Surface Water Assessment of the Tookayerta Catchment

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Foreword

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

Management of water resources requires a sound understanding of key factors such as physical extent (quantity), quality, availability, and constraints to development. It also requires a collaborative effort between government departments, catchment water management boards and the community. This study was undertaken as a collaboration between the River Murray Catchment Water Management Board and the Department of Water, Land and Biodiversity Conservation, with support from the local community group, Compass Creek Care Inc. The material provided in this report will form a technical basis for future water resources management policies and measures.

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EXECUTIVE SUMMARY

Surface water use in the highlands and ground water 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 ecosystems dependent on them. Preliminary investigations indicate 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 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 State 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 declaration of the Notices, the Eastern Mount Lofty Ranges Water Resources Management Program was set up between the River Murray Catchment Water Management Board ("RMCWMB") and the Department of Water, Land and Biodiversity Conservation ("DWLBC"). One of the objectives of the program was to carry out a series of detailed hydrological studies of the individual catchments in the EMLR. This study of the Tookayerta catchment forms a part of that series of studies.

This technical report describes the methodology and outcomes of the detailed hydrological study of the Tookayerta catchment. The study quantifies the surface water resources within the catchment, examines the impact of farm dams on the resources using rainfall-runoff modelling and provides guidance regarding future water resources management policies. This report will be used as a technical foundation for the State Government's consideration of water resources management measures required for this catchment. The main findings of the study are summarised below and further detailed in the "Conclusions" section of the report.

The Catchment The Tookayerta catchment, located in the south-eastern side of the EMLR, is one of the few catchments in the EMLR where flows occur year round. The catchment is hydrogeologically unique to the region due to the presence of extensive Permian sand aquifers with extensive good quality ground water resources that contribute to high baseflows during summer. The catchment is also considered to be of high ecological value with its numerous swamps and wetlands that provide habitat to a variety of unique flora and fauna.

Hydrology The catchment is one of the high rainfall catchments of the EMLR, with annual rainfall varying between 500 mm to 850 mm across the catchment and a mean annual rainfall of 770 mm. 80% of this rainfall occurs during the winter months between May and November. Long-term rainfall records indicate that the average decadal rainfall during the last two decades have been generally lower than the long-term average.

The absence of long-term recorded streamflow data necessitated the use of modelled streamflow data for analysis purposes. The data indicates that the Tookayerta is a high yielding catchment (25% of rainfall runs off) in comparison to other catchments in the EMLR. It also indicates that base flows contribute to around half of the catchment flows, which is quite high in comparison with other EMLR catchments. This highlights the importance of the high yielding and extensive groundwater resources that contribute to those baseflows.

Farm Dam Development Farm dam development, indicated by the density of dams, is much lower in the Tookayerta catchment compared with similar high rainfall catchments in the EMLR. Based on 2001 data, there are around 540 farm dams with an estimated total storage capacity of 1100 ML. The current level of farm dam development in all the three major sub-catchments viz., the Nangkita Creek, the Cleland Gully and the Lower Tookayerta are below the allowable development limits set in the RMCWMP.

The allowable development limits set in the RMCWMP were estimated with a runoff coefficient of 0.10. While this runoff coefficient is an average estimate for the entire EMLR, and was used as an initial basis for planning on a regional basis, it varies widely on an individual catchment level. Streamflow records and modelled runoff data for the catchment indicate a much higher runoff coefficient of 0.25 for the Tookayerta catchment.

Impacts of Farm Dams on Catchment Runoff The rainfall-runoff model constructed and calibrated for the catchment was run for three farm dam development scenarios, viz., (i) Pre-farm dam development – current farm dams (2001) removed from catchment model, (ii) Farm Dams developed to RMCWMP limits[*] and (iii) Farm Dams development with provision for free-to-flow areas ("Free-to-Flow scenario"). Comparison of catchment runoff from the three scenarios indicate that:

Annual Impacts The current (2001) level of farm dam development in the Tookayerta catchment has potentially reduced the median annual adjusted runoff (runoff simulated with the impact of farm dams removed) from the catchment by 4%. This reduction is estimated to have been higher during drier years (10% reduction in1980) and marginal during wetter years (2% reduction 1979, 1992). A further reduction of 10% and 8% to the current median annual runoff was estimated if current farm dam capacities were increased to the development limits set in the RMCWMP and in the Free-to-Flow scenarios respectively. On a sub-catchment level the Lower Tookayerta has the greatest potential impact from development for each scenario, because it is currently the least developed catchment. Elsewhere, the level of development is fairly even.

Seasonal Impacts Flows during summer months have potentially been more impacted (17% reduction) by the current dams than winter flows, which have potentially been reduced by a minimal 1%. Setting diversion limits as well as development limits appears to reduce seasonal impacts. There is a much lower impact on summer flows from the Free-to-Flow scenario, which incorporates a 50% diversion limit, than the development control scenario based on the RMCWMP. Setting of the diversion limits led to retention of only a part of the summer flows by the dams and consequently leading to a delay in the filling and spilling of the dams.

Daily Impacts The current dams have potentially impacted only a limited section of the catchment's flow regime (10ML/day – 50 ML/day), and have had no significant impacts on other flows ranges viz., baseflows/low flows, high mid flows and high flows. Increasing development in the Tookayerta catchment will increase the daily flow band that is impacted significantly. However, the Free-to-Flow development scenario has a siginificantly lower impact than development under RMCWMP scenario. For instance, the current median daily flow of 23.6 ML/day was reduced by 5 ML under the Free-to-Flow scenario, while this reduction doubled under the RMCWMP scenario.

[*] *RMCWMP Limits - only 30% of May to November runoff can be captured by dams; in this study a runoff ceoffecient of 0.25 was used in runoff calcluations as against a runoff coefficient of 0.10 used in the RWMCWP.*

Key Findings, Conclusions and Recommendations The estimated impact of current farm dams on Tookayerta catchment's flow regime is low in comparison to similar catchments in the EMLR. However, as indicated by the results of modelling, uncontrolled future development can have a significant impact on the catchment's flow regime. The results of two possible future development scenarios modelled in this study also layout some key principles for sustainable future development within the catchment. These key principles, as outlined below, should be considered during the water allocation planning process.

- Define streams, permanent pools and wetlands from where water extraction is not allowed (for example, the main streams viz., the Cleland Gully, the Nangkita Creek and the lower Tookayerta Creek)

- Limit on-stream dam development to areas higher in the catchment

- Define conditions for permissible diversions into new off-stream dams located in other areas of the catchment.

This will ensure that the current baseflows that are crucial to the catchment's extensive water dependent ecosystems are not captured, while further development is allowed to continue to sustainable limits.

Groundwater potentially faces a greater risk of over extraction in the Tookayerta catchment, due to extensive good quality resources of it being available. Over exploitation of groundwater will reduce baseflow, and consequently impact the health of the numerous water dependant ecosystems in the catchment. Due to the high interaction between the surface and ground water resources in the catchment, it is recommended that the two resources be integrated in any future water allocation planning process.

Further studies are required to assess the current status of the catchments diverse water-dependent ecosystems and estimate their water requirements. Study(s) that quantify the groundwater resources within the catchment are crucial for obtaining a comprehensive catchment water balance, a key requirement for future water resources planning for the catchment.

This study has been based on limited streamflow data, and hence numerous assumptions have been necessary. The Tookayerta catchment is hydrologically and hydrogeologically unique and has extensive and diverse water dependant ecosystems highlighting the need for an ongoing monitoring program that includes surface water, ground water and the ecosytems.

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1. INTRODUCTION

1.1 Purpose and Scope of the Study

This technical report describes the methodology and outcomes of a hydrological study of the Tookayerta catchment and examines the impact of farm dams on the surface water resources within the catchment. 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 River Murray Catchment Water Management Board ("RMCWMB").

The scope of work of this study covers the following:

- Quantification of the surface water resources within the Tookayerta catchment
- Construction and calibration of a computer Rainfall-Runoff 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 region, but in recent years concerns have been raised by the community and other stakeholders as to the appropriateness of the high volumes of development in the region. The rapid development of farm dams over the last two decades in this region has raised considerable concern on the sustainability of water resources and the impacts seen in the ecosystems dependent on them.

To prevent further resource decline and to provide security to all water users, the State Government (with advice from DWLBC and RMCWMB), on 16 October 2003, declared two Notices of Prohibition, one on the taking of water from wells and the other on the taking of surface water and water from watercourses in the EMLR catchments. On the same day a Notice of Intent to Prescribe the Surface Water, Watercourses and Wells of the EMLR catchments was issued under section 8 of the Water Resources Act 1997.

The River Murray Catchment Water Management Board, established under the *Water Resources Act 1997,* is responsible for protection of the water resources and associated ecosystems in the River Murray Catchment in the State. The Catchment Water Management Plan (2003) (prepared by the RMCWMB), in its policy on development has set limits for development on a regional basis for the entire Eastern Mount Lofty Ranges ("EMLR").

The 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 Mt Lofty Ranges. Surface and groundwater assessments of the Marne Catchment (2002) and the surface water assessment of the Upper Finniss Catchment (2003) are some of the studies that have been completed under the program in the recent past.

