in comparison to flows under the 'current dams' and 'no dams' scenarios. In other words, increasing farm dam capacities to limits defined in the RMCWMP without incorporating diversion limits would potentially reduce the current mean annual flows by 7% (446 ML) and mean annual pre-development flows by 20% (1451 ML).

Figure 18 illustrates the potential annual flow reductions under the 'current dams' scenario and the 'farm dam development to RMCWMP limits without diversion limits' scenario.

While the potential average reduction to mean annual pre-development flows is 20%, it varies annually with rainfall. For example:

- during a dry year like 1982, the potential flow reduction under this scenario would be a high 55%, in comparison to the 39% potential reduction already caused by the current dams
- during a wet year like 1992, the potential flow reduction would be 9%, which is not much higher than the 6% reduction already caused by the current dams.

This, once again, highlights the higher impacts of dams during drier years and minimal impacts during wetter years.

Monthly and Seasonal Flows

Analysis of flows on a monthly times scale and comparison to flow under the 'current' and 'pre-development' scenarios are represented in Figure 19. As displayed in the chart, while the current flows will be reduced throughout the year, the reductions are more pronounced during summer. For example:

- during the months of January and February, the potential average flow reduction by current dams is around 60%; this increases to an estimated 90% reduction under this scenario
- during the months of July, August and September, the potential average flow reductions by the current dams were 7%, 3% and 2% respectively, while they are estimated to be ~1% more during those months under this scenario.

Analysis of flows on a seasonal (winter and summer) time scale and comparison to flows modelled under the 'current' and 'pre-development' scenarios are presented in Table 20.

Table 20. Seasonal flows for Upper Angas — future scenario 1

Time scale	**Modelled flows** (ML)			**Flow reduction**[1] **by** (%)	
	Pre-development scenario	*Current dams scenario*	*Future scenario 1*	*Current dams*	*Future scenario 1 dams*
Annual	7087	6082	5636	14	20
Winter	6178	5620	5394	9	13
Summer	910	462	243	50	74

1 Flow reduction in comparison to 'pre-development' scenario

Data presented above indicate that increasing farm dam capacities to the RMCWMP development limits, and not adopting any diversion rules to the new development, would:

- Have a higher impact on summer flows than winter flows. This main reason for this is the new dams would capture the summer or low flows occurring from the currently 'free-to-flow' areas of the catchment.

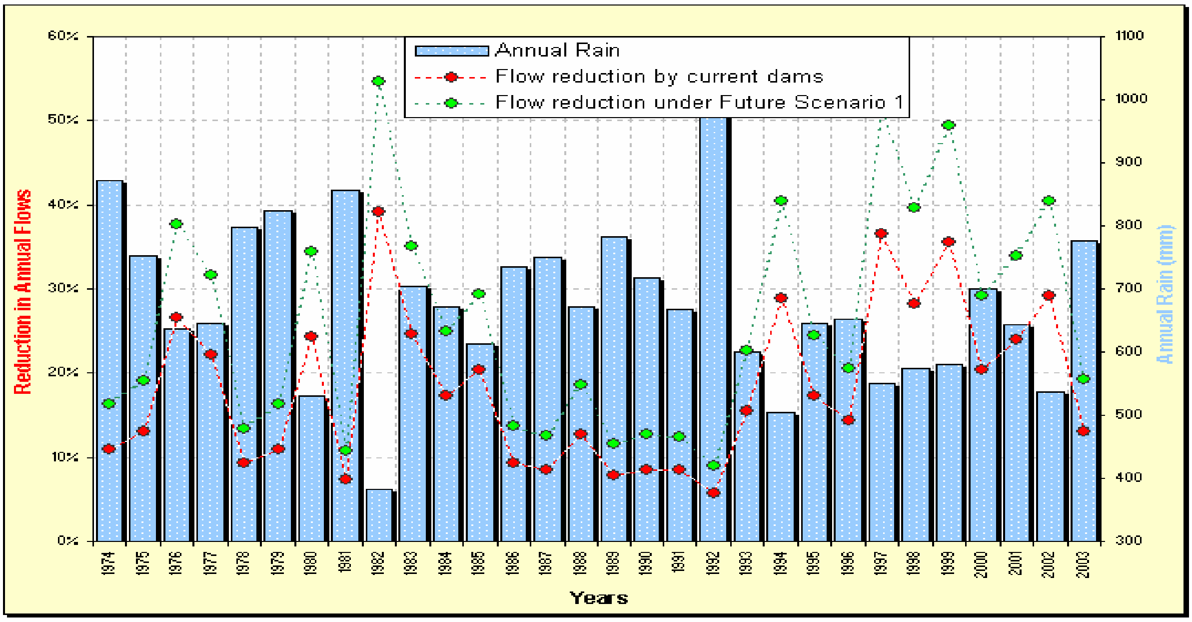


Figure 18. Annual flow reduction in the Upper Angas by current and future scenario 1

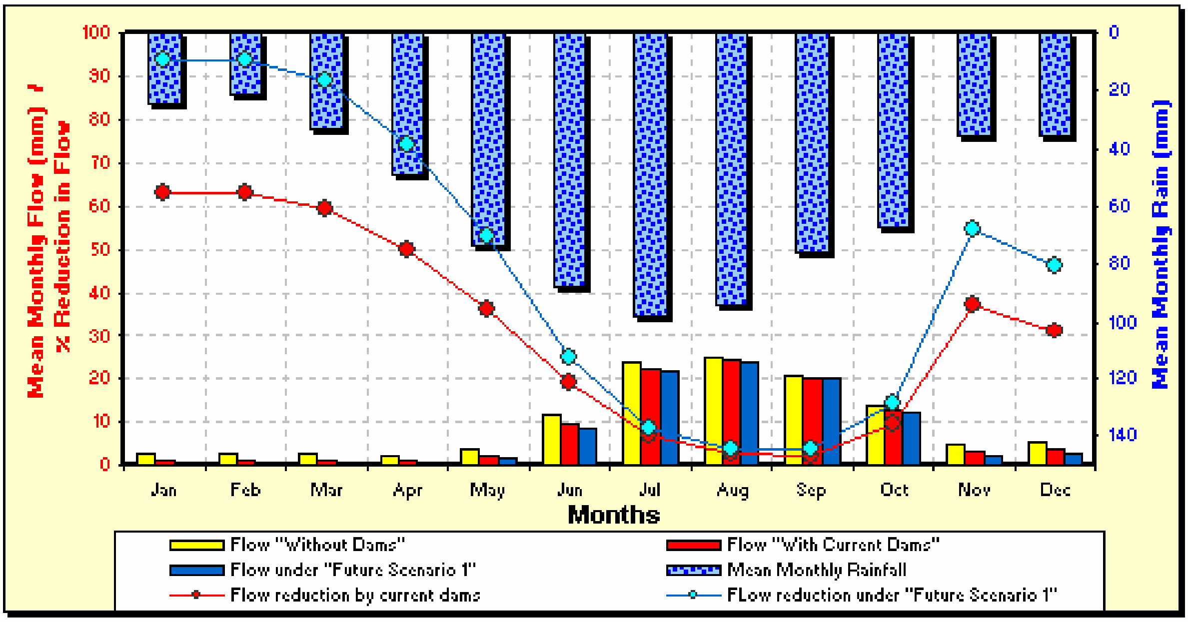


Figure 19. Impact of dams on monthly flows — 'current' and 'future scenario 1'

- The impacts during winter, though lower than summer, would be on the delay of 'break-of-season' and early winter flows caused by the time taken to fill the new dams. Once they are full, their impacts would be the same as the current dams until late in the season when rainfall decreases, evaporation increases and pumping from the dams starts to occur. This would result in more late-season low flows being captured by the new dams. These impacts are further discussed in the next section on daily flows.

Daily Flows

Analysis of flows on a daily time scale and comparison to flow under the 'current' and 'pre-development' scenarios for the Upper Angas sub-catchment are represented in Figure 20, Table 21 and Table 22. The impacts of increasing the farm dam capacity of the catchment to its development limits without incorporating diversion rules are listed below:

- The flow reduction by new dams increases as the daily flow decreases. For example, in an average year, the difference between the number of days of occurrence of daily flows of 10 ML under the 'current dams' scenario and this scenario is only four days. This difference increases to 16 days for flows of 5 ML/d and to more than 50 days for flows of 1 ML/d (Table 21).
- The 80th and 90th percentile flows modelled under this scenario are both 0.0 ML/d. The data (Fig. 23) also indicate that the catchment would flow for only 75% of the time during an average year, compared to year round flows under the 'without dams' and 'current dams' scenarios. This will have a significant impact on the catchment's water-dependent ecosystems.
- The modelled median daily flow is 1.8 ML, which is 75% less in comparison to 6.7 ML/d generated under the 'without dams' scenario. It is also almost 50% less than the current median daily flow of 3.2 ML (Table 22).
- The high flows (10th and 20th percentile) are almost the same for this scenario and the 'current dams' scenario, indicating the minimal impact on high flows by increasing the farm dam capacities (Table 22).

Table 21. Daily flow frequencies for the Upper Angas — future scenario 1

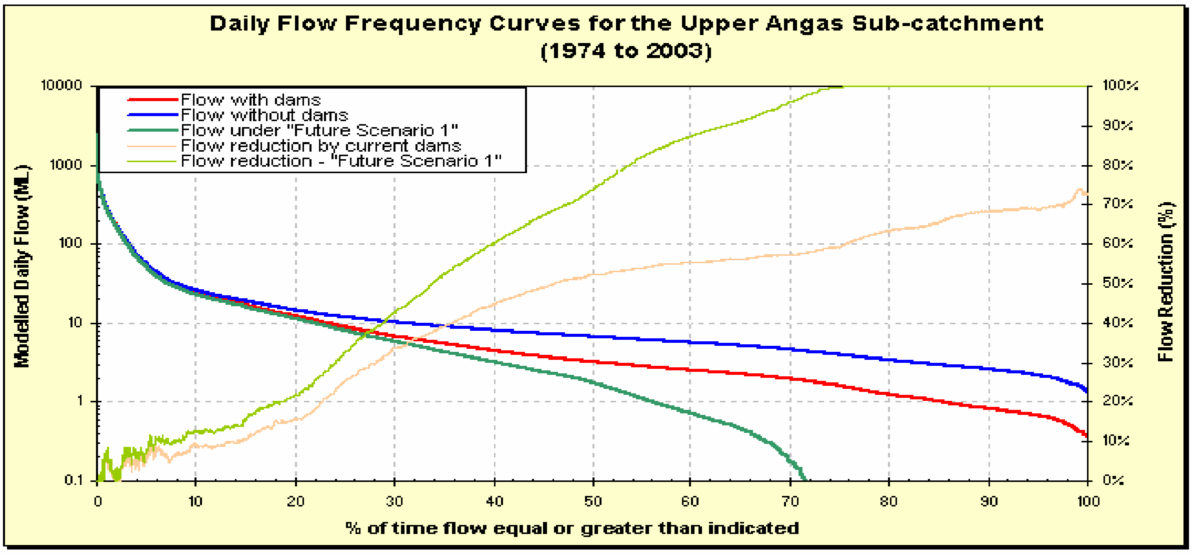
Flow (ML/d)	**Number of days in a year that flows are equalled or exceeded**			**Difference in flow exceedance days**[1]	
	'Without dams' scenario	*'Current dams' scenario*	*Future scenario 1*	*'Current dams' scenario*	*Future scenario 1*
≥1	365	311	205	53	160
≥5	243	136	120	107	124
≥10	112	84	80	28	32
≥50	19.8	19	18.7	0.8	1.1
≥100	11.8	11.3	11.2	0.5	0.6
≥500	1.5	1.6	1.6	0.1	0.1

1 In comparison to 'without dams' scenario flows.

Table 22. Daily flow percentiles for the Upper Angas — future scenario 1

Flow percentile	**Daily flow** (ML)			**Difference in flow**[2] (%)	
	'Without dams'	*'Current dams'*	*Future scenario 1*	*'Current dams'*	*Future scenario 1*
10%	26.1	23.7	22.8	9	13
20%	14.6	12.3	11.4	16	22
50%	6.7	3.2	1.8	52	74
80%	3.4	1.2	0.0	63	100
90%	2.6	0.8	0.0	68	100

2 In comparison to 'without dams' scenario flows.



* modelled low flows to be used with caution. Refer Section 5.1.2 for details

Figure 20. Upper Angas sub-catchment daily flows — future scenario 1

5.4 FUTURE SCENARIO 2: FARM DAM DEVELOPMENT TO RMCWMP LIMITS, WITH DIVERSION LIMITS

Future scenario 2 refers to increasing the farm dam capacities of the surface water zones in the Upper Angas sub-catchment to its allowable limit as defined in the RMCWMP (RMCWMB 2003), incorporating diversion limits to the new dams and modelling their possible impacts on catchment run-off.

The difference between future scenario 1 and future scenario 2 is the incorporation of diversion limits to the new dams in this scenario, while no diversion limits were incorporated in the earlier scenario.

5.4.1 METHODOLOGY

The methodology used for running this scenario was the same as that used in future scenario 1 except for step number 5 in Section 5.3.1 (Methodology for future scenario 1), which is:

5. Diverting all flows above the threshold flow rates (RMCWMB 2003) through the new dams. The 10th percentile flows (flows occurring 10% of the time during a normal year) were considered to be threshold flow rates. This implies that only the high flows (up to 10th percentile) can be diverted to dams. Flows below this limit have to be allowed to flow downstream.

The threshold flow rates for the unsaturated surface water zones in the Upper Angas sub-catchment are listed in Table 23.

Flows generated under this scenario were then compared to flows generated under the other scenarios, the results of which are presented in the next section.

Table 23. Threshold flows rates for surface water zones in the Upper Angas sub-catchment

Number	Surface water zone	Area (km^2)	Threshold flow rate* (ML/d)
1	UA-Z1	8.4	–
2	UA-Z2	5.0	–
3	UA-Z3	3.7	–
4	UA-Z4	2.0	–
5	UA-Z5	4.6	8.17
6	UA-Z6	5.7	1.97
7	UA-Z7	3.5	1.20
8	UA-Z8	3.3	4.31
9	UA-Z9	5.7	1.98
10	UA-Z10	2.3	0.80
11	UA-Z11	1.4	7.57
12	UA-Z12	5.3	1.82
13	UA-Z13	2.3	10.19
14	UA-Z14	3.0	–
15	UA-Z15	2.2	12.00
16	UA-Z16	1.6	20.73

* Threshold flow rate (ML/d) = unit threshold rate[1] for the major sub-catchment x area of catchment above the new dam in the surface water zone.

5.4.2 RESULTS AND DICUSSION

Since only high flows (10th percentile and higher) are diverted to the new dams under this scenario, the new farm dams do not impact on medium and low flows. Since most of the high flows occur during winter, the summer baseflows and low flows during other seasons will not be impacted under this scenario.

Flows modelled under this scenario were analysed on annual, seasonal, monthly and daily time scales, results of which are presented in the following sections.

Annual Flows

The average annual run-off generated for the period 1974–2003 under this scenario is 5718 ML. This amounts to a few megalitres (~1.5%) more than the 5636 ML of flow generated under the previous scenario, where all flows were diverted to the new dams without incorporating any diversion rules. In other words, the loss of water under this scenario is a bit lower in comparison to the previous scenario due to the lower evaporation losses. The impact varies annually as shown in Figure 21.

[1] Unit threshold flow rate is the 10th percentile flow rate, which for the Upper Angas (A1) sub-catchment is 4 L/s/km^2 as defined in the RMCWMP (RMCWMB 2003, pp. 183 and 244).

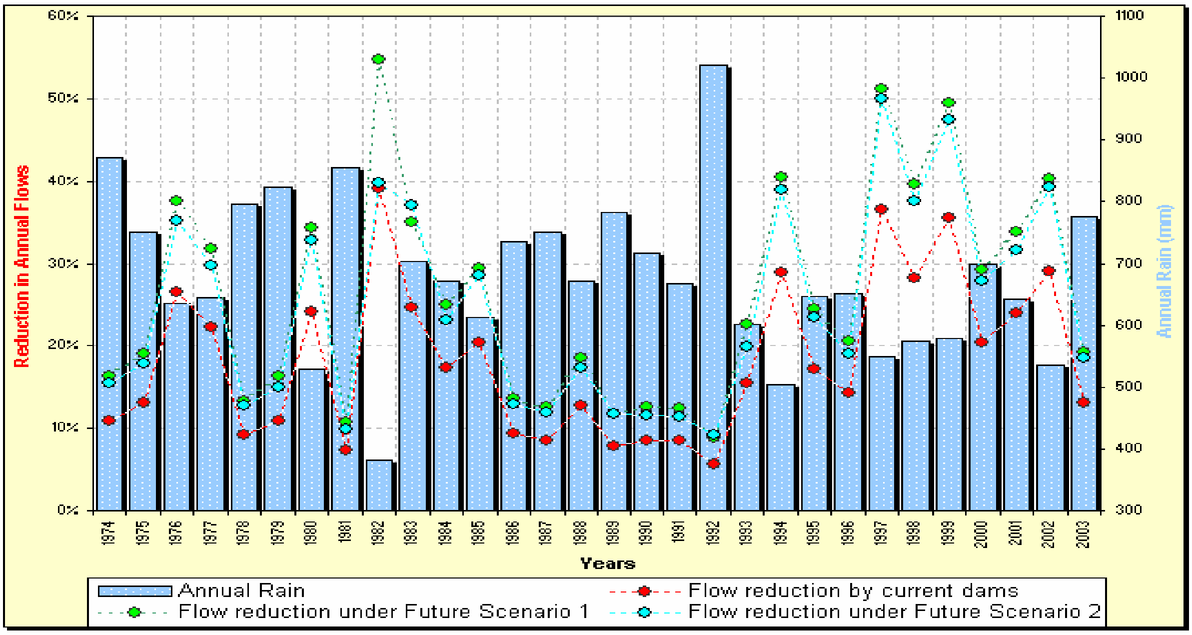


Figure 21. Potential reduction in annual flows in the Upper Angas — various scenarios

The difference in impacts on annual flows between the two scenarios is pronounced during drier years and minimal during wetter years. As shown in Figure 21, during a dry year like 1982, the flow reduction under future scenario 1 is ~55%, while the flow reduction under this scenario is only 40%, which is also the same as the flow reduction under the 'current dams' scenario. This is due to low rainfall years generating more low-run-off events, most of which will be captured by the new dams if all the flows are diverted through them. On the other hand, if diversion limits were incorporated, most of the of those low-flow events will pass through the dam.

During a wet year like 1992, the annual flow reduction caused under this scenario is the same as that caused under future scenario 1. The difference in impacts between the two is more clearly demonstrated when analysed on monthly and daily time scales.

Monthly Flows

Adding new dams at the end of each surface water zone would have negligible impact on currently occurring summer baseflows and low flows if diversion limits were incorporated to the new dams. This is illustrated in Figure 22, where the flow reductions under this scenario and the 'current dams' scenario are similar for summer (between January and April). As indicated in Table 24, summer flow reduction under this scenario is 50%, which is the same as the flow reduction caused by the current dams. This is because the current low flows will not be captured by the new dams under this scenario and they will only capture flows above the threshold flow rate.

Under this scenario, dams start to capture flows only from May when flows are above threshold flow rates. This delays the filling-up of dams and consequently the spilling of dams as well. This results in more winter flows being captured under this scenario (15%) than under the previous scenario (13%) without diversion limits. Once the dams are full (probably in September–October), the impact of dams on flows will be the same in both scenarios (with and without diversion limits).

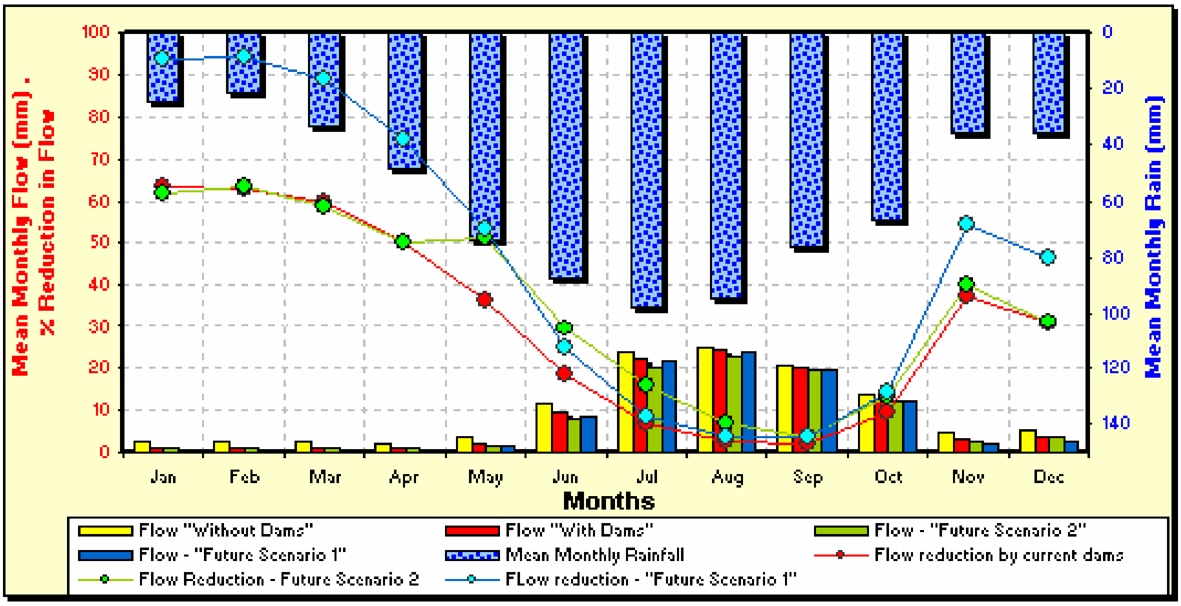


Figure 22. Impact of dams on the Upper Angas sub-catchment monthly flows — various scenarios

Table 24. Seasonal flows for the Upper Angas sub-catchment — various scenarios

Time scale	**Modelled flows** (ML)				**Flow reduction*** (%)		
	'Without dams' scenario	*'Current dams' scenario*	*Future scenario 1*	*Future scenario 2*	*'Current dams' scenario*	*Future scenario 1*	*Future scenario 2*
Annual	7087	6082	5636	5718	14	20	19
Winter	6178	5620	5394	5256	9	13	15
Summer	910	462	243	462	50	74	50

* Flow reduction in comparison to 'without dams' scenario.

Daily Flows

Results of daily flow analysis under this scenario and comparison to flows from the previous scenario for the Upper Angas sub-catchment are presented in Tables 25 and 26.

Table 25. Daily flow frequencies for the Upper Angas sub-catchment — various scenarios

Flow (ML/d)	**Number of days in a year that flows are equalled or exceeded**				**Difference in flow exceedance days***		
	'Without dams' scenario	*'Current dams' scenario*	*Future scenario 1*	*Future scenario 2*	*'Current dams' scenario*	*Future scenario 1*	*Future scenario 2*
≥1	365	311	205	311	53	160	53
≥5	243	136	120	135	107	124	107
≥10	112	84	80	80	28	32	32
≥50	19.8	19	18.7	17	0.8	1.1	2.8
≥100	11.8	11.3	11.2	10.5	0.5	0.6	1.4
≥500	1.5	1.6	1.6	1.6	0.1	0.1	0.1

* In comparison to 'without dams' scenario flows.

Table 26. Daily flow percentiles for the Upper Angas sub-catchment — various scenarios

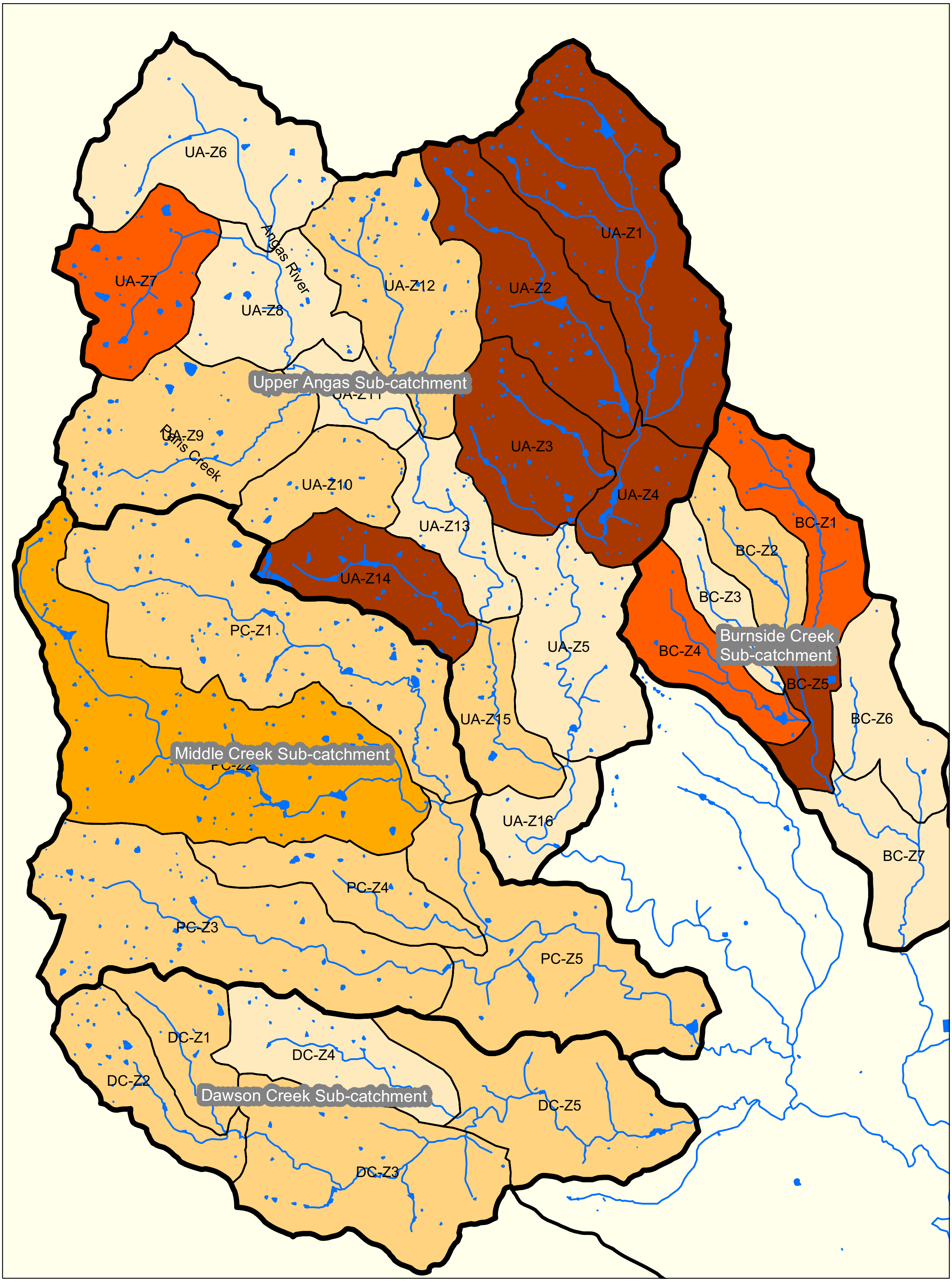
Flow percentile	**Daily Flow** (ML)				**Difference in flow*** (%)		
	'Without dams' scenario	*'Current dams' scenario*	*Future scenario 1*	*Future scenario 2*	*'Current dams' scenario*	*Future scenario 1*	*Future scenario 2*
10%	26.1	23.7	22.8	21.0	9	13	19
20%	14.6	12.3	11.4	11.4	16	22	22
50%	6.7	3.2	1.8	3.2	52	74	52
80%	3.4	1.2	0.0	1.2	63	100	63
90%	2.6	0.8	0.0	0.8	68	100	68

* In comparison to 'without dams' scenario flows.