The Tookayerta Creek is one of the high rainfall catchments in the southern side of the EMLR (Figure 1). The river and its catchment are a major source of water for irrigation (through water stored in farm dams), 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 was carried out as part of the “Eastern Mount Lofty Ranges Water Resources Management Program”, a joint program of the DWLBC and the RMCWMB. This, along with the studies to be carried out for the 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 basis of this study and the results presented in this report are based on a rainfall-runoff model constructed by using the surface water management platform WaterCress (Cresswell, 2000). The Tookayerta Catchment was sub-divided (using GIS package ArcMap) into 3 major sub-catchments viz., the Nangkita Creek Catchment, the Cleland Gully Catchment and the Lower Tookayerta Creek Catchment, based on the primary streams in the catchment (Figure 4). These were further sub-divided into 70 minor sub-catchments based on size, location and intensity of farm dams. A catchment model was then constructed as a series of 140 catchment and farm dam nodes representing the whole Tookayerta Catchment (Appendix G).

The catchment model constructed was then calibrated for the period 1997 to 2002 (“Current Scenario”) using observed daily rainfall data, observed streamflow data and 2001 levels of estimated farm dam capacities. Streamflow data was then simulated for the period 1922 to 2002 using observed rainfall data. Different catchment scenarios were then modelled to assess the impact of farm dams on catchment runoff. The scenarios modelled were:

- **Pre-Farm Dam Development Scenario:** Farm dams were removed from the catchment model and streamflow data for the catchment was simulated. This runoff was then compared to the runoff from the catchment “with dams” to quantify the impact of farm dams on catchment runoff.

- **RMCWMP Development Limits with best estimate of runoff coefficient (2004) Scenario:** Based on long-term observed rainfall records and modelled streamflow data (due to lack of long-term observed streamflow records), the best estimate of runoff coefficient for the Tookayerta catchment is 0.25 (25%).

  The allowable development limits for the individual sub-catchments were then estimated with this higher runoff coefficient. Capacities of the existing dams in the sub-catchments that have not exceeded the limits were then increased to the new allowable limits with 100% flow diversion to the dams. Streamflow generated from the catchment with the increased farm dam capacities was then modelled and the possible impact of increased farm dam capacities on catchment runoff was then assessed.

- **Similar to Clare WAP Scenario:** Since the current (2001) farm dam capacities in all three major sub-catchments have not exceeded the RMCWMP development limits, it was assumed the resource would further be developed. In addition to the previously mentioned scenario, farm dam development limits as set in the Clare Water Allocation Plan was modelled as an additional scenario for future development. The plan stipulates that 50% of the catchment area should be under “free-to-flow” conditions. 50% of the runoff generated from the remaining 50% of the catchment area can then be allowed to be diverted to off-stream dams. This effectively sets the allowable development limits to 25% of the runoff generated from the whole catchment.

  Capacities of the existing dams in the sub-catchments that have not exceeded the limits were then increased to the new allowable limits with a 50% flow diversion to the dams. Streamflow generated from the catchment with the increased farm dam capacities was then modelled and the impact of increased farm dam capacities on catchment runoff was then assessed.

Results for each case scenario are presented in this report on a sub-catchment level, and also, on 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.