The possible impacts of increasing farm dam capacities of the catchment to its development limit and incorporating diversion rules are:

- Less impact on summer baseflows, and medium and low flows in comparison to impacts in future scenario 1.
- Negligible impact to the current lows flows. For example, the 50th, 80th and 90th percentile flows are the same for this and the 'current dams' scenario. Incorporation of diversion rules prevents flows from being captured by the new dams until they exceed the threshold flow rates.
- Higher impact on high flows in comparison to impacts in future scenario 1 as most of the flows captured by the dams under this scenario will be high flows, which generally occur during winter.

Map 11. Surface Water Zones - Development Levels



Surface Water Zones
Development Level

- < 25%
- 25 - 50%
- 50 - 75%
- 75 - 100%
- > 100%

N

0 0.5 1 1.5 Km

Datum GDA 94
Map projection MGA Zone 54

Projection: Map Grid of Australia 1994 (UTM)
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 Resource Investigations Group
Knowledge and Information Division.

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

6. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

6.1 HYDROLOGICAL DATA

The spatial and temporal representivity of the hydrological data used in this study and future data requirements for better analyses are summarised in this section.

Streamflow Data

Spatial Representivity: Streamflow gauging is carried out for only one of the four major tributaries in the Angas River catchment. Streamflow data for the three remaining ungauged catchments (Middle Creek, Dawson Creek and Burnside Creek) were derived from extending the rainfall-run-off model calibrated for the gauged catchment. The rainfall-run-off model used for estimating streamflow from the three ungauged catchments incorporates the variation in rainfall pattern, location and distribution of farm dams in those catchments. However, the catchment parameters used were the same for the gauged and ungauged catchments. Hence, the potential variations in catchment characteristics were not incorporated while generating flows for the ungauged catchments.

To obtain streamflow data that represents the whole catchment more accurately, the following are recommended:

- Streamflow gauging either (a) downstream of the confluence of the major tributaries or (b) of the three ungauged streams, for more accurate streamflow estimates from the 'hills zone' of the catchment.
- Streamflow or water level gauging site(s) in the 'plains zone' of the catchment (d/s of Strathalbyn) to identify if sections of the stream in the plains are 'losing' water or 'gaining' water from the groundwater systems.

Temporal Representivity: Streamflow data are available for 1969 onwards (for the one tributary) at gauging station AW426503. But, data prior to 1996 could not be used, as data on the amount of water diverted from gauging station to the Strathalbyn Reservoir was unavailable at the time of analysis. Data used was therefore for the period 1996–99. Since, eight years of streamflow data were considered insufficient to provide temporal representation, long-term modelled data were used for assessment purposes. Streamflow monitoring at the existing gauging station needs to be continued to obtain long-term data for future analysis purposes.

Evaporation Data

Evaporation data from Mount Bold reservoir was used in this study due to the proximity of the site to the Angas River Catchment. Data from a monitoring site within the catchment would better represent the catchment characteristics than Mount Bold site, which is on the other side of the ranges.

6.2 CATCHMENT MODELLING

A rainfall-run-off catchment water balance model was constructed and calibrated for the Upper Angas sub-catchment using the WaterCress modelling platform. The model was calibrated to four years of streamflow data, which was then used to generate long-term streamflow data for that sub-catchment and the 'hills zone' neighbouring sub-catchments. The model was then used to simulate catchment management scenarios to study their impacts on streamflow. The results of streamflow analysis from the modelling scenarios are summarised in this section.

6.2.1 CALIBRATION RESULTS

The suitability of the data sets (data type, quality and duration of availability) used as inputs to the rainfall-run-off model, the effectiveness and confidence in the model used to represent the catchment conditions, and further data requirements for better calibration are summarised below.

The rainfall-run-off model used in this study provided acceptable levels of calibration, given that only four years of streamflow data were available for calibration. On a seasonal basis, winter flows were better calibrated than summer and late autumn – early winter flow events. Summer events and later autumn – early winters are generally difficult to calibrate accurately because:

- Summer events are predominantly rainfall-intensity driven, while data input to the model was only on a daily time scale.
- Flow events during late autumn – early winter represent 'break-of-season', when the initial wetting-up followed by saturation of soil happens. This results in the first run-off events being generated from various parts of the catchment. Late winter – spring events are primarily baseflows that are dependent on surface – groundwater interactions. Both the abovementioned types of events require extensive data sets, which are generally unavailable.

Calibrating the flows to a higher degree of accuracy is not an uncommon problem with most hydrological models. Summer flows and late winter baseflows account for only a small percentage (<5%) of the total annual flows, and hence it does not affect the main outcome of the study, which is to assess the overall surface water resources of the catchment. However, it makes assessment of water requirements for ecosystems difficult, as those are the seasons when ecosystems require water the most.

Calibration of the model can be further refined by using the following as inputs to the model:

- Rainfall intensity data rather than daily rainfall data.
- Rainfall records from more sites within the catchment.
- Daily evaporation data rather than mean monthly data.
- Long-term streamflow data with good representation of different flow ranges.
- Distinction between stock–domestic and irrigation dams and, hence, the variation in pattern of use. This is the only data set that will be available in the near future, from the land and water use surveys currently being carried out as part of the prescription process.
- Actual water-use data (metering data) from irrigation dams.

6.2.2 SCENARIO MODELLING

The rainfall-run-off model constructed and calibrated for the Upper Angas sub-catchment was used to simulate three different scenarios to assess the impact of farm dams on catchment hydrology. The results of the scenarios are:

1. **Pre-farm dam development scenario** — The model was run, first with the 2001 levels of farm dam development ('current scenario'), and then with the impact of farm dams removed ('pre-farm dam development scenario'). Run-off data from the two scenarios were compared, the results of which indicate:

    - *Annual impacts* — The farm dams, at 2001 level of development, intercept on an average 1000 ML/y of run-off generated from the Upper Angas sub-catchment. This equates to a 14% reduction in average annual run-off (in comparison to 'pre-development' flows). This reduction varies annually, with higher impacts during drier years (39% reduction in a year with 380 mm of rain) and lower impacts during wet years (only 6% reduction in a year with 1000 mm of rain).
    - *Seasonal impacts* — On a seasonal basis, the impact of dams is much higher during summer than during the winter months. For the Upper Angas sub-catchment, the estimated reduction in mean summer run-off is 50% (445 ML), while it is only 9% (555 ML) during winter months.

      While summer flows constitute <10% of annual flows, they are crucial to the catchment's water-dependent ecosystems. Hence, a 50% reduction to those flows could be consequential to the health of those ecosystems.
    - *Daily impacts* — On a daily basis, the dams appear to have impacted flows lower than 10 ML/d, the medium and low flow range. But, the impacts on low flows (<1 ML/d) are uncertain due to lack of accurate data and calibration difficulties. The estimated median (50th percentile) daily flows would be twice the current flows if the dams did not exist.

To summarise, the 2001 levels of farm dam development is estimated to have impacted on the medium and low flows. This impact appears to be predominant during the late baseflow season and during late autumn – early winter 'break-of-season'. While the current low flows at the end of the catchment might be more baseflow dependent and relatively less impacted by dams, the low flows in the upper parts of the catchment could potentially have been impacted by dams. These flows could be crucial to the local water-dependent ecosystems.

Further surveys and monitoring of the health and water requirements of the local water-dependent ecosystems and flows from the individual tributaries (upstream of the existing gauging station) are required to more accurately evaluate the extent of impact of dams on local flow regimes.

2. **Future scenario 1** — Farm dams developed to RMCWMP limits, without diversion rules. The 2001 level of farm dam development in the Upper Angas sub-catchment (1377 ML) is 74% of the RMCWMP's allowable development limit of 1853 ML. The additional allowable development of 476 ML was proportionally distributed among the under-allocated surface water zones within the catchment. They were represented as additional dams in the model, at the end of each under-allocated surface water zone, with all upstream flows diverted to them. The run-off generated was then compared to run-off generated from the 'current scenario'. The possible impacts to current flows if farm dam capacities were increased to the RMCWMP limits, without implementing any diversion rules, would be:

    - *Annual impacts* — The new farm dams would potentially reduce the annual mean flows by an additional 7% (in comparison to current flows). The impact would be much higher during drier years (55% reduction in a 380 mm rainfall year in comparison to the 39% reduction already caused by the current dams). The impact during wetter years would be minimal in comparison to the impacts already caused by their current dams.

- *Seasonal impacts* — The impacts would be higher during summer as the new dams would capture the summer or low flows generated from the currently 'free-to-flow' areas within the catchment. The impacts during winter would be on the delay of the 'break-of-season' and early winter flows being captured by the new dams. Once the new dams are full, their impacts would be the same as the current dams until late in the season when rainfall decreases, evaporation increases and pumping from the dams starts to occur. This would result in more late-season low flows being captured by the new dams.
- *Daily impacts* — The highest impacts would be on medium and low flows, with the current median daily flows almost halved. The impact increases as the flow value decreases.

To summarise, while the current dams have possibly impacted on the low and medium flows, increasing the number of dams without incorporating diversion rules would further deteriorate the situation by reducing the frequency of those flow ranges. As mentioned earlier, further surveys and monitoring of water-dependent ecosystems and flows in the tributaries are required to more precisely estimate their impacts.

3. **Future scenario 2** — Farm dams developed to RMCWMP limits with diversion limits. This is the same as the last scenario but with diversion limits assigned to the new dams. This was undertaken by diverting all flows below the threshold flow rate around the new dams in the model. The run-off generated was then compared to run-off generated from the 'current scenario'. The possible impacts on current flows if farm dam capacities were increased to the RMCWMP limits with diversion rules would be:

    - Since, only high flows (10th percentile and higher flows) are diverted to the new dams under this scenario, the new farm dams would not have any additional impact on medium and low flows. Since most of the high flows occur during winter, the summer baseflows and low flows currently occurring during other seasons will not be impacted under this scenario. The impacts during winter would be the delay of 'break-of-season' events caused by the time taken to fill the new dams.

6.3 TECHNICAL RECOMMENDATIONS

The primary data used for hydrological analysis and modelling in this study were rainfall, streamflow, evaporation and farm dam capacity data. While the data available at the time of the study sufficed the primary need of assessing the surface water resources within the catchment, more data with better geographical and temporal representation would enable further refinement of the model and its outcomes. Recommendations include:

- Upgrading the existing streamflow gauging station to enable better monitoring of low and baseflows.
- Streamflow gauging either (a) downstream of the confluence of the major tributaries for more accurate streamflow estimates from the 'hills zone' of the catchment, and/or (b) gauging of the three ungauged streams to better define flows from the respective catchments.
- Streamflow gauging site(s) in the 'plains zone' of the catchment (d/s of Strathalbyn) to identify whether sections of the stream are 'losing' or 'gaining' water from the groundwater systems.
- Better estimates of farm dam capacities.

APPENDICES

A. TANH FUNCTION

The Tanh function (Grayson et al. 1996) is a standard hyperbolic function and was used by Boughton (1996) as simple rainfall-run-off relationship.

Calculation

$$Q = (P - L) - F \times \tanh[(P - L)/F]$$

where

Q is run-off [mm]

P is rainfall [mm]

L is notional loss [mm]

F is notional infiltration [mm]

The equation can be applied to any data but should be used for data where average storage of soil water is approximately constant (i.e. where the notional loss and infiltration might be expected to be similar). Annual data satisfies this requirement but monthly data will need to be separated into data for each month or at least for season, and a different L and F derived for each month's (or season's) set.

Determination of F and L

The values of the notional loss (L) and infiltration (F) are determined by plotting monthly flow sets, seasonal flow sets or annual flow sets against the associated rainfall. A preliminary value of L is chosen from the data and F fitted either by trial and error or with a curve-fitting technique. Similarly, the preliminary estimate of L can be changed to improve the fit. It is often simplest to just plot the data in a spreadsheet and visually fit the parameters.

Modification to the Tanh function

Streamflow in the Tookayerta Catchment has a large baseflow component which occurs throughout the year and is predominant during summer. Hence, this baseflow component was added to the Tanh equation as a constant (C).

$$Q = ((P - L) - F \times \tanh[(P - L)/F]) + C$$

The iterative trial and error process was used to visually fit the curve and the best estimates of L, F and C were obtained.

B. MIDDLE CREEK SUB-CATCHMENT — DAILY FLOWS

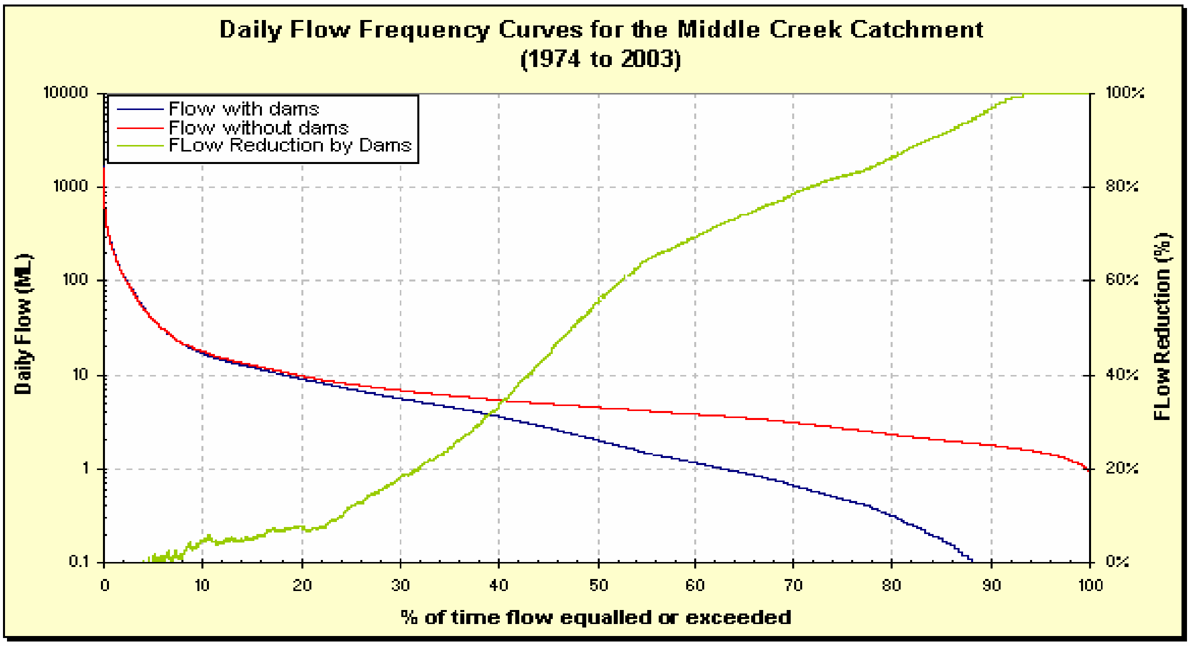


Figure 23. Comparison of Middle Creek sub-catchment daily flows

Table 27. Daily flow frequencies for the Middle Creek sub-catchment — 'with and without dams'

Flow (ML/d)	**Number of days in a year flows equalled or exceeded** *'With dams'*	*'Without dams'*	**Difference in flow exceedance days**
≥5	120	160	41
≥10	66	72	5
≥50	15	15	0
≥100	8	8	0
≥500	0.7	0.7	00

Table 28. Daily flow percentiles for the Middle Creek — 'with and without dams'

Flow percentile	**Daily flow** (ML) *'With dams'*	*'Without dams'*	**Difference in flow** (%)
10%	16.9	27.7	5
20%	9.1	9.8	8
50%	2.0	4.5	56
80%	0.3	2.3	86
90%	0.05	1.78	97

C. DAWSON CREEK SUB-CATCHMENT — DAILY FLOWS

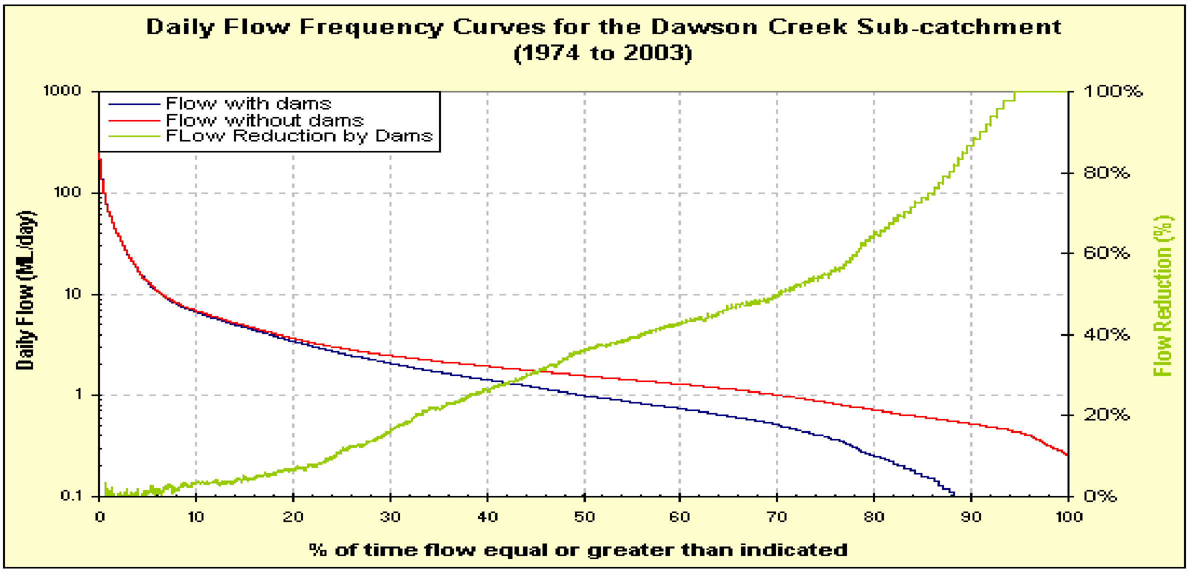


Figure 24. Comparison of Dawson Creek sub-catchment daily flows

Table 29. Daily flow frequencies for the Dawson Creek sub-catchment — 'with and without dams'

Flow (ML/d)	**Number of days in a year flows equalled or exceeded** *'With dams'*	*'Without dams'*	**Difference in flow exceedance days**
≥1	183	257	74
≥5	51	54	3
≥10	23.6	23.8	0.2
≥50	5.3	5.4	0.1
≥100	2	2	0
≥500	0	0	0

Table 30. Daily flow percentiles for the Dawson Creek sub-catchment — 'with and without dams'

Flow percentile	**Daily flow** (ML) *'With dams'*	*'Without dams'*	**Difference in flow** (%)
10%	6.6	6.9	3
20%	3.4	3.7	7
50%	1.0	1.6	36
80%	0.25	0.72	65
90%	0.07	0.52	87

D. BURNSIDE CREEK SUB-CATCHMENT — DAILY FLOWS

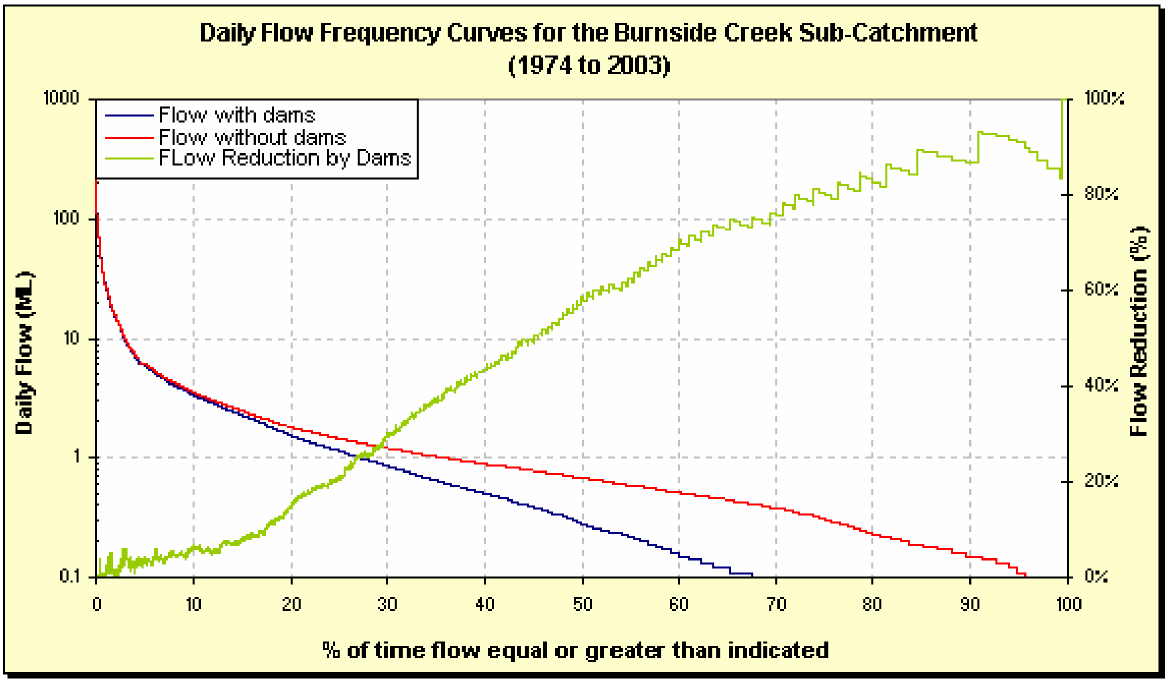


Figure 25. Comparison of Burnside Creek sub-catchment daily flows

Table 31. Daily flow frequencies for the Burnside Creek sub-catchment — 'with and without dams'

Flow (ML/d)	**Number of days in a year flows equalled or exceeded** *'With dams'*	*'Without dams'*	**Difference in flow exceedance days**
≥0.1	253	349	95
≥1	99	129	30
≥5	22	23	1
≥10	10.8	11.1	0.3
≥50	1.76	1.83	0.1
≥100	0.6	0.6	0

Table 32. Daily flow percentile for the Burnside Creek sub-catchment — 'with and without dams'

Flow percentile	**Daily flow** (ML) *'With dams'*	*'Without dams'*	**Difference in flow** (%)
10%	3.3	3.5	6
20%	1.5	1.8	15
50%	0.3	0.67	58
80%	0.04	0.23	83
90%	0.02	0.15	87

E. SURFACE WATER ZONE DETAILS FOR THE FOUR MAJOR SUB-CATCHMENTS

NO.	SW Zones	Area (SqKm)	Avg Ann Rain (mm)	No.of Dams	Dams' Capacity 2001(ML)	Dam Density (ML/SqKm)	Winter Rain[1] (mm)	Winter Runoff without dams[2] (mm)	Winter runoff without dams (ML)	RMCWMP Development Limit[3]	Current Level of Development
Upper Angas (UA)											
1	UA-Z1	8.4	668	81	256.1	30.6	528	98.0	820.5	246.1	104.0%
2	UA-Z2	5.0	696	45	209.3	42.2	550	112.3	556.8	167.0	125.3%
3	UA-Z3	3.7	690	46	123.6	33.2	545	109.0	406.0	121.8	101.5%
4	UA-Z4	2.0	644	15	96.1	48.0	509	86.4	172.7	51.8	185.5%
5	UA-Z5	4.6	647	24	27.7	6.0	511	87.6	402.1	120.6	23.0%
6	UA-Z6	5.7	771	15	33.2	5.8	609	154.2	880.8	264.2	12.6%
7	UA-Z7	3.5	787	32	127.6	36.7	622	164.1	570.9	171.3	74.5%
8	UA-Z8	3.3	766	16	35.1	10.7	605	151.2	495.7	148.7	23.6%
9	UA-Z9	5.7	786	48	114.3	19.9	621	163.4	936.4	280.9	40.7%
10	UA-Z10	2.3	752	20	29.5	12.7	594	143.1	332.4	99.7	29.6%
11	UA-Z11	1.4	750	0	0.0	0.0	592	141.7	195.0	58.5	0.0%
12	UA-Z12	5.3	737	47	80.1	15.2	582	134.4	706.2	211.9	37.8%
13	UA-Z13	2.3	707	15	10.9	4.7	559	118.4	275.3	82.6	13.2%
14	UA-Z14	3.0	727	33	199.8	65.9	574	128.8	390.5	117.1	170.6%
15	UA-Z15	2.2	664	8	25.7	11.6	525	96.1	212.2	63.7	40.4%
16	UA-Z16	1.6	634	3	8.4	5.2	501	81.6	132.5	39.8	21.1%
Middle\Paris Creek (PC)											
1	PC-Z1	9.5	753	81	191.3	20.2	595	143.8	1363.7	409.1	46.8%
2	PC-Z2	11.1	762	86	312.0	28.1	602	149.0	1656.3	496.9	62.8%
3	PC-Z3	8.4	738	61	96.2	11.4	583	135.1	1139.2	341.8	28.1%
4	PC-Z4	2.9	692	10	33.6	11.6	547	110.3	319.3	95.8	35.1%
5	PC-Z5	7.1	607	14	71.0	10.0	480	69.8	494.6	148.4	47.9%
Dawson Creek (DC)											
1	DC-Z1	2.2	726	11	28.9	12.9	574	128.8	289.0	86.7	33.3%
2	DC-Z2	2.6	735	24	45.4	17.3	581	133.7	351.4	105.4	43.1%
3	DC-Z3	6.3	634	21	47.0	7.4	501	81.6	516.7	155.0	30.3%
4	DC-Z4	3.3	668	16	17.2	5.2	528	98.0	322.5	96.7	17.8%
5	DC-Z5	5.4	581	8	34.7	6.4	459	58.9	320.3	96.1	36.1%
Burnside Creek (BC)											
1	BC-Z1	2.9	578	19	38.5	13.4	457	57.9	166.7	50.0	77.0%
2	BC-Z2	2.1	590	11	10.9	5.3	466	62.5	128.9	38.7	28.2%
3	BC-Z3	1.4	599	4	5.2	3.7	473	66.1	92.8	27.9	18.7%
4	BC-Z4	2.6	600	9	43.1	16.8	474	66.6	170.9	51.3	84.1%
5	BC-Z5	1.3	555	3	19.5	14.9	438	48.9	64.2	19.3	101.3%
6	BC-Z6	2.7	535	6	5.8	2.1	423	42.3	116.3	34.9	16.6%
7	BC-Z7	3.1	516	0	0.0	0.0	408	36.3	111.4	33.4	0.0%