Figure 1. Tookayerta Catchment - Location Map

Figure 2. Tookayerta Catchment - Topography

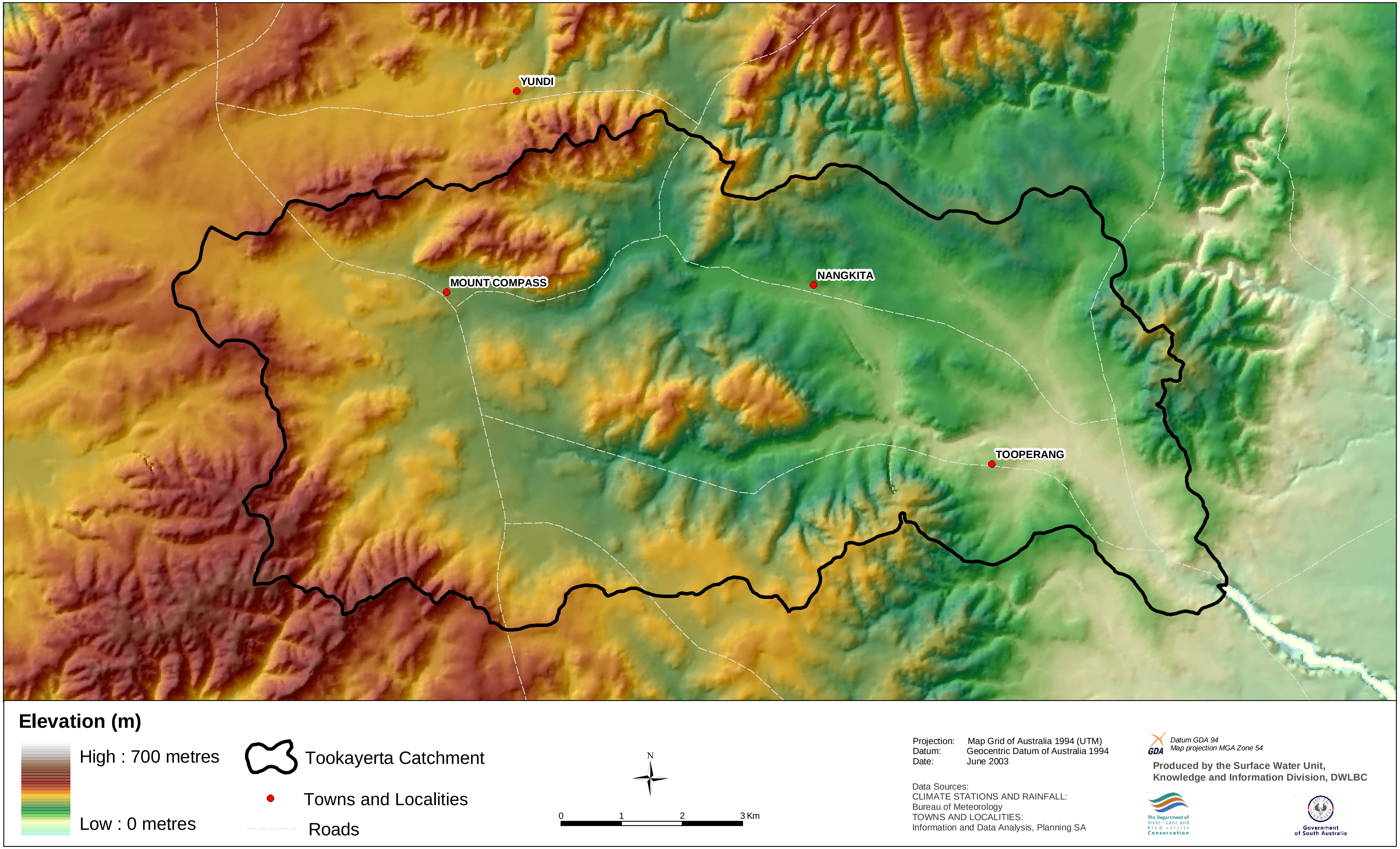


Figure 3. Tookayerta Catchment - Topography & Surface Water Features

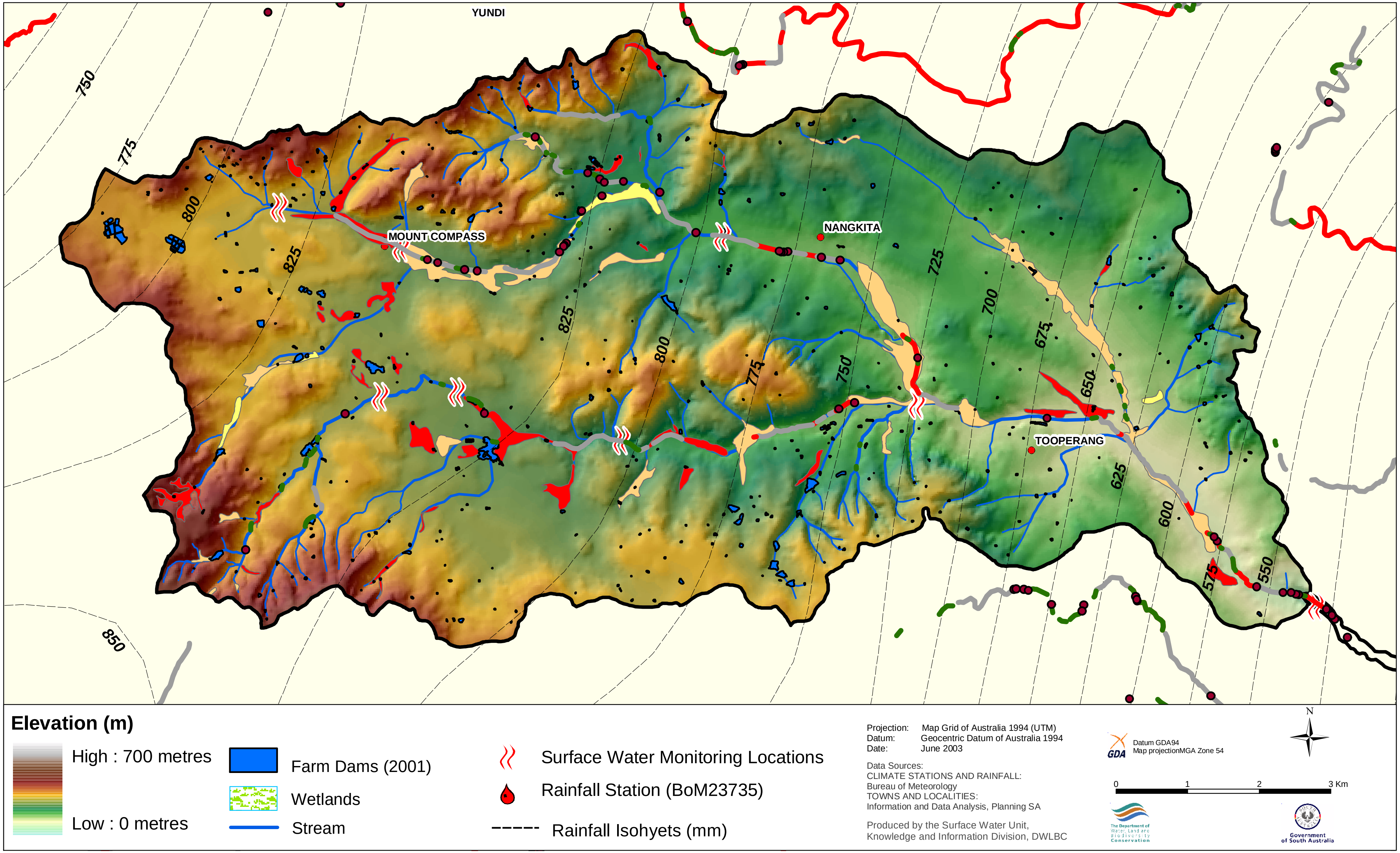
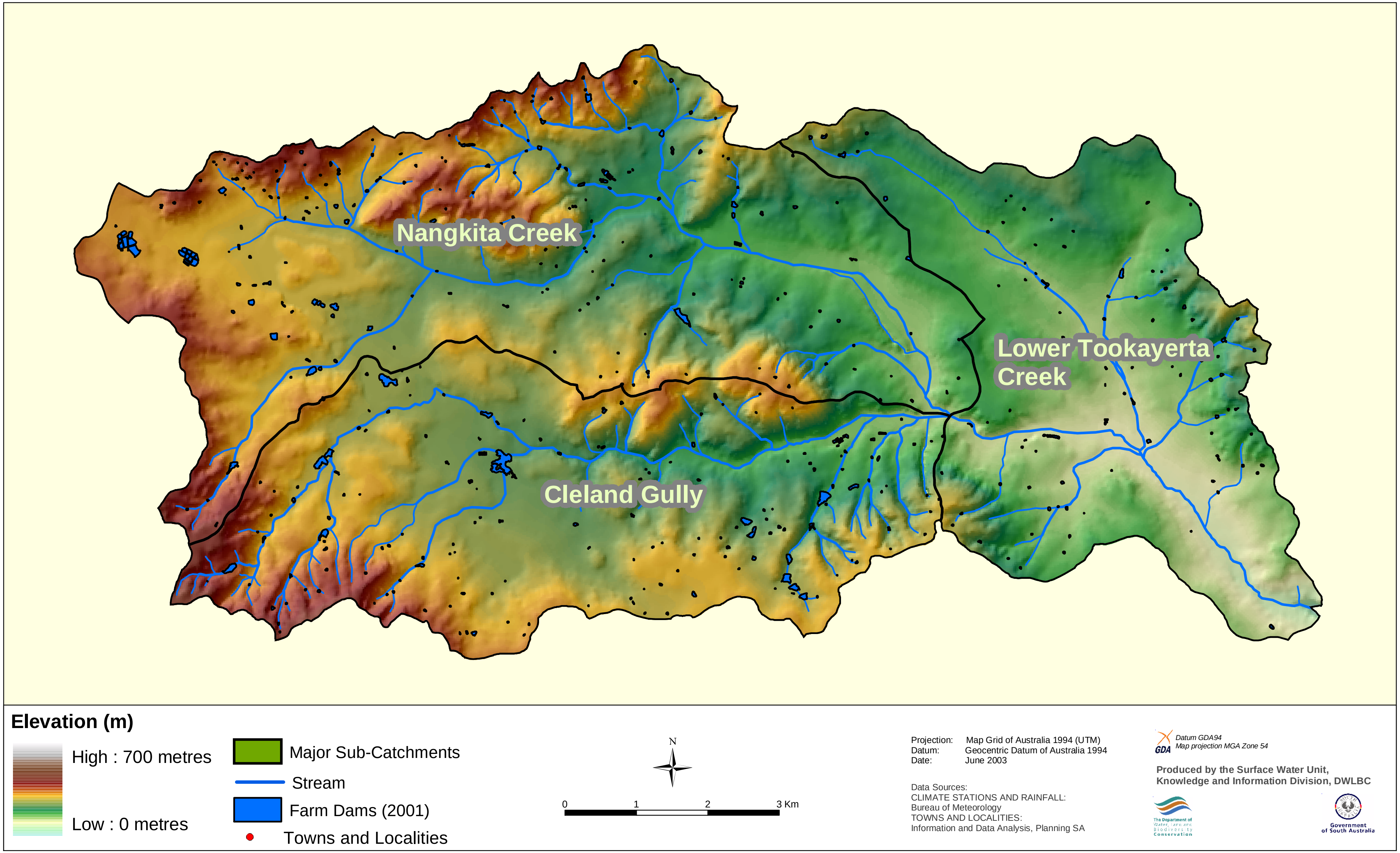


Figure 4. Tookayerta Catchment - Primary Streams and Major Sub-Catchments



2. CATCHMENT DESCRIPTION

2.1 Overview

The Tookayerta Creek catchment is located in the south-eastern Mount Lofty Ranges, around 60 kilometres south of Adelaide (Figure 1). The catchment can be hydrological classified as a high rainfall catchment with permanently flowing streams. It is also hydrogeologically unique to the region due to the presence of extensive Permian sand aquifers with very good quality groundwater resources, which is a major contributor to the streamflow during summer months (Harrington, 2004). It is one of the most ecologically diverse catchments in the EMLR, characterised by its swamps and wetlands that provide a variety of habitats inhabited by some rare and endangered species (RMCWMB, 2003). Mount Compass, Nangkita and Tooperang are some of the towns in the catchment.

The topography of the catchment ranges from around 400m in western ridges of the catchment to around 60m in the eastern end of the catchment (Figure 2 & Figure 3). The catchment encompasses two glacially eroded valleys carved out of surrounding basement rocks, which have been infilled by various glaciene sediments (Barnett, 1999). Nangkita Creek and Cleland Gully, which originate from the north-western and south-western side of the catchment, are the two major streams in the catchment. The two streams flow in an easterly direction before joining and flowing into lake Alexandrina as the Lower Tookayerta Creek. (Figure 4)

Annual rainfall in the catchment varies from 850 mm in the western highlands, near Mount Compass, to around 500 mm on the side at the confluence with Lake Alexandrina, with an estimated average annual rainfall for the catchment being 770 mm. Observed streamflow data indicate that the catchment runoff during the years 1998, 1999 and 2000 were 15,844 ML, 13,329 ML and 24,661 ML. Long-term (1922 – 2002) streamflow data generated from rainfall-runoff modelling provide an estimated median annual runoff of 17,973 ML and mean annual runoff of 19,107 ML. Runoff coefficient for the catchment is estimated to be 0.25 (25% of rainfall runs off), which is higher than most of the catchments (already assessed) in the EMLR.

Ground water in the catchment probably flows through the pore spaces in the extensive Permian sand aquifer before it eventually discharges to the Tookayerta or Nangkita Creek (Barnett, 1999). This discharge constitutes the baseflow of the streams and results in more than 50% of the flow from the catchment, particularly during summer and between rainfall events.

Dairy Cattle is a characteristic of this catchment with around 60% of the catchment area being used for grazing. Other major landuses in the catchment include intensive grazing (9%), forestry & protected areas (13%), Vines (2%) and Horticulture.

Based on 2001 aerial surveys, there are around 537 farm dams with an estimated total capacity of 1100 ML within the catchment. The farm dam density is 11 $ML/Km^{2,}$ which is lower than most of the major catchments in the EMLR.

2.2 Catchment Sub-division

2.2.1 MAJOR SUB-CATCHMENTS

Division of catchment into sub-catchments based on major streams, rainfall and land use variation enhances understanding of the variable nature of catchment behaviour. This also increases efficiency of the catchment rainfall-runoff modelling process and in the case of this study, the variable impact of farm dams on different sub-catchments.

The Tookayerta catchment was divided into three major sub-catchments based on the primary streams in the catchments, viz., the Nangkita Creek, Cleland Gully and the Lower Tookayerta Creek (Figure 4). The Nangkita Creek and the Cleland Gully are the primary streams that join and flow eastwards as the Lower Tookayerta Creek.

Table 1. Major Sub-Catchments in the Tookayerta

No.	Sub-Catchment	Area (Km^2)	Average Annual Rainfall (mm)
1	Nangkita Creek	42	808
2	Cleland Gully	33	806
3	Lower Tookayerta	25	663

2.2.2 MINOR SUB-CATCHMENTS

The next stage was to further sub-divide the major sub-catchments into smaller catchments. The primary criterion for this sub-division was the presence of a significant on-stream dam (‘controlling dam’), which is deemed to control or block the flow from the upstream catchment area. In the absence of major on-stream dams other factors were used in the sub-division of catchments. In general, based on all the factors used, each sub-catchment is either:

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

The sub-division process was initially done manually on a map, which was followed by digitising of the sub-catchments in ArcMap. The area of each of these sub-catchments and the cumulative farm dam capacity in each of those sub-catchments were then calculated. The total number of minor sub-catchments within each major sub-catchment and the total number of minor sub-catchments within the entire Tookayerta catchment are tabulated in Table 2 and shown in Figure 5. Further details of the minor sub-catchments are listed Appendix B.