Notes:

[1] Winter Rain: - Annual Rain * 0.79 (factor 0.79 obtained from rainfall data for the period 1974 to 2003)

[2] Winter Runoff without dams: - derived using Tanh function (initial loss 160mm, continuing loss 340 mm)
- derived using modelled runoff without dams for the period 1974 to 2003

[3] RMCWMP Limits: - 30% of winter runoff without dams

F. FARM DAM CATCHMENT DETAILS

No.	Farm dam catchments	Area (km^2)	No. of dams	Dam capacity (ML)	Dam density (ML/km^2)	Av. annual rain (mm)	Rainfall factor	Diversion	Winter rain (mm)	Winter run-off (mm)	Winter run-off (ML)	RMCWMP limit (ML)	Level of development
Upper Angas sub-catchment													
1	A1-1	1.67	7	11.4	6.9	785	1.071	100%	620	163	271	81	14%
2	A1-2	1.11	1	0.8	0.7	772	1.053	25%	610	155	171	51	2%
3	A1-3	0.47	2	9.8	20.8	763	1.041	35%	603	150	70	21	46%
4	A1-4	0.63	5	11.1	17.7	757	1.033	80%	598	146	92	28	40%
5	A1-5	1.84	0	0.0	0.0	765	1.044	0%	605	151	278	83	0%
6	A1-6	2.39	25	94.1	39.4	792	1.081	90%	626	167	399	120	79%
7	A1-7	0.29	4	28.6	97.6	778	1.062	100%	615	159	47	14	205%
8	A1-8	0.80	3	4.8	6.1	777	1.060	100%	614	158	125	38	13%
9	A1-9	0.30	2	1.8	6.0	770	1.051	50%	609	154	46	14	13%
10	A1-10	0.48	3	22.0	45.8	773	1.055	100%	611	156	75	22	98%
11	A1-11	0.57	1	0.5	0.9	774	1.056	10%	611	156	89	27	2%
12	A1-12	0.52	8	8.1	15.5	759	1.036	90%	600	147	77	23	35%
13	A1-13	1.16	0	0.0	0.0	765	1.043	0%	604	151	174	52	0%
14	A1-14	1.31	21	29.7	22.7	803	1.096	90%	635	174	228	68	44%
15	A1-15	1.85	12	17.3	9.4	789	1.076	90%	623	165	305	91	19%
16	A1-16	0.51	5	63.0	122.9	788	1.075	100%	623	165	84	25	249%
17	A1-17	0.54	6	3.2	6.0	775	1.057	90%	612	157	84	25	13%
18	A1-18	0.46	4	0.9	1.9	772	1.053	10%	610	155	72	22	4%
19	A1-19	1.06	0	0.0	0.0	768	1.048	0%	607	153	162	49	0%
20	A1-20	0.25	2	2.8	10.9	754	1.029	100%	596	145	37	11	25%
21	A1-21	0.78	6	14.8	19.0	763	1.042	100%	603	150	117	35	42%

No.	Farm dam catchments	Area (km^2)	No. of dams	Dam capacity (ML)	Dam density (ML/km^2)	Av. annual rain (mm)	Rainfall factor	Diversion	Winter rain (mm)	Winter run-off (mm)	Winter run-off (ML)	RMCWMP limit (ML)	Level of development
22	A1-22	1.04	8	11.2	10.8	751	1.024	60%	593	142	148	44	25%
23	A1-23	1.40	0	0.0	0.0	750	1.023	0%	592	142	198	60	0%
24	A1-24	0.82	14	25.0	30.5	745	1.017	90%	589	139	115	34	73%
25	A1-25	0.28	4	4.9	17.4	755	1.030	100%	596	145	41	12	40%
26	A1-26	0.40	3	26.4	66.5	734	1.001	100%	580	133	53	16	167%
27	A1-27	0.51	3	3.2	6.3	734	1.001	90%	580	133	68	20	16%
28	A1-28	0.31	6	5.1	16.1	752	1.026	100%	594	143	45	14	37%
29	A1-29	0.90	7	10.0	11.1	723	0.986	100%	571	127	114	34	29%
30	A1-30	0.37	3	2.7	7.2	723	0.986	50%	571	127	47	14	19%
31	A1-31	1.65	6	2.1	1.3	740	1.009	10%	584	136	225	68	3%
32	A1-32	0.48	6	3.5	7.3	736	1.004	60%	581	134	64	19	18%
33	A1-33	0.27	6	3.5	12.7	714	0.974	100%	564	122	33	10	35%
34	A1-34	2.05	9	7.4	3.6	707	0.964	20%	558	118	242	73	10%
35	A1-35	3.03	33	199.8	65.9	727	0.992	100%	575	129	392	117	170%
36	A1-36	0.49	6	7.7	15.9	679	0.926	100%	536	103	50	15	51%
37	A1-37	0.36	2	17.9	49.3	662	0.904	100%	523	95	34	10	173%
38	A1-38	1.36	0	0.0	0.0	660	0.900	0%	521	94	127	38	0%
39	A1-39	1.17	19	87.3	74.9	691	0.943	100%	546	110	128	38	227%
40	A1-40	0.58	5	5.6	9.6	670	0.915	90%	530	99	58	17	32%
41	A1-41	0.83	11	17.4	21.0	690	0.941	100%	545	109	90	27	64%
42	A1-42	1.18	7	25.8	21.9	661	0.901	100%	522	94	111	33	77%
43	A1-43	1.26	16	43.7	34.6	696	0.950	100%	550	112	142	43	103%
44	A1-44	0.18	3	2.7	14.4	681	0.929	100%	538	104	19	6	46%
45	A1-45	0.50	2	1.5	3.1	670	0.914	10%	529	99	49	15	10%
46	A1-46	1.44	9	36.7	25.5	632	0.862	90%	499	80	116	35	106%

No.	Farm dam catchments	Area (km^2)	No. of dams	Dam capacity (ML)	Dam density (ML/km^2)	Av. annual rain (mm)	Rainfall factor	Diversion	Winter rain (mm)	Winter run-off (mm)	Winter run-off (ML)	RMCWMP limit (ML)	Level of development
47	A1-47	1.18	9	35.3	29.8	652	0.889	100%	515	90	106	32	111%
48	A1-48	4.96	45	209.3	42.2	696	0.950	100%	550	112	557	167	125%
49	A1-49	1.63	18	66.7	40.9	689	0.939	100%	544	108	177	53	126%
50	A1-50	2.05	15	96.1	47.0	644	0.879	100%	509	86	176	53	182%
51	A1-51	0.66	9	29.6	45.0	678	0.925	100%	536	103	68	20	146%
52	A1-52	0.84	17	26.6	31.5	707	0.964	100%	558	118	100	30	89%
53	A1-53	0.57	2	0.8	1.4	687	0.937	20%	543	107	61	18	4%
54	A1-54	0.70	11	5.4	7.8	675	0.921	70%	533	101	70	21	26%
55	A1-55	0.72	7	5.0	6.9	639	0.872	90%	505	84	61	18	27%
56	A1-56	0.30	2	2.4	8.1	663	0.904	100%	524	95	28	8	28%
57	A1-57	2.90	4	14.8	5.1	641	0.874	100%	506	85	246	74	20%
58	A1-58	1.62	3	8.4	5.2	634	0.865	100%	501	82	132	40	21%
Paris Creek sub-catchment													
59	A2-1	0.26	4	8.0	31.0	806	1.099	100%	637	175	45	14	59%
60	A2-2	0.08	1	0.2	3.1	806	1.099	100%	637	175	14	4	6%
61	A2-3	0.60	8	8.4	13.8	795	1.084	100%	628	168	102	31	27%
62	A2-4	0.77	2	3.4	4.5	781	1.066	50%	617	160	123	37	9%
63	A2-5	1.26	9	5.3	4.2	791	1.079	50%	625	166	209	63	8%
64	A2-6	0.53	9	14.0	26.3	772	1.053	100%	610	155	83	25	57%
65	A2-7	0.41	2	17.1	41.5	768	1.048	100%	607	153	63	19	91%
66	A2-8	1.48	8	21.4	14.5	769	1.049	100%	608	153	226	68	32%
67	A2-9	0.83	11	20.9	25.3	749	1.022	100%	592	142	117	35	59%
68	A2-10	0.82	5	24.2	29.6	734	1.002	100%	580	133	109	33	74%
69	A2-11	2.46	22	68.4	27.7	699	0.953	90%	552	114	280	84	81%
70	A2-12	1.42	14	48.9	34.4	814	1.110	100%	643	181	256	77	64%

No.	Farm dam catchments	Area (km^2)	No. of dams	Dam capacity (ML)	Dam density (ML/km^2)	Av. annual rain (mm)	Rainfall factor	Diversion	Winter rain (mm)	Winter run-off (mm)	Winter run-off (ML)	RMCWMP limit (ML)	Level of development
71	A2-13	0.49	5	5.3	10.7	809	1.104	80%	639	178	88	26	20%
72	A2-14	0.48	4	5.2	10.9	804	1.097	50%	635	174	84	25	21%
73	A2-15	6.22	51	201.9	32.5	764	1.043	100%	604	150	935	281	72%
74	A2-16	1.18	10	39.2	33.1	728	0.993	100%	575	130	153	46	85%
75	A2-17	0.38	1	11.0	29.0	689	0.939	50%	544	108	41	12	89%
76	A2-18	0.93	1	0.5	0.5	697	0.950	5%	550	113	104	31	2%
77	A2-19	1.00	0	0.0	0.0	656	0.895	0%	519	92	92	28	0%
77	A2-19A	0.50	4	7.5	15.1	656	0.896	100%	519	92	46	14	54%
78	A2-20	1.21	7	24.7	20.5	722	0.985	90%	571	126	153	46	54%
79	A2-21	0.38	3	8.8	23.2	675	0.920	100%	533	101	39	12	76%
80	A2-22	1.31	0	0.0	0.0	670	0.914	0%	529	99	129	39	0%
81	A2-23	0.44	7	10.5	24.1	790	1.078	80%	624	166	72	22	48%
82	A2-24	0.56	2	1.3	2.3	790	1.077	90%	624	165	92	28	5%
83	A2-25	0.86	15	14.6	16.9	807	1.101	100%	638	176	152	46	32%
84	A2-26	0.95	12	14.0	14.8	752	1.026	100%	594	143	136	41	34%
85	A2-27	0.94	11	24.3	25.9	767	1.046	100%	606	152	143	43	57%
86	A2-28	0.85	0	0.0	0.0	770	1.051	0%	609	154	131	39	0%
87	A2-29	0.29	3	2.0	6.9	708	0.967	90%	560	119	35	11	19%
88	A2-30	0.42	3	6.8	15.9	710	0.969	100%	561	120	51	15	44%
89	A2-31	1.34	2	4.7	3.5	714	0.974	100%	564	122	163	49	10%
90	A2-32	1.78	6	18.1	10.1	665	0.907	100%	525	96	172	52	35%
91	A2-33	1.05	3	15.5	14.8	602	0.822	70%	476	68	71	21	73%
92	A2-34	0.28	2	3.0	11.0	603	0.823	80%	477	68	19	6	54%
93	A2-35	4.26	5	44.9	10.6	591	0.807	100%	467	63	268	80	56%

No.	Farm dam catchments	Area (km^2)	No. of dams	Dam capacity (ML)	Dam density (ML/km^2)	Av. annual rain (mm)	Rainfall factor	Diversion	Winter rain (mm)	Winter run-off (mm)	Winter run-off (ML)	RMCWMP limit (ML)	Level of development
Dawson Creek sub-catchment													
94	A3-1	1.03	17	34.4	33.3	766	1.045	100%	605	151	156	47	74%
95	A3-2	1.07	5	6.5	6.1	729	0.995	100%	576	130	139	42	16%
96	A3-3	0.90	3	5.0	5.5	744	1.015	90%	588	139	125	38	13%
97	A3-4	0.54	4	21.2	39.2	723	0.987	100%	572	127	69	21	103%
98	A3-5	0.80	4	2.7	3.4	708	0.966	100%	560	119	95	29	10%
99	A3-6	0.52	2	4.5	8.6	689	0.940	100%	544	108	57	17	26%
100	A3-7	0.55	1	3.1	5.6	682	0.930	90%	539	105	58	17	18%
101	A3-8	1.12	8	24.5	21.9	653	0.891	90%	516	90	101	30	81%
102	A3-9	0.74	5	9.3	12.6	602	0.822	100%	476	68	50	15	62%
103	A3-10	0.23	2	3.1	13.6	640	0.873	100%	506	84	19	6	54%
104	A3-11	0.89	3	5.0	5.6	651	0.889	50%	515	90	80	24	21%
105	A3-12	0.32	2	2.0	6.4	587	0.801	50%	464	61	19	6	35%
106	A3-13	2.61	16	17.2	6.6	678	0.925	80%	536	103	269	81	21%
107	A3-14	2.48	0	0.0	0.0	623	0.850	0%	492	77	190	57	0%
108	A3-15	0.68	0	0.0	0.0	628	0.857	0%	496	79	53	16	0%
109	A3-16	1.10	0	0.0	0.0	625	0.853	0%	494	78	86	26	0%
110	A3-17	0.27	1	2.1	7.9	594	0.811	100%	470	64	17	5	41%
111	A3-18	0.86	2	2.3	2.7	596	0.812	100%	470	65	55	17	14%
112	A3-19	3.21	5	30.3	9.5	560	0.764	100%	443	51	164	49	62%
Burnside Creek sub-catchment													
113	A4-1	1.82	17	26.7	14.6	588	0.802	100%	465	62	112	34	79%
114	A4-2	0.38	4	3.8	10.0	613	0.836	100%	484	72	28	8	46%
115	A4-3	0.69	4	4.8	6.9	597	0.815	100%	472	66	45	14	35%
116	A4-4	0.41	2	2.0	4.8	582	0.793	90%	459	59	24	7	27%

No.	Farm dam catchments	Area (km^2)	No. of dams	Dam capacity (ML)	Dam density (ML/km^2)	Av. annual rain (mm)	Rainfall factor	Diversion	Winter rain (mm)	Winter run-off (mm)	Winter run-off (ML)	RMCWMP limit (ML)	Level of development
117	A4-5	1.05	2	11.8	11.2	560	0.764	100%	443	51	54	16	73%
118	A4-6	0.57	1	0.3	0.5	573	0.782	100%	453	56	32	10	3%
119	A4-7	0.17	1	15.7	91.3	556	0.758	70%	439	49	8	3	617%
120	A4-8	0.74	3	2.5	3.4	612	0.835	100%	483	72	53	16	16%
121	A4-9	0.66	1	2.7	4.1	584	0.797	100%	461	60	40	12	23%
122	A4-10	0.69	2	2.1	3.0	624	0.851	100%	493	77	53	16	13%
123	A4-11	0.15	1	3.3	22.6	623	0.850	100%	492	77	11	3	98%
124	A4-12	0.46	1	0.5	1.1	605	0.826	100%	478	69	32	10	5%
125	A4-13	1.26	5	37.2	29.5	583	0.796	100%	461	60	75	23	164%
126	A4-14	1.14	2	3.8	3.4	554	0.756	100%	438	49	56	17	23%
127	A4-15	1.83	4	2.1	1.2	542	0.739	90%	428	45	82	25	9%
128	A4-16	0.23	2	3.7	16.2	520	0.709	100%	411	37	9	3	144%
129	A4-17	0.68	0	0.0	0.0	521	0.711	0%	411	38	26	8	0%
130	A4-18	3.07	0	0.0	0.0	516	0.703	0%	407	36	111	33	0%

G. WC-1 — MODEL DESCRIPTION (CRESSWELL 2002)

WC-1 is a water balance model developed by David Cresswell based on experience with South Australian rainfall–run-off calibration in the Mount Lofty Ranges, Barossa Valley and Mid North. The program was developed in 1988 to estimate the impact of farm dams in the Barossa Valley when it was found that most of the existing models tried were not able to reproduce the recorded run-off of South Australia's drier catchments. When annual rainfall lies in the range 450–650 mm, the estimation of run-off becomes a tricky exercise.

Model Concept

WC-1 is a 10-parameter model using three storages as shown in Figure 26 to track interception, soil moisture and groundwater. The soil store is generally the main run-off producing component requiring four parameters for calibration.

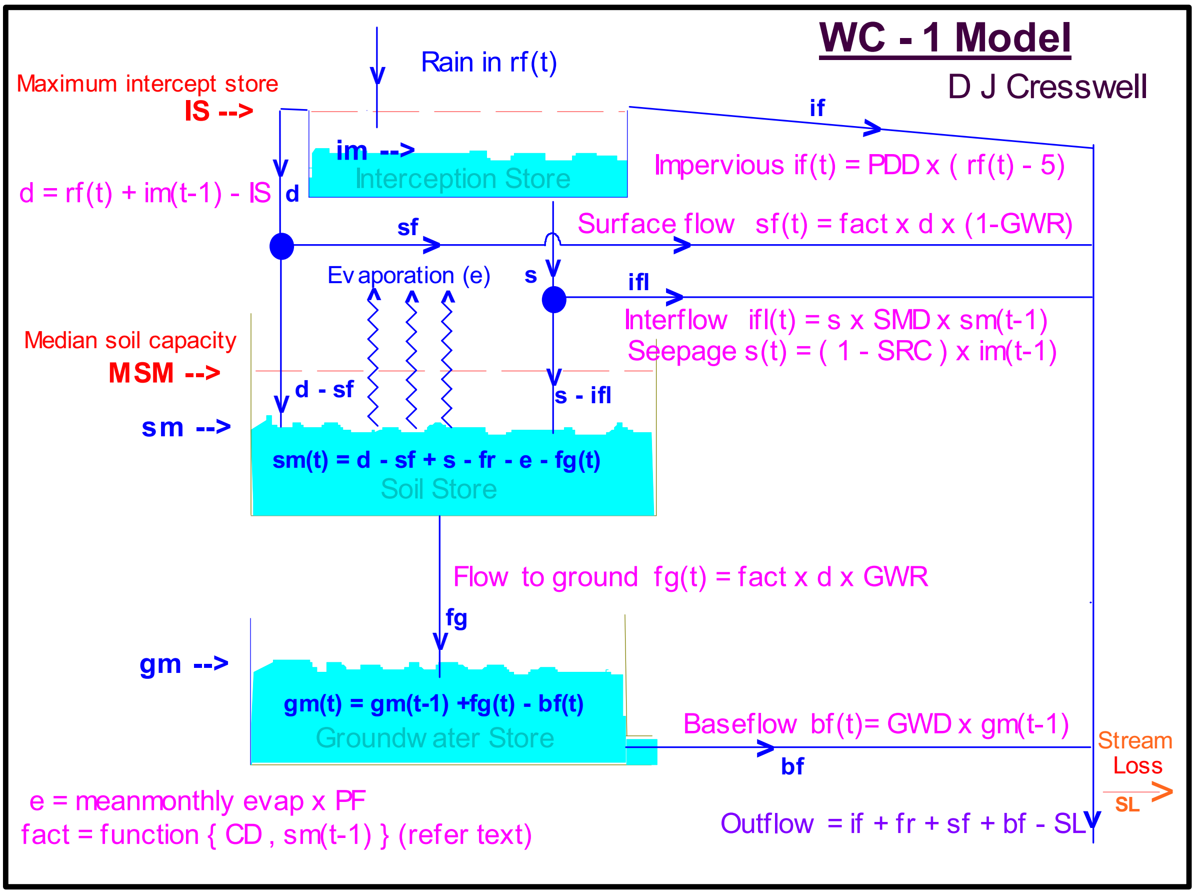


Figure 26. WC-1 model concept

Surface run-off (not including the groundwater contribution) is calculated with both a hortonian and saturated surface area component. The hortonian component is generally small and is calculated as the run-off from an impervious area that has a daily loss rate of 5 mm. The parameter PDD is used to input the fraction of the catchment contributing.

By far the greatest proportion of surface flow is dependent on the saturated surface area of the catchment. This can be determined by the model which tracks the soil storage and calculates the area saturated based on the assumption that the soil moisture holding capacity is normally distributed across the catchment. This is shown in Figure 27.

To calibrate such a model, two parameters are required, the median soil moisture of the catchment (MSM) and the catchment standard distribution (CD). These values are typically in the range 150–250 mm (MSM) and 20–80 mm (CD).

When dry, the soil moisture lies >3 standard deviations to the left of the median centre and as the catchment wets up moves towards the fully saturated catchment which occurs at median soil moisture +3 standard deviations. At any point on the axis, the proportion of catchment assumed to be saturated is calculated as the area under the normal distribution curve.

For example, Figure 27 indicates that when the soil moisture of the soil store reaches MSM – 1.6 x CD, the area shaded is the proportion of the catchment contributing to the run-off. From normal distribution tables this is 5.5% of the catchment.

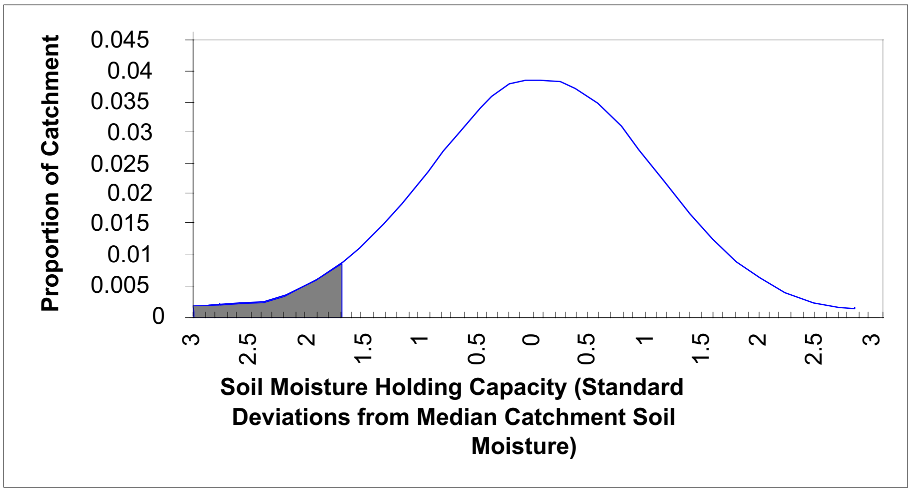


Figure 27. Contributing catchment calculated from soil moisture

When the median soil moisture is reached, the catchment contributing is 50% as shown in Figure 28.

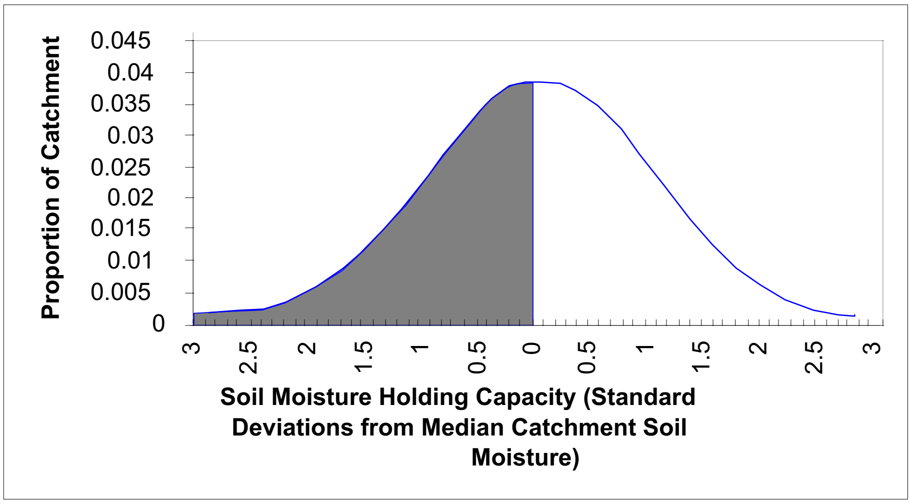


Figure 28. Contributing catchment calculated from soil moisture

The shape of this relationship (Fig. 29) is similar to a power curve but asymptotic to Y = 0 and Y = 1. Intuitively, this is what is expected and overcomes the problem of the power curve that is required to be limited to 1.0.