Table 2. Minor Sub-Catchments in the Tookayerta Catchment

Major Sub-Catchment	Area (Km^2)	Number of Minor Sub-Catchments
Nangkita Creek	42	35
Cleland Gully	33	22
Lower Tookayerta	25	13
Total	**100**	**70**

2.3 Landuse

Landuse data provides information on the nature of the use of land, for example, forestry, livestock grazing, horticulture, residential. This, in addition to the land and water management information viz., 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.

Landuse data for the catchment area was obtained from the land status data set that was an outcome of the land status mapping exercise for the Mt Lofty Ranges Watershed carried out by the Department for Environment and Heritage in the year 2001. (Bradley, 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 7 main categories. They are:

- **Livestock / Broadscale grazing** – this includes grazing land for Sheep, Horse, Beef and Goats – *generally unirrigated*
- **Dairy Cattle / Improved Pastures** – *generally irrigated*
- **Vines** – includes Grapes, Kiwifruit, Passion fruit and Hop
- **Horticulture** – this includes Orchards, Berries and Vegetables
- **Forestry Plantation / Protected Area**
- **Residential / Industrial** – this includes residential, industrial, commercial, cultural and transport/storage areas.
- **Mining** – this includes mining and extractive industries

The land use categories as shown above were then mapped for the catchment area (Figure 6), the details of which are shown in the table below.

Table 3. Landuse Classification of Tookayerta Catchment

No.	Landuse Category	Area (Km2) & % Of Total Area
1	Livestock / Broadscale grazing	60
2	Dairy Cattle / Improved Pastures	18
3	Vines	2
4	Horticulture	0.8
5	Forestry Plantation / Protected Area	14
6	Residential / Industrial	4.6
7	Mining	0.6

2.4 Farm Dams

Farm dams are water storage structures generally constructed in regional areas (rural areas) for capturing the runoff generated from the catchment area above them. The water stored in the dams is then used for domestic, stock and irrigation purposes during summer. While water stored in the farm dams provide an additional source of water (in addition to rainfall and water pumped from groundwater bores) for agriculture, they also act as barrier for the runoff 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 farm dams has been more predominant and rapid in the highlands of the Mount Lofty Ranges due to intense vineyard development. A few cases for this are,

- a 10-fold increase in total farm dam storage capacity being observed in the Barossa Valley since the early 1970's (Cresswell, 1991).
- the total farm dam capacity in the Upper Marne catchment being observed to have more than doubled between 1991 and 1999 (Savadamuthu, 2002),

Similar trends in farm dam development have been observed in most of the other catchments in the Mount Lofty Ranges.

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 of Environment and Heritage and stored in a format to be used by Geographic Information System packages. Surface areas of dams that were digitised 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 bigger dams. Physical surveys of farm dams (the bigger dams, at the 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 – volume relationship (McMurray 2002):

For surface area < 15,000 m^2

$$\text{Dam Capacity (ML)} = 0.0002 \times \text{Surface Area}^{1.25}$$

For surface area >= 15,000 m^2

Dam Capacity (ML) = 0.0002 x Surface Area

Based on the 2001 farm dam survey, the total number of farm dams in the Tookayerta catchment was 537 (Figure 7). Using the formulae shown above the total estimated storage capacity of the farm dams is 1103 ML. The number of dams and their storage capacity based on size classification is shown in Table 4.

Table 4. Farm Dams in the Tookayerta Catchment - Size Classification

No.	Dam Size Category	Number of Dams (% Of total dams)	Total storage Capacity (ML) (% Total capacity)
1	< 0.5 ML	280 (52%)	74 (7%)
2	0.5 – 2 ML	172 (32%)	167 (15%)
3	2 – 5 ML	43 (8%)	142 (13%)
4	5 – 10 ML	17 (3%)	122 (11%)
5	10 – 20 ML	16 (3%)	236 (21%)
6	20 – 50 ML	8 (1%)	270 (25%)
7	> 50 ML	1	93 (8%)
	Total	537 (100%)	1104 (100%)

The distribution of farm dams show that although dams with capacity less than 2 ML constitute to 84% of the total number of dams, they contribute to only 22% of the total dam capacity within the catchment. Therefore, 78% of the total dam capacity of the catchment is contained in only 16% of the dams.

2.4.2 DAM DENSITY

Farm dam density is an important parameter in indicating the level of farm dam development in a catchment than just the number and capacity of farm dams, as it includes catchment area in its calculation, as shown below.

Farm Dam Density = Total Farm Dam Capacity / Catchment Area
(ML/Km^2) (ML) (Km^2)

Table 5. Farm Density of Catchments in the Eastern Mount Lofty Ranges

No.	Catchment	Farm Dam Density (ML/Km^2)
1	Finniss catchment U/S AW426504	30
2	Angas catchment U/S AW426503	32
3	Currency Creek catchment U/S AW426530	32
4	Mt Barker Creek catchment U/S AW426557	27
5	Dawesley Creek catchment U/S AW426558	18
6	Tookayerta Creek Catchment	11
7	Marne catchment U/S AW426559	10

The farm dam density of Tookayerta catchment is 11 ML/Km^2. Tookayerta catchment has the lowest farm dam density in comparison to all but one of the catchments listed in Table 5. While the Marne catchment has a marginally lower farm dam density, it also has a much lower runoff coefficient of 0.05 (5% of rainfall runs off) in comparison to the Tookayerta catchment, which has a runoff coefficient of 0.25. This implies that the impact of dams on catchment runoff is much higher in the Marne catchment than in the Tookayerta catchment.

Furthermore, the Finniss and the Currency creek are Tookayerta neighbouring catchments and have much higher dam densities of 30 and 32. This might be an indicator that the Tookayerta catchment is not as highly developed as those catchments and hence, the impact of dams on Tookayerta catchment runoff might also be lower. This will be further analysed and tested in the later sections of this report.

A better understanding of local impacts of farm dams is provided through analysis of dams on a sub-catchment scale. The farm details for the three sub-catchments are listed in Table 6.

Table 6. Farm Dam Details of Sub-Catchments

Sub-Catchment	Catchment Area (Km^2)	Dam Size Classification Number of Dams (Total Dam Capacity ML)							Total Number of Dams	Total Dam Capacity (ML)	Dam Density (ML/Km^2)
		< 0.5 ML	0.5-2 ML	2-5 ML	5-10 ML	10-20 ML	20-50 ML	>50 ML			
Nangkita Creek	42	131 (35)	70 (70)	27 (91)	11 (76)	8 (121)	2 (71)	0	249	464	11.0
Cleland Gully	33	102 (26)	58 (56)	10 (32)	2 (14)	8 (114)	6 (200)	1 (93)	187	534	16.2
Lower Tookayerta	25	47 (13)	44 (41)	6 (19)	4 (32)	0	0	0	101	105	4.0
Total Catchment		280 (74)	172 (167)	43 (142)	17 (122)	16 (236)	8 (270)	1 (93)	537	1103	11.0

While the farm dam density of the whole catchment is 11 ML/Km^2, it varies on a subcatchment level as shown in the table above. The Cleland Gully catchment is more developed than the other two sub-catchments as indicated by the higher dam density (16.2 ML/Km^2). It has a higher percentage of the larger dams in the catchment, which also includes the biggest dam in the catchment. The Lower Tookayerta sub-catchment does not have any big dams (capacity greater than 10 ML), which indicates that most of the dams in that catchment are probably used for stock and domestic purposes.

Analysis of farm dam density on a minor sub-catchment level was also carried out to identify areas within major sub-catchments that were highly developed and also areas that were relatively free-to-flow. As shown in the (Figure 8) Cleland Gully has more highly developed minor sub-catchments (farm dam densities greater than 20 ML/Km^2) and Lower Tookayerta has the least number of highly developed minor sub-catchments. This confirms the earlier discussion on Cleland gully being the highest developed major sub-catchment and Lower Tookayerta being the lowest.

2.4.3 DAM DEVELOPMENT LIMITS

A "*Notice of Prohibition on Taking Surface Water and Water from Watercourses*" is currently in place in the Eastern Mount Lofty Ranges. 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 16th 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 Eastern Mount Lofty Ranges*" was also issued on the same day of the notice of prohibition.

The prohibition period of 2 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 levels development in the individual catchments.

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 EMLR exceeding the sustainable development limits set in the Catchment Water Management Plan for the River Murray in South Australia (River Murray Catchment Water Management Plan, 2003. pp 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 runoff coefficient; where the runoff coefficient is 0.1 (10%), unless otherwise specified in a relevant Water Allocation Plan*." (River Murray Catchment Water Management Plan, 2003. pp 182).

The 2001 levels of farm dam development in the Nangkita Creek, Cleland Gully and Lower Nangkita Creek sub-catchments have not exceeded the Catchment Plan's allowable limits.