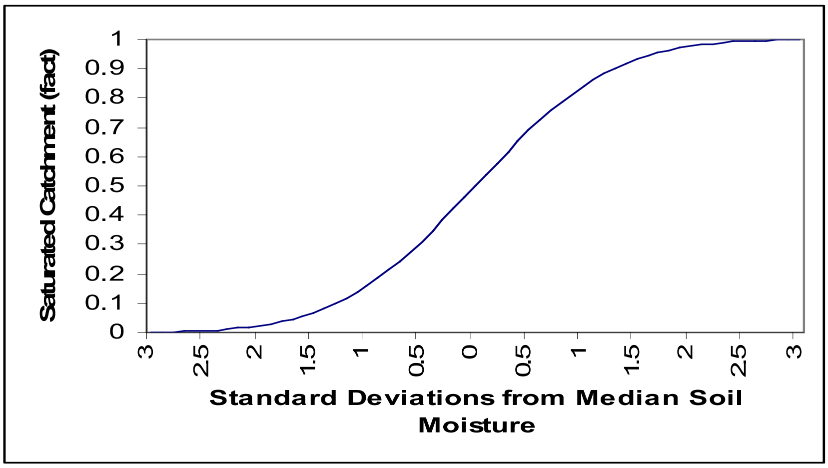


Figure 29. Contributing catchment calculated from soil moisture

The volume of water running off the catchment is then the product of the contributing area and the effective rainfall. Catchments in semi-arid areas show a capacity to retain quite significant rainfall events requiring the use of an interception store for accurate simulation.

The effective rainfall is defined as the volume of water spilling the interception store.

The maximum interception store (IS) may typically range from 0 to 30 mm and is tracked continuously within the model. Water may leave the interception storage either by overtopping the storage, thus becoming effective rainfall, or it may percolate slowly into the soil store where it contributes to an interflow component of flow. This percolation occurs at a rate calculated in a similar way to the Annual Precipitation Index (API).

The transfer rate is independent of season and is set by the soil wetness multiplier (SWM) typically to a value of 0.9. The value set is the proportion of the water held in the store (im(t)) which is retained to the next day. Seepage (s) is calculated as:

S = (1 – SWM) x im(t)

During the wet season, the baseflow of the streams is seen to rise but the duration of such flow remains dependent on relatively continuous rain falling on the catchment. It is proposed that this baseflow return occurs due to the over-saturated areas of the catchment returning a fraction of this moisture back to the streams. As the catchment dries or during long spells of no rain, it is expected that this return will drop to zero.

This interflow (Ifl) is assumed in the model to equal

Ifl = s x SMD x sm(t)

SMD is the parameter defining the proportion returned to the stream.

The catchment response is therefore defined by the six parameters mentioned above but evaporation can potentially override all of these. In semi-arid catchments, choosing the correct evaporation rate is critical.

Models use various formulas ranging from linear to power functions to estimate the moisture loss from soils. Experimentation with the linear model was not found to improve the estimate of run-off and was discarded for the simpler constant model. Here, evapo-transpiration is assumed to equal the pan factor times recorded daily evaporation. A value of 0.6–0.7 is typically used for class A pan recordings.

Groundwater is simulated within the model using two parameters — GWR (recharge) and GWD (discharge). Both operate in a simple linear fashion.

Groundwater recharge is seen to have a greater relationship with streamflow than total rainfall. This suggests that groundwater recharge requires similar conditions to streamflow, hence the wetting up of the catchment, to occur. Tying recharge to streamflow simulates this, which assumes the greater saturated catchment-generated streamflow occurring the more recharge occurs from the soil to groundwater store.

The parameter GWR is used to define the proportion passing to ground and often this may be up to 20–30%.

Baseflow discharging from the groundwater store is simply a linear relationship defined by parameter GWD. No loss is assumed to occur from the groundwater store to external basins.

Summary of WC-1 Parameters

Medium soil moisture (MSM) — Represents the field capacity of the soil, which is usually in the range 150–300 mm. Increasing this value delays the early season initiation of run-off, decreases run-off by providing greater opportunity for evapo-transpiration and assists in keeping late season groundwater flows up.

Interception store (IS) — Represents the maximum initial abstraction from rainfall before any run-off can occur. The normal range is 10–25 mm. A larger value will inhibit run-off after dry spells and reduce the total amount of run-off.

Catchment distribution (CD) — Describes the deviation of soil moisture from a mean value (MSM). Usual values are 25–60 mm. A larger value will initiate run-off earlier and more often.

Groundwater Discharge (GWD) — The proportion of the groundwater store that discharges as baseflow to the stream. This is a simple linear function:

Baseflow = groundwater store x GWD

Usual values are small, in the range 0.001–0.0001.

Soil moisture discharge (SMD) — As soil moisture increases there is a rise in the baseflow that occurs due to the saturation of the soil storage. Values are usually small, around 0.0001.

Pan factor for soil (PF) — This factor is applied to the daily evaporation calculated from the monthly pan evaporation data. The usual range is 0.6–1.0. The higher the value, the less the run-off and the earlier that run-off ceases after winter.

Proportion direct drainage (PDD) — This is the proportion of the catchment that can be considered relatively impervious. After an initial loss of 5 mm, rainfall on this area will be discharged as surface flow. Usual values for this are zero.

Store wetness multiplier (SWM) — This value determines the rate that water from the interception store moves to the soil store. The transfer rate is independent of season and ensures that the amount of water retained in the interception store follows a similar power recession curve of the API. Usual values are around 0.9.

Groundwater recharge (GWR) — The proportion of rainfall that recharges the groundwater store. Usual values are 0.05–0.3, indicating that 5–30% of the flow running off the catchment is entering the groundwater system.

Creek loss (CL) — A reduction factor used to decrease run-off. It is generally set to zero.

Values for the parameters used for calibrating the Upper Angas sub-catchment model:

MSM	102.5
IS	15
CD	25
GWD	0.003
SWD	0.0008
PF	0.7
FGL	0.15
SWM	0.9
GWR	0.35
Routing coefficients	2.0, 0.7

H. METHODOLOGY USED FOR DISAGGREGATION OF ACCUMULATED RAINFALL RECORDS

Rainfall data are 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 Sinclair Knight Merz for disaggregation of rainfall data is based on the method outlined by Ladson and Porter (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 are 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,

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

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, the consultants developed an automated procedure for in-filling the data and it was limited to a search of 15 closest rainfall stations only.

I. TREND TEST *(Grayson et al. 1996)*

Mann's Test (Kendall 1970)

Given a time series (X_1, X_2, X_3, …..X_n), Mann's Test statistically tests the null hypothesis H_0 that the observations are randomly ordered versus the alternative of a monotonic trend over time. Let R_1, R_2, R_3, …R_n be the ranks of the corresponding X values and define the function sgn(x) as follows:

sgn(x) = 1 for x > 0, sgn(x) = 0, for x = 0 and sgn(x) = -1 for x < 0

If the null hypothesis is true, the statistic:

$$S = \sum_{i<j} \mathrm{sgn}(R_j - R_i)$$

has a mean of zero and a variance of:

Var(S) = (n (n-1) (2n+5)) / 18

and is asymptotically normal. The normal Z-test statistic is,

$u(n) = S / [Var(S)]^{0.5}$

The statistic u(n) can be computed for any values of i to detect whether there is a trend in the data up to i at the chosen level of significance using the z-test. A positive value of u(n) indicates that there is an increasing trend and vice versa.

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
day	d	24 h	time interval
gigalitre	GL	10^6 m^3	volume
gram	g	10^{-3} kg	mass
hectare	ha	10^4 m^2	area
hour	h	60 min	time interval
kilogram	kg	base unit	mass
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
metre	m	base unit	length
microgram	µg	10^{-6} g	mass
microlitre	µL	10^{-9} m^3	volume
milligram	mg	10^{-3} g	mass
millilitre	mL	10^{-6} m^3	volume
millimetre	mm	10^{-3} m	length
minute	min	60 s	time interval
second	s	base unit	time interval
tonne	t	1000 kg	mass
year	y	365 or 366 days	time interval

GLOSSARY

Act (the). In this document, refers to The *Natural Resources Management Act* (South Australia) 2004.

Annual adjusted catchment yield. Annual catchment yield with the impact of dams removed.

Aquifer. An underground layer of rock or sediment which holds water and allows water to percolate through.

Aquifer, confined. Aquifer in which the upper surface is impervious and the water is held at greater than atmospheric pressure. Water in a penetrating well will rise above the surface of the aquifer.

Aquifer, storage and recovery (ASR). The process of recharging water into an aquifer for the purpose of storage and subsequent withdrawal.

Aquifer, unconfined. Aquifer in which the upper surface has free connection to the ground surface and the water surface is at atmospheric pressure.

Aquitard. A layer in the geological profile that separates two aquifers and restricts the flow between them.

Baseflow. The water in a stream that results from groundwater discharge to the stream. (This discharge often maintains flows during seasonal dry periods and has important ecological functions.)

Basin. The area drained by a major river and its tributaries.

Biological diversity (biodiversity). The variety of life forms: the different life forms including plants, animals and micro-organisms, the genes they contain and the *ecosystems (see below)* they form. It is usually considered at three levels — genetic diversity, species diversity and ecosystem diversity.

Catchment. A catchment is that area of land determined by topographic features within which rainfall will contribute to run-off at a particular point.

Catchment water management board. A statutory body established under Part 6, Division 3, s. 53 of the Act whose prime function under Division 2, s. 61 is to implement a catchment water management plan for its area.

Catchment water management plan. The plan prepared by a CWMB and adopted by the Minister in accordance with Part 7, Division 2 of the Water Resources Act 1997.

CWMB. Catchment Water Management Board.

Dams, off-stream dam. A dam, wall or other structure that is not constructed across a watercourse or drainage path and is designed to hold water diverted, or pumped, from a watercourse, a drainage path, an aquifer or from another source. Off-stream dams may capture a limited volume of surface water from the catchment above the dam.

Dams, on-stream dam. A dam, wall or other structure placed or constructed on, in or across a watercourse or drainage path for the purpose of holding and storing the natural flow of that watercourse or the surface water.

Dams, turkey nest dam. An off-stream dam that does not capture any surface water from the catchment above the dam.

Domestic purpose. The taking of water for ordinary household purposes and includes the watering of land in conjunction with a dwelling not exceeding 0.4 hectares.

Domestic wastewater. Water used in the disposal of human waste, for personal washing, washing clothes or dishes, and swimming pools.

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

EC. Abbreviation for electrical conductivity. 1 EC unit = 1 micro-Siemen per centimetre (µS/cm) measured at 25 degrees Celsius. Commonly used to indicate the salinity of water.

Ecological processes. All biological, physical or chemical processes that maintain an ecosystem.

Ecological values. The habitats, the natural ecological processes and the biodiversity of ecosystems.

Ecologically sustainable development (ESD). Using, conserving and enhancing the community's resources so that ecological processes, on which life depends, are maintained, and the total quality of life, now and in the future, can be increased.

Ecology. The study of the relationships between living organisms and their environment.

Ecosystem. Any system in which there is an interdependence upon and interaction between living organisms and their immediate physical, chemical and biological environment.

EMLR. Eastern Mount Lofty Ranges.

Environmental values. The uses of the environment that are recognised as of value to the community. This concept is used in setting water quality objectives under the Environment Protection (Water Quality) Policy, which recognises five environmental values — protection of aquatic ecosystems, recreational water use and aesthetics, potable (drinking water) use, agricultural and aquaculture use, and industrial use. It is not the same as ecological values, which are about the elements and functions of ecosystems.

Environmental water provisions. Those parts of environmental water requirements that can be met, at any given time. This is what can be provided at that time with consideration of existing users' rights, social and economic impacts.

Environmental water requirements. The water regimes needed to sustain the ecological values of aquatic ecosystems, including their processes and biological diversity, at a low level of risk.

Ephemeral streams/wetlands. Those streams or wetlands that usually contain water only on an occasional basis after rainfall events. Many arid zone streams and wetlands are ephemeral.

Erosion. Natural breakdown and movement of soil and rock by water, wind or ice. The process may be accelerated by human activities.

Evapotranspiration. The total loss of water as a result of transpiration from plants and evaporation from land, and surface waterbodies.

Floodplain. Of a watercourse means: (a) the floodplain (if any) of the watercourse identified in a catchment water management plan or a local water management plan; adopted under Part 7 of the Water Resources Act 1997; or (b) where paragraph (a) does not apply — the floodplain (if any) of the watercourse identified in a development plan under the Development Act 1993, or (c) where neither paragraph (a) nor paragraph (b) applies — the land adjoining the watercourse that is periodically subject to flooding from the watercourse.

Flow bands. Flows of different frequency, volume and duration.

Gigalitre (GL). One thousand million litres (1 000 000 000).

GIS (geographic information system). Computer software allows for the linking of geographic data (for example land parcels) to textual data (soil type, land value, ownership). It allows for a range of features, from simple map production to complex data analysis.

GL. *See gigalitre.*

Geological features. Include geological monuments, landscape amenity and the substrate of land systems and ecosystems.

Groundwater. *See undergroundwater.*

Habitat. The natural place or type of site in which an animal or plant, or communities of plants and animals, lives.

Hydrogeology. The study of groundwater, which includes its occurrence, recharge and discharge processes and the properties of aquifers. *(See hydrology.)*

Hydrography. The discipline related to the measurement and recording of parameters associated with the hydrological cycle, both historic and real time.

Hydrology. The study of the characteristics, occurrence, movement and utilisation of water on and below the earth's surface and within its atmosphere. *(See hydrogeology.)*

Indigenous species. A species that occurs naturally in a region.

Infrastructure. Artificial lakes; or dams or reservoirs; or embankments, walls, channels or other works; or buildings or structures; or pipes, machinery or other equipment.