Table 7. Catchment Plan's Development Limits for the Tookayerta Catchment

Sub-Catchment	Catchment Area (Km^2)	Average Annual Rainfall (mm)	Average May-November Rainfall (mm)	Average May-Nov runoff (10% of May-Nov Rainfall)(mm)	30% of May-Nov Runoff (mm)	Allowable Farm Dam Volume (ML)	2001 levels of estimated Farm Dam Volumes (ML)	2001 levels of development divided by allowable volume
Nangkita Creek	42	808	626	63	19	786	464	59%
Cleland Gully	33	806	622	62	19	622	534	86%
Lower Tookayerta	25	663	514	51	15	391	105	27%
Total	**100**					**1799**	**1103**	**60%**

(*Data in all but the last two columns are from the River Murray Catchment Water Management Plan, 2003, pp 244*)

The allowable development limits set in the catchment plan (Table 7) were developed using a runoff coefficient of 0.10 (10% of rainfall runs off). While the runoff coefficient of 0.10 used in the catchment plan is the estimated average runoff coefficient across the entire Eastern Mount Lofty Ranges, it varies widely with individual catchments, as does rainfall. For example, runoff coefficient varies from 0.06 for the Marne catchment in the North, to 0.09 for the Bremer catchment in the middle of the ranges, to 0.17 for the Finniss catchment U/S of the gauging station and 0.25 for the Tookayerta catchment in the southern EMLR.

Furthermore, streamflow data from the Tookayerta catchment shows that the average May-November runoff for the period 1997 to 2000 is 13596 ML (136 mm). The average modelled May to November runoff for the period 1922 to 2000 is 16714 ML (167 mm). These would result in the allowable limits of development to be 4079 ML and 5014 ML as against 1799 ML, which is the current development limit set in the catchment plan. Catchment modelling with development limits based on runoff coefficient of 0.25 was carried out as part of this study and results are presented in the later sections of this report.

2.5 Environment

The Tookayerta catchment is one of the most ecologically diverse catchments in the EMLR, characterised by its swamps and wetlands that provide a variety of habitats inhabited by some rare and endangered species (RMCWMB, 2003).

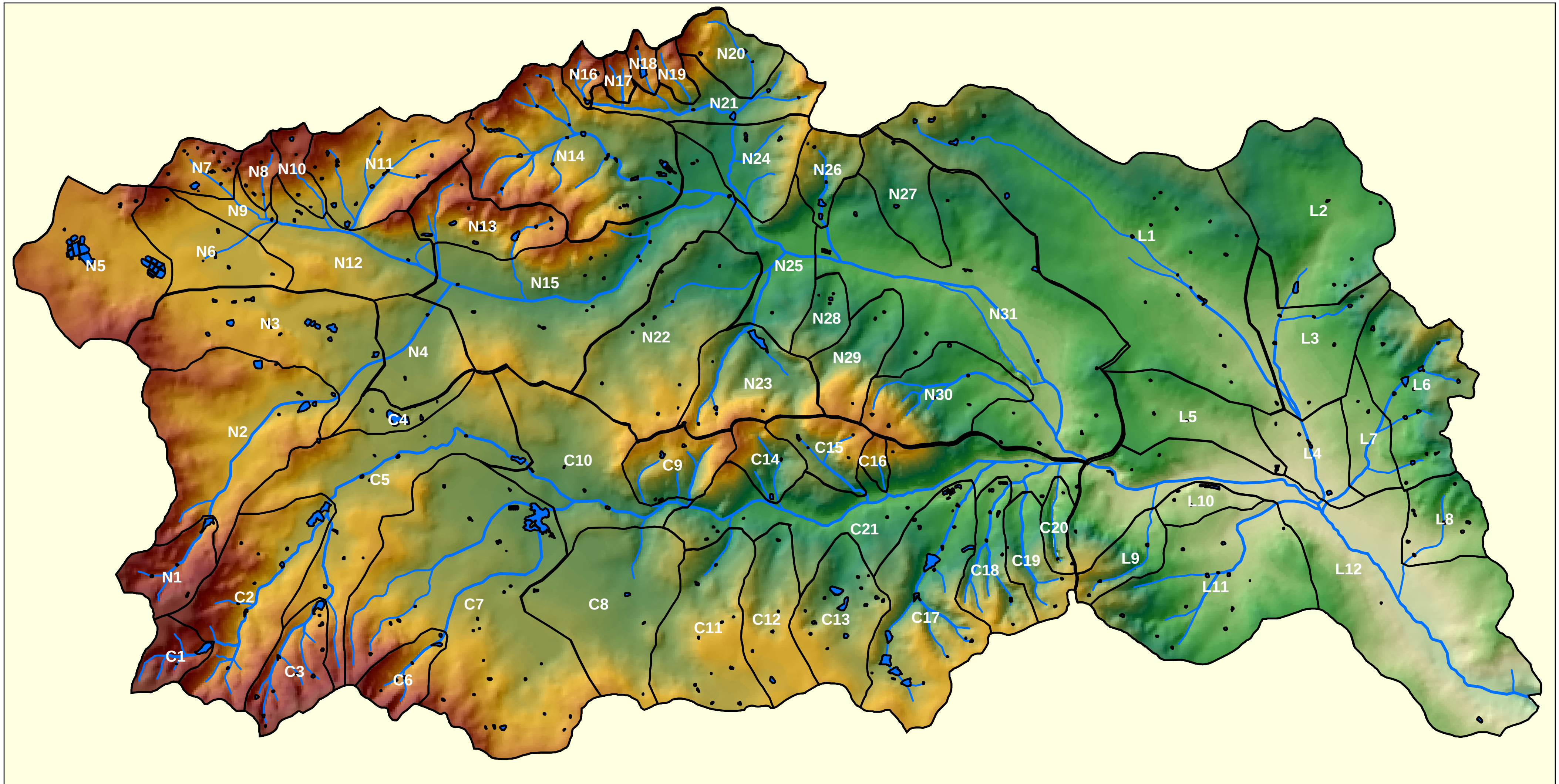
Since its establishment in 1997, the River Murray Catchment Water Management Board has carried out investigations related to water resources and associated ecosystems in the Eastern Mount Lofty Ranges ("EMLR"), including the Tookayerta Catchment. The results of these investigations have identified the EMLR streams as providing valuable habitats for many species. For example, the Tookayerta and Nangkita Creeks and the Finniss River support 19 threatened species of flora and rare fauna (River Murray Catchment Water Management Plan, 2003). The Compass Creek Care Inc, a local community group and the local school have actively been involved in identifying, monitoring and managing some of the wetlands and swamps.

The Southern Pygmy Perch (*Nannpperca australis*) is a native fish, and one species identified in the Catchment Plan that was historically found all over the Lower Murray, EMLR and Lake Alexandrina. They can now only be found in some of the EMLR streams including the Tookayerta River. The fish is considered to be an endangered species in South Australia and is also a protected species. Living in cool, clean water (usually pools and swamps), their presence is a good indicator of the health of the stream and ground water systems that sustain them (Hammer, 2002).

The Tookayerta drains into Lake Alexandrina, which is listed as a Ramsar wetland in international treaties for the protection of migratory birds. The Tookayerta estuary is a potential habitat for the Mt Lofty Southern Emu Wren (*Stipiturus malachurus*) (Duffield, 2001), a nationally endangered species listed under the EPBC Act. While it has been stated that their habitat is located entirely within the artificially regulated freshwater pool of the Murray Lakes and Lower Murray, further studies need to be carried out to assess the impact of reduced flows from the Tookayerta on the estuary and hence the habitat.

This study does not directly assess the status of or impacts on the habitats of the Southern Pygmy Perch, Mt Lofty Southern Emu Wren or other water dependent ecosystems. However, the main outcomes of the study, that is, the impact of farm dams on the flow regime, will be useful to further assess the status and effect on water dependent ecosystems within the catchment. Additionally, the status of the groundwater resources (quantity & quality) possibly plays a crucial role in influencing the health of the catchment's water dependant ecosystems. This is due to the high inter-dependability between groundwater, baseflow and the catchment's water dependent ecosystems.

Figure 5. Tookayerta Catchment - Minor Sub-Catchments



Minor Sub-Catchments

C1, C2, C3, ... - Cleland Gully - Minor Sub-Catchments

N1, N2, N3, ... - Nangkita Creek - Minor Sub-Catchments

L1, L2, L3, ... - Lower Tookayerta - Minor Sub-Catchments

Farm Dams (2001)

Stream

N

0 1 2 3 Km

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

GDA Datum GDA94
Map projection MGA Zone 54

Produced by the Surface Water Unit, Knowledge and Information Division, DWLBC

Figure 6. Tookayerta Catchment - Land Use

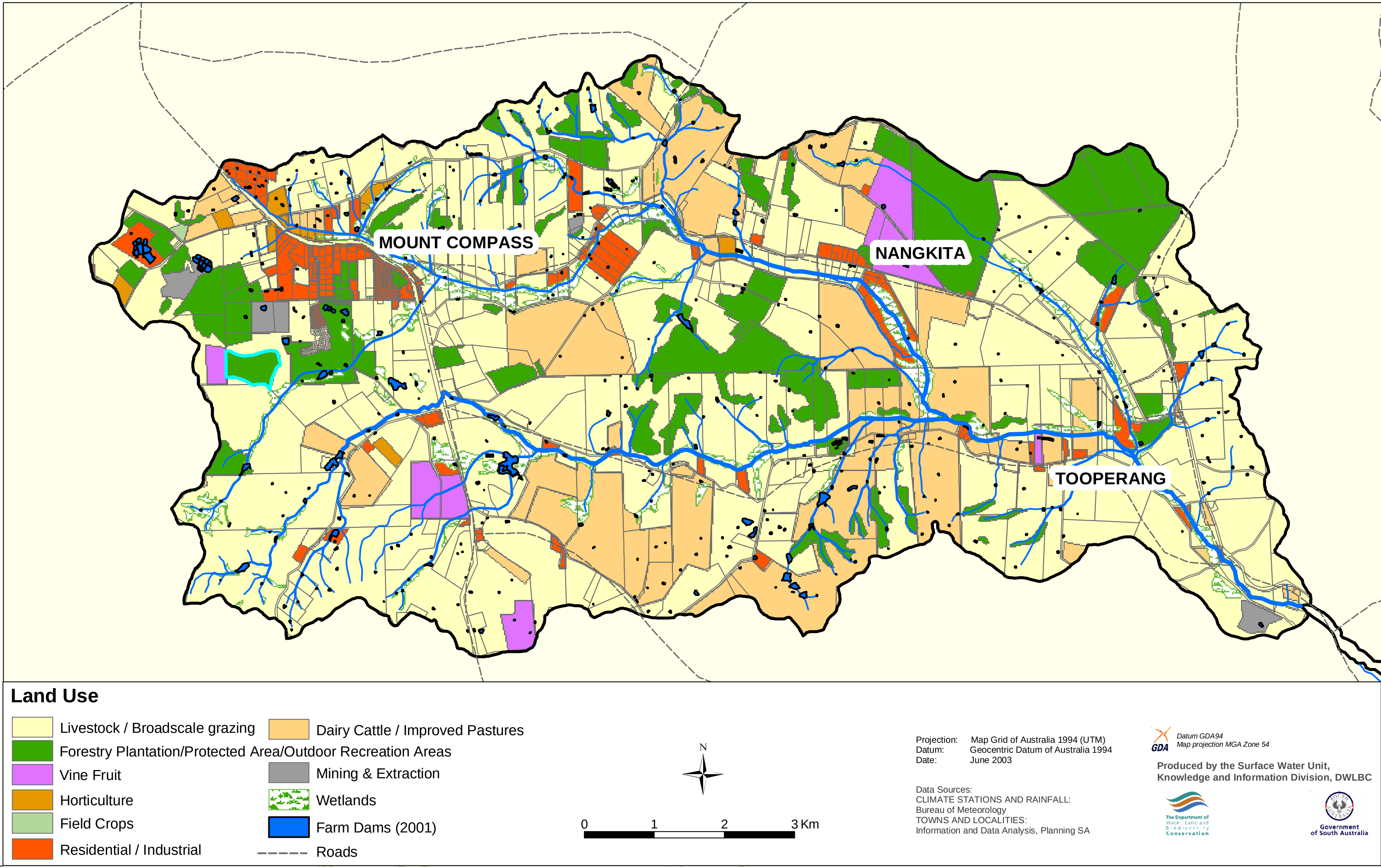


Figure 7. Tookayerta Catchment - Farm Dams (2001)

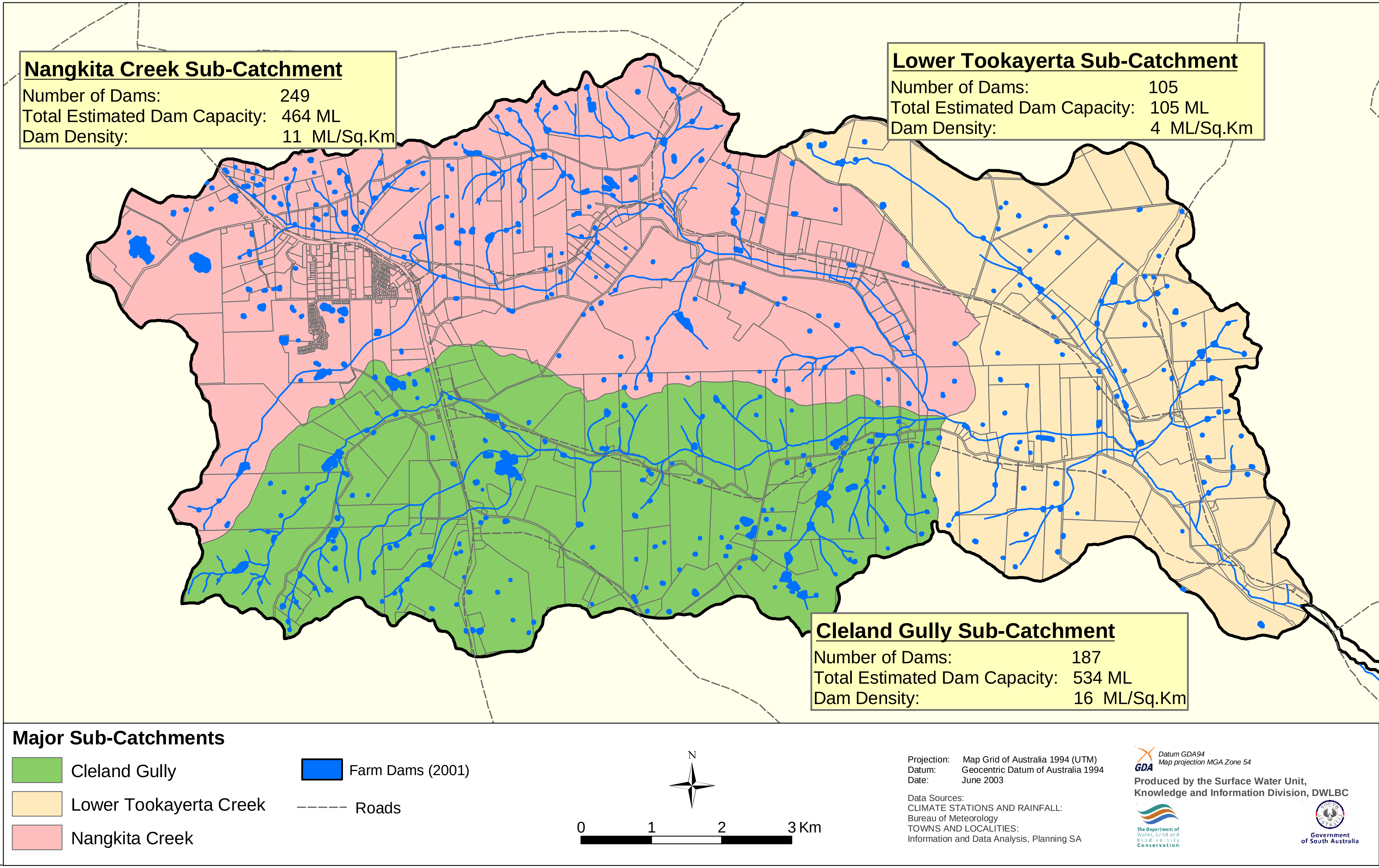
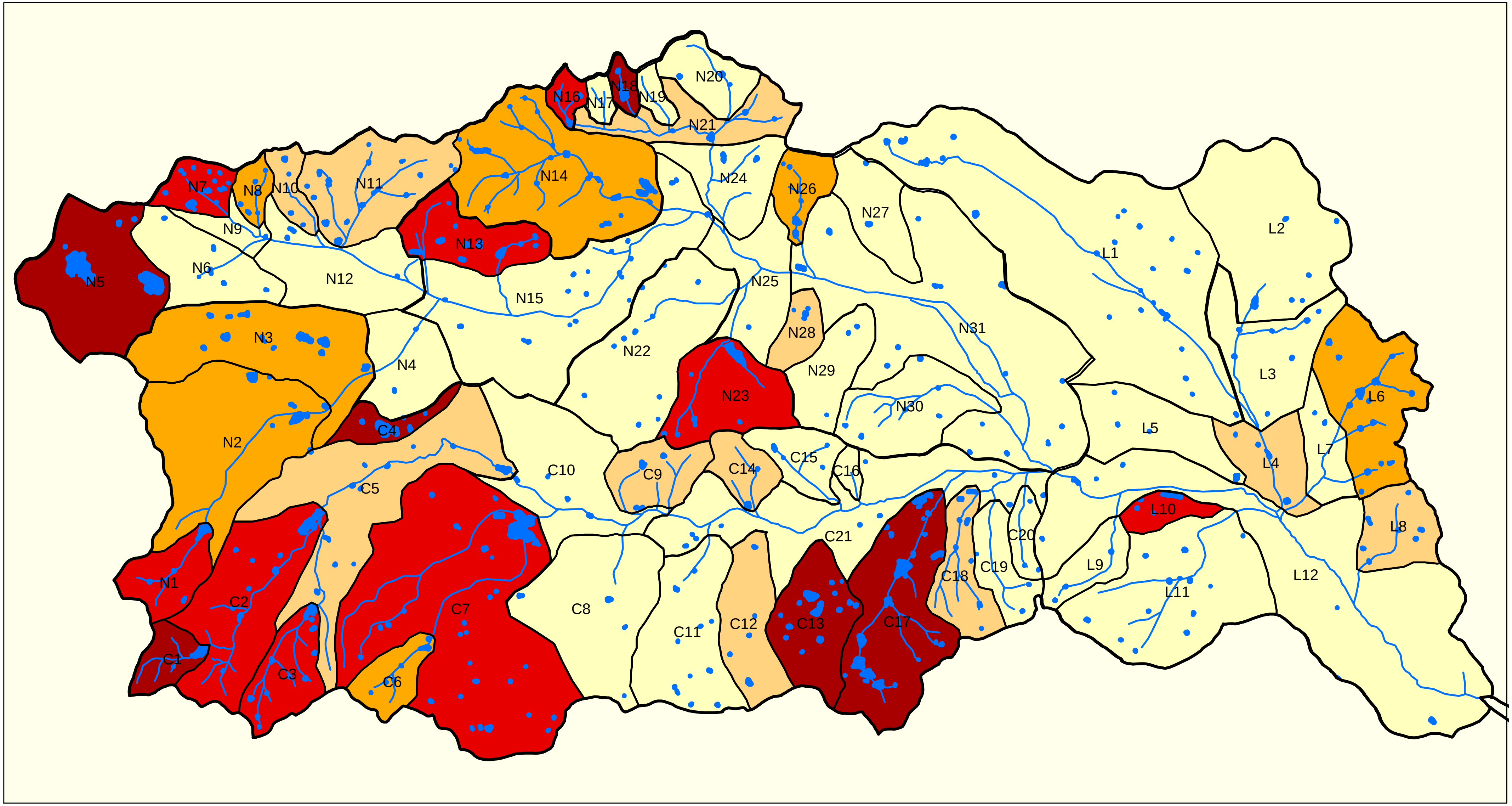


Figure 8. Farm Dam Density of Minor Sub-Catchments in the Tookayerta Catchment



Farm Dam Density (ML/SqKm)

< 5.0
5 - 10
10 - 20
20 - 30
> 30 ML/SqKm

Minor Sub-Catchments
Farm Dams (2001)

N

0 1 2 3 Km

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

GDA Datum GDA94
Map projection MGA Zone 54

Produced by the Surface Water Unit,
Knowledge and Information Division, DWLBC

The Department of Water, Land and Biodiversity Conservation

Government of South Australia

3. CATCHMENT HYDROLOGY

3.1 Rainfall

Rainfall is one of the primary drivers of the hydrological cycle, with the amount of rainfall directly affecting the volume of water available within a catchment and hence it's productivity. Rainfall is generally not uniform within a catchment and often varies spatially with catchment 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 within a catchment for estimation of effective runoff from different areas or sub-catchments within the catchment. In this study, this was achieved by using rainfall records from the Bureau of Meteorology (BoM) station at Mount Compass and rainfall isohyets developed from other BoM stations in the region.

3.1.1 DATA AVAILABILITY & PROCESSING

Rainfall records for the Tookayerta catchment are available from the BoM station at Mount Compass from 1922 onwards. 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 like instrument malfunction are also not uncommon. Hence, disaggregation of accumulated data and infilling of data for periods of missing records were carried out by Sinclair Knight Merz (SKM, 2000) for DLWBC (Appendix D) to obtain complete data sets.

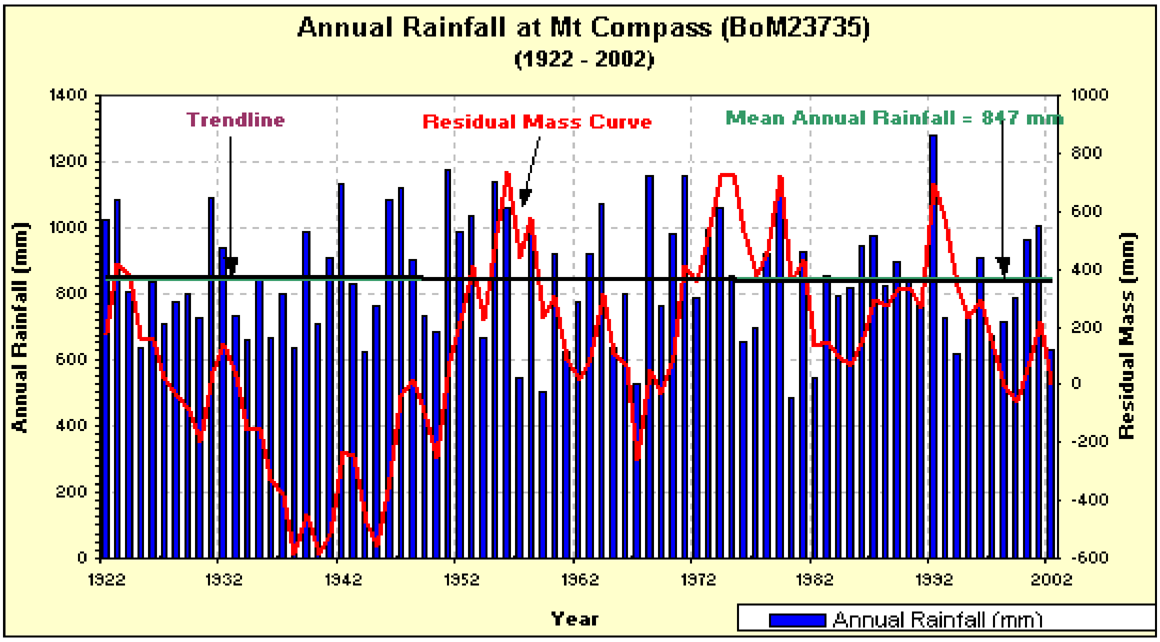


Figure 9. Annual Rainfall at Mount Compass

3.1.2 DATA ANALYSIS

Analysis of rainfall data was undertaken at annual, monthly and decadal time scales in this study. In addition, trend analysis of annual rainfall was also carried out using different methodologies.

The long-term (1922 to 2002) mean and median annual rainfall at Mount Compass are 847 mm and 828 mm respectively. The BoM station at Mount Compass (BoM23735) (Figure 3) is located almost on the north-west corner of the catchment and does not represent the average rainfall for the catchment. Hence, the average annual rainfall for the catchment was calculated in GIS (ArcMap) using the rainfall isohyets and the area of the catchments between them. Annual rainfall within the catchment varies from 850 mm in the western highlands of the catchment to around 500 mm in the east end, with the average rainfall for the whole being 770 mm. 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, while the actual isohyet values were not used in the modelling exercise, their distribution pattern was used to estimate rainfall in the major and minor sub-catchments from the observed records at Mount Compass.

Trend Analysis methodologies are used to determine 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 Mount Compass for the period 1922 to 2002 indicate a decreasing trend, statistically significant at just 28% using the Mann's test (Grayson, 1996) (Appendix C) and statistically significant at 21% using the "t" and "F" tests (Draper, 1998). This clearly indicates a lack of any significant trend in the rainfall data. Generally, significance levels of 95% and above are regarded to indicate definite trends in data. This result differs from the decreasing trend in annual rainfall observed in nearby BoM stations in other catchments. Data from those stations indicate that the decades 1900s, 1910s and 1920s had the highest average decadal rainfall. The high rainfall during those early decades increases the long-term average, and this, combined with the next few low rainfall decades generates a decreasing trend of the long-term rainfall. This decreasing trend is not evident in Mount Compass rainfall data probably due to lack of rainfall data during for the earlier decades of 1890s, 1900s and 1910s. If data prior to 1922 were available for Mount compass it is expected that a decreasing trend would have been seen.

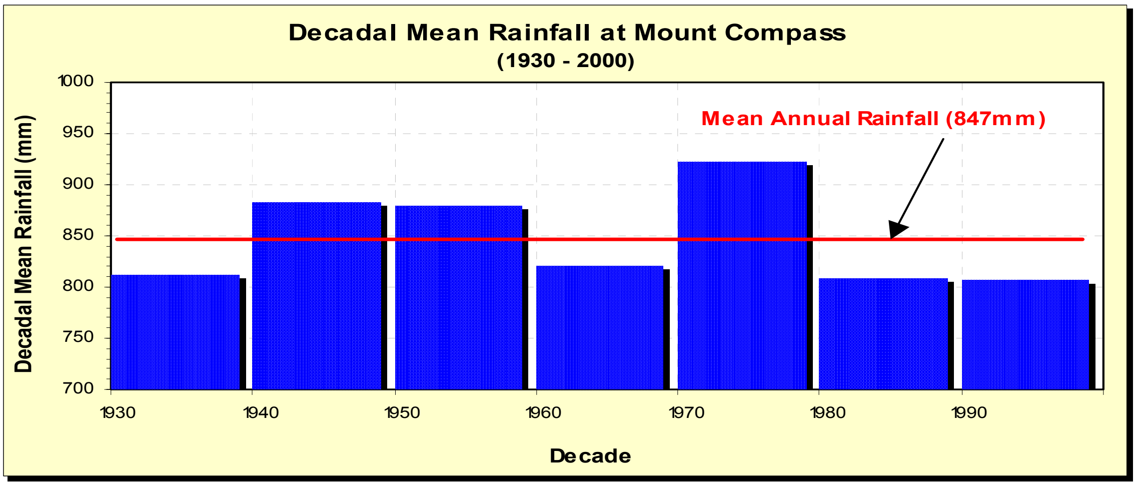


Figure 10. Decadal Mean Rainfall at Mount Compass

Long-term rainfall trends can also be observed using residual mass curves. A residual mass curve is a plot of the cumulative deviation of a set of data from the mean value of the data. In a residual mass curve plotted for annual rainfall data, a distinctive upward slope above the mean indicates a wetter than average period for that section of the curve and vice versa. A residual mass curve plotted for the annual rainfall at Mount Compass (Figure 9) indicates wetter than average periods from 1945 to 1956 and from 1967 to 1974. Some of the drier than average periods are from 1923 to 1937 and from 1992 to 1999 in recent periods.

Analysis of rainfall data on a decadal time scale indicates that the last two decades (1990s and 2000s) had rainfall that were around 40mm lower the long-term mean annual rainfall (Figure 10).

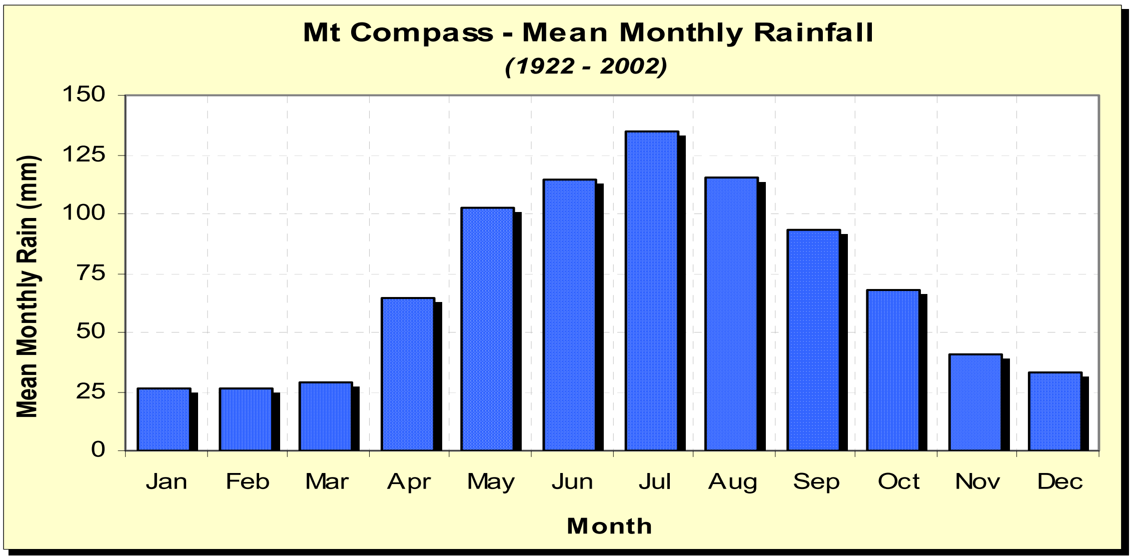


Figure 11. Monthly Rainfall at Mount Compass

The monthly rainfall data at Mount Compass (Figure 11) indicates the around 80% of the annual rainfall occurs during the period between May and November. As shown in the figure the average rainfall during April is much more than the November.

3.2 Streamflow

Streamflow gauging is generally carried out by DWLBC in catchments in South Australia. But there is no DWLBC streamflow gauging station in the Tookayerta catchment. Compass Creek Care Inc, a local community group and THATCH Environmental Consultancy have been collecting streamflow data during the last few years at 8 locations in the catchment. Data collected form one of the locations (location F8) downstream of the confluence of Nangkita Creek and Cleland Gully was used in this study (Figure 3). Data from the other sites were not used as either the period of record was considered to be too short or the data had too many periods of missing data.

3.2.1 DATA AVAILABILITY & PROCESSING

Streamflow data (Farrow, 2001) from location F8 is available for the period 19/04/1997 to 15/04/2002, with long periods of missing data. While flow for some of the missing periods were estimated from rainfall and flow data of previous years, they were not used for analysis in this study. Five years of streamflow data is too short to understand or evaluate a catchment's hydrology. This necessitated the use modelled long-term streamflow data generated from rainfall-runoff modelling for further analysis. In this study, the 5 years of observed streamflow data was used to calibrate a rainfall-runoff model, which was then used to simulate and extend streamflow data back to1922 from when rainfall records are available for the catchment. Further information on rainfall-runoff modelling used in this study is detailed in the "Modelling" section of this report.

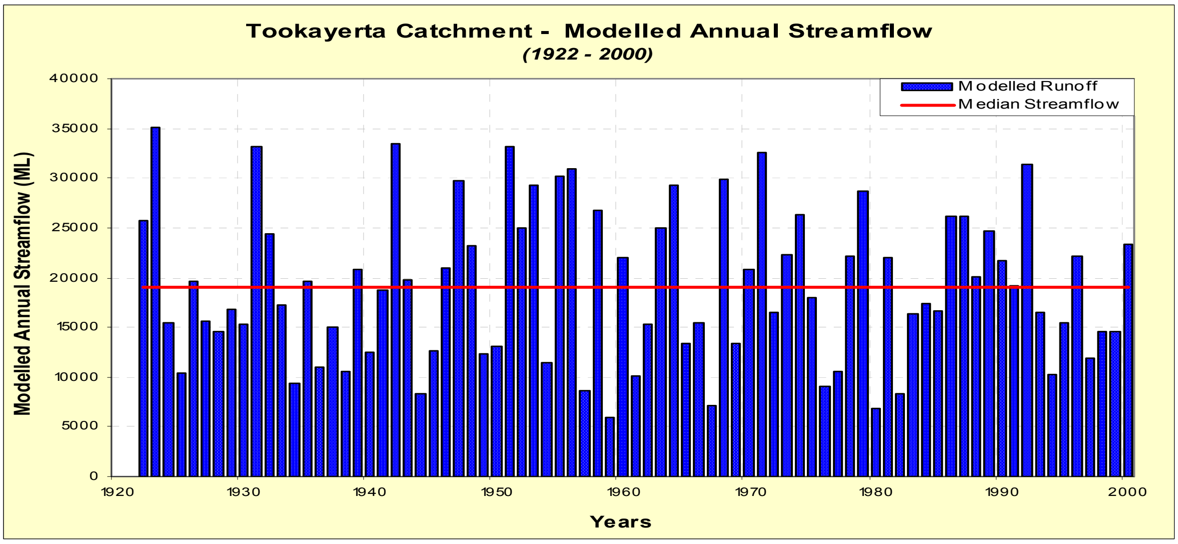


Figure 12. Tookayerta Catchment Annual Runoff

Since,

a. only 5 years of gauged streamflow data was used to calibrate the rainfall-runoff model used to generate the modelled long-term stream flow data (Figure 12), and
b. the accuracy of the gauged streamflow data is unknown,

the accuracy of the results of presented in this section on streamflow would not be as high as results obtained from analysis of long-term and good quality gauged streamflow data.

3.2.2 DATA ANALYSIS

Analysis and results presented in this section are based on modelled streamflow data generated by the rainfall-runoff model (presented in the later sections) for the period 1922 to 2000, as observed data is available for 3 years only. Hence, the word “streamflow” from this section onwards refers to “modelled streamflow”.

Figure 12 shows the modelled annual streamflow totals for the Tookayerta catchment and highlights the inter-annual streamflow variability, with annual streamflow ranging from 5909 ML in 1959 (with 500 mm rainfall), to 33475 in 1942 when the catchment rainfall was 1132 mm. The mean and median streamflow for the catchment are 19,107 ML and 17,973 ML for the modelled period 1922 to 2000. The chart also indicates that during the last decade only three years had above average streamflows, which directly corresponds to the last decade being a less than average rainfall one.

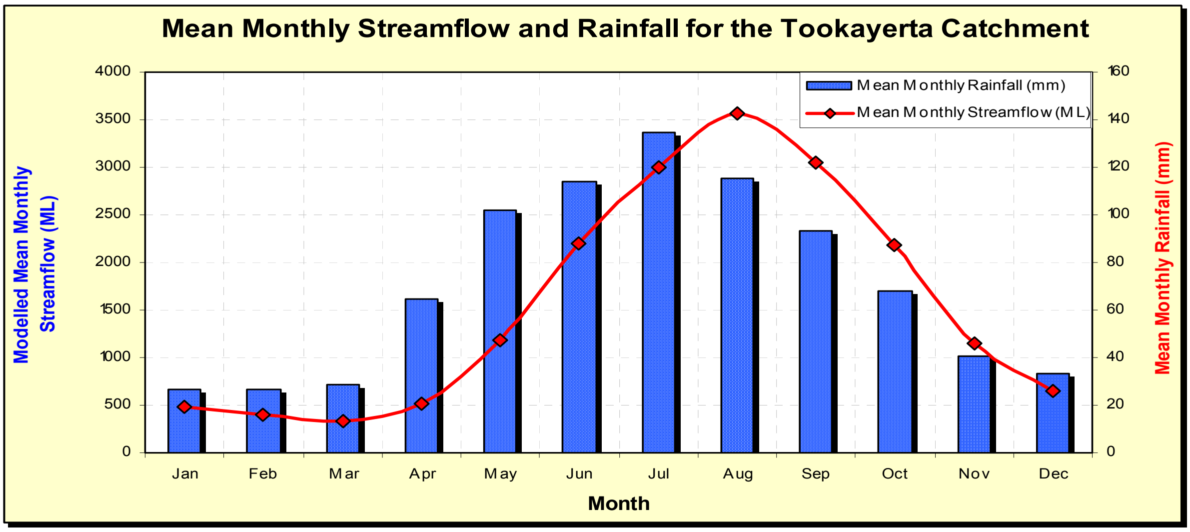