Integrated catchment management. Natural resources management that considers in an integrated manner the total long-term effect of land and water management practices on a catchment basis, from production and environmental viewpoints.

Intensive farming. A method of keeping animals in the course of carrying on the business of primary production in which the animals are confined to a small space or area and are usually fed by hand or by mechanical means.

Irrigation. Watering land by any means for the purpose of growing plants.

Irrigation season. The period in which major irrigation diversions occur, usually starting in August–September and ending in April–May.

Lake. A natural lake, pond, lagoon, wetland or spring (whether modified or not) and includes: part of a lake; and a body of water declared by regulation to be a lake; a reference to a lake is a reference to either the bed, banks and shores of the lake or the water for the time being held by the bed, banks and shores of the lake, or both, depending on the context.

Land. Whether under water or not and includes an interest in land and any building or structure fixed to the land.

Land capability. The ability of the land to accept a type and intensity of use without sustaining long-term damage.

Licence. A licence to take water in accordance with the Water Resources Act 1997. *(See water licence.)*

Licensee. A person who holds a water licence.

Local water management plan. A plan prepared by a council and adopted by the Minister in accordance with Part 7, Division 4 of the Act.

Macro-invertebrates. Animals without backbones that are typically of a size that is visible to the naked eye. They are a major component of aquatic ecosystem biodiversity and fundamental in food webs.

MDBC. Murray-Darling Basin Commission.

Megalitre (ML). One million litres (1 000 000).

ML. *See megalitre.*

MLR. Mount Lofty Ranges.

Model. A conceptual or mathematical means of understanding elements of the real world which allows for predictions of outcomes given certain conditions. Examples include estimating storm run-off, assessing the impacts of dams or predicting ecological response to environmental change.

Mount Lofty Ranges Watershed. The area prescribed by Schedule 1 of the regulations.

Natural recharge. The infiltration of water into an aquifer from the surface (rainfall, streamflow, irrigation etc.) *(See recharge area, artificial recharge.)*

Natural Resources. Soil; water resources; geological features and landscapes; native vegetation, native animals and other native organisms; ecosystems.

Natural Resources Management (NRM). All activities that involve the use or development of natural resources and/or that impact on the state and condition of natural resources, whether positively or negatively.

Occupier of land. A person who has, or is entitled to, possession or control of the land.

Owner of land. In relation to land alienated from the Crown by grant in fee simple — the holder of the fee simple; in relation to dedicated land within the meaning of the *Crown Lands Act 1929* that has not been granted in fee simple but which is under the care, control and management of a Minister, body or other person — the Minister, body or other person; in relation to land held under Crown lease or licence — the lessee or licensee; in relation to land held under an agreement to purchase from the Crown — the person entitled to the benefit of the agreement; in relation to any other land — the Minister who is responsible for the care, control and management of the land or, if no Minister is responsible for the land, the Minister for Environment and Heritage.

Pasture. Grassland used for the production of grazing animals such as sheep and cattle.

Percentile. A way of describing sets of data by ranking the data set and establishing the value for each percentage of the total number of data records. The 90th percentile of the distribution is the value such that 90% of the observations fall at or below it.

Permeability. A measure of the ease with which water flows through an aquifer or aquitard.

Personal property. All forms of property other than real property. For example, shares or a water licence.

PIRSA. (Department of) Primary Industries and Resources South Australia.

Potable water. Water suitable for human consumption.

Prescribed area, surface water. Part of the State declared to be a surface water prescribed area under the Water Resources Act 1997.

Prescribed lake. A lake declared to be a prescribed lake under the Water Resources Act 1997.

Prescribed water resource. A water resource declared by the Governor to be prescribed under the Act, and includes undergroundwater to which access is obtained by prescribed wells. Prescription of a water resource requires that future management of the resource be regulated via a licensing system.

Prescribed watercourse. A watercourse declared to be a prescribed watercourse under the Water Resources Act 1997.

Prescribed well. A well declared to be a prescribed well under the Water Resources Act 1997.

Property right. A right of ownership or some other right to property, whether real property or personal property.

Proponent. The person or persons (who may be a body corporate) seeking approval to take water from prescribed water.

PWA. Prescribed Wells Area.

PWCA. Prescribed Watercourse Area.

PWRA. Prescribed Water Resources Area.

Recharge area. The area of land from which water from the surface (rainfall, streamflow, irrigation, etc.) infiltrates into an aquifer. *(See artificial recharge, natural recharge.)*

Rehabilitation (of waterbodies). Actions that improve the ecological health of a waterbody by reinstating important elements of the environment that existed prior to European settlement.

Remediation (of waterbodies). Actions that improve the ecological condition of a waterbody without necessarily reinstating elements of the environment that existed prior to European settlement.

Restoration (of waterbodies). Actions that reinstate the pre-European condition of a waterbody.

Reticulated water. Water supplied through a piped distribution system.

Riparian landholder. A person whose property abuts a watercourse or through whose property a watercourse runs.

Riparian rights. These were old common law rights of access to, and use of water. These common law rights were abolished with the enactment of the Water Resources Act 1997, which now includes similar rights under s. 7. Riparian rights are therefore now statutory rights under the Act. Where the resource is not prescribed (Water Resources Act 1997, s. 8) or subject to restrictions (Water Resources Act 1997, s. 16), riparian landholders may take any amount of water from watercourses, lakes or wells without consideration to downstream landholders, if it is to be used for stock or domestic purposes. If the capture of water from watercourses and groundwater is to be used for any other purpose then the right of downstream landholders must be protected. Landholders may take any amount of surface water for any purpose without regard to other landholders, unless the surface water is prescribed or subject to restrictions.

Riparian zone. That part of the landscape adjacent to a water body, that influences and is influenced by watercourse processes. This can include landform, hydrological or vegetation definitions. It is commonly used to include the in-stream habitats, bed, banks and sometimes floodplains of watercourses.

Seasonal watercourses or wetlands. Those watercourses and wetlands that contain water on a seasonal basis, usually over the winter/spring period, although there may be some flow or standing water at other times.

State water plan. The plan prepared by the Minister under Part 7, Division 1, s. 90 of the Act.

Stock Use. The taking of water to provide drinking water for stock other than stock subject to intensive farming (as defined by the Act).

Stormwater. Run-off in an urban area.

Surface water. (a) water flowing over land (except in a watercourse), (i) after having fallen as rain or hail or having precipitated in any another manner, (ii) or after rising to the surface naturally from underground; (b) water of the kind referred to in paragraph (a) that has been collected in a dam or reservoir.

To take water. From a water resource includes (a) to take water by pumping or siphoning the water; (b) to stop, impede or divert the flow of water over land (whether in a watercourse or not) for the purpose of collecting the water; (c) to divert the flow of water in a watercourse from the watercourse; (d) to release water from a lake; (e) to permit water to flow under natural pressure from a well; (f) to permit stock to drink from a watercourse, a natural or artificial lake, a dam or reservoir.

Transfer. A transfer of a licence (including its water allocation) to another person, or the whole or part of the water allocation of a licence to another licensee or the Minister under Part 5, Division 3, s. 38 of the Act. The transfer may be absolute or for a limited period.

Undergroundwater (groundwater). Water occurring naturally below ground level or water pumped, diverted or released into a well for storage underground.

Volumetric allocation. An allocation of water expressed on a water licence as a volume (e.g. kilolitres) to be used over a specified period of time, usually per water use year (as distinct from any other sort of allocation).

Water affecting activities. Activities referred to in Part 4, Division 1, s. 9 of the Act.

Water allocation. (a) in respect of a water licence means the quantity of water that the licensee is entitled to take and use pursuant to the licence; (b) in respect of water taken pursuant to an authorisation under s. 11 means the maximum quantity of water that can be taken and used pursuant to the authorisation.

Water allocation, area based. An allocation of water that entitles the licensee to irrigate a specified area of land for a specified period of time usually per water use year.

Water allocation plan (WAP). A plan prepared by a CWMB or water resources planning committee and adopted by the Minister in accordance with Division 3 of Part 7 of the Act.

Water licence. A licence granted under the Act entitling the holder to take water from a prescribed watercourse, lake or well or to take surface water from a surface water prescribed area. This grants the licensee a right to take an allocation of water specified on the licence, which may also include conditions on the taking and use of that water. A water licence confers a property right on the holder of the licence and this right is separate from land title.

Water plans. The State Water Plan, catchment water management plans, water allocation plans and local water management plans prepared under Part 7 of the Act.

Water service provider. A person or corporate body that supplies water for domestic, industrial or irrigation purposes or manages wastewater.

Waterbody. Waterbodies include watercourses, riparian zones, floodplains, wetlands, estuaries, lakes and groundwater aquifers.

Watercourse. A river, creek or other natural watercourse (whether modified or not) and includes: a dam or reservoir that collects water flowing in a watercourse; and a lake through which water flows; and a channel (but not a channel declared by regulation to be excluded from the this definition) into which the water of a watercourse has been diverted; and part of a watercourse.

Water-dependent ecosystems. Those parts of the environment, the species composition and natural ecological processes, which are determined by the permanent or temporary presence of flowing or standing water, above or below ground. The in-stream areas of rivers, riparian vegetation, springs, wetlands, floodplains, estuaries and lakes are all water-dependent ecosystems.

Water-use year. The period between 1 July in any given calendar year and 30 June the following calendar year. This is also called a licensing year.

Well. (a) an opening in the ground excavated for the purpose of obtaining access to undergroundwater; (b) an opening in the ground excavated for some other purpose but that gives access to undergroundwater; (c) a natural opening in the ground that gives access to undergroundwater.

Wetlands. Defined by the Act as a swamp or marsh and includes any land that is seasonally inundated with water. This definition encompasses a number of concepts that are more specifically described in the definition used in the Ramsar Convention on Wetlands of International Importance. This describes wetlands as areas of permanent or periodic/intermittent inundation, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tides does not exceed six metres.

BIBLIOGRAPHY

Boughton, WC 1996, ‘A mathematical model for relating run-off to rainfall with daily data’, Institute of Engineers Australia, *Civil Engineering Transactions,* CE8(1).

Bradley, J & Billington, K 2002, ‘Land status data mapping of the Mount Lofty Ranges watershed’, Watershed Protection Office, Environment Protection Agency, Department for Environment and Heritage, South Australia.

Cresswell, DJ 1991, *Integrated management of farm dams in the Barossa Valley*, Report EWS 91/7, Engineering and Water Supply Department, Adelaide.

Cresswell, DJ 2002, ‘WaterCress — Water – Community Resource Evaluation and Simulation System’, Department of Water, Land and Biodiversity Conservation, Adelaide.

Draper, NR and Smith, H 1998, *Applied regression analysis,* 3rd edn, John Wiley & Sons Inc., New York.

Earth Tech Engineering Pty Ltd 2004, ‘Watercourse risk assessment — geomorphology and vegetation, Angas and Tookayerta Catchments’, River Murray Catchment Water Management Board, Berri, South Australia.

Grayson, RB, Argent, RM, Nathan, RJ, McMahon, TA & Mein, GR, 1996, *Hydrological recipes — estimation techniques in Australian hydrology,* Cooperative Research Centre for Catchment Hydrology, Clayton, Victoria, pp.77-83.

Hammer, M 2002, ‘Faunal patterns and environmental flow requirements for fishes in the Angas River Catchment, South Australia’, draft report, River Murray Catchment Water Management Board, Berri, South Australia.

Heneker, TM 2003, *Surface water assessment of the Upper River Torrens Catchment,* Report DWLBC 2003/24, Department of Water, Land and Biodiversity Conservation, Adelaide.

Kendall, MG 1970, *Rank correlation methods* 4th edn, Griffen, London.

Ladson, AR & Porter JW 1993, ‘An application for fixed-area rainfall reduction factors’, Hydrology and Water Resources Symposium, Newcastle, 30 June–2 July 1993.

McMurray, D 2003, ‘Assessment of water use from farm dams in the Mount Lofty Ranges’, draft report, Department of Water, Land and Biodiversity Conservation, Adelaide.

River Murray Catchment Water Management Board, 2003. Catchment Water Management Plan for the River Murray in South Australia, 2003–2008, Berri, South Australia.

Shaw, EM 1994, *Hydrology in practice*, Nelson Thornes Ltd, UK.

Sinclair Knight Merz Pty Ltd 2000, ‘South Australian daily rainfall data — explanation of infilled and disaggregated data sets’, CD Version 1, Melbourne.

Stanger, G 1994, *Dictionary of hydrology and water resources.* Flinders University, Adelaide.

Savadamuthu, K 2002, *Impact of farm dams on streamflow in the Upper Marne Catchment,* Report DWR 01/01/2003, Department for Water Resources, Adelaide.

Savadamuthu, K 2003, *Surface water assessment of the Upper Finniss Catchment,* Report DWLBC 2003/18, Department of Water, Land and Biodiversity Conservation, Adelaide.

Savadamuthu, K 2004, *Surface water assessment of the Tookayerta Catchment,* Report DWLBC 2004/23, Department of Water, Land and Biodiversity Conservation, Adelaide.

Teoh, KS 2002, *Estimating the impact of current farm dams development on the surface water resources of the Onkaparinga River Catchment,* Report DWR 2002/22, Department of Water, Land and Biodiversity Conservation, Adelaide.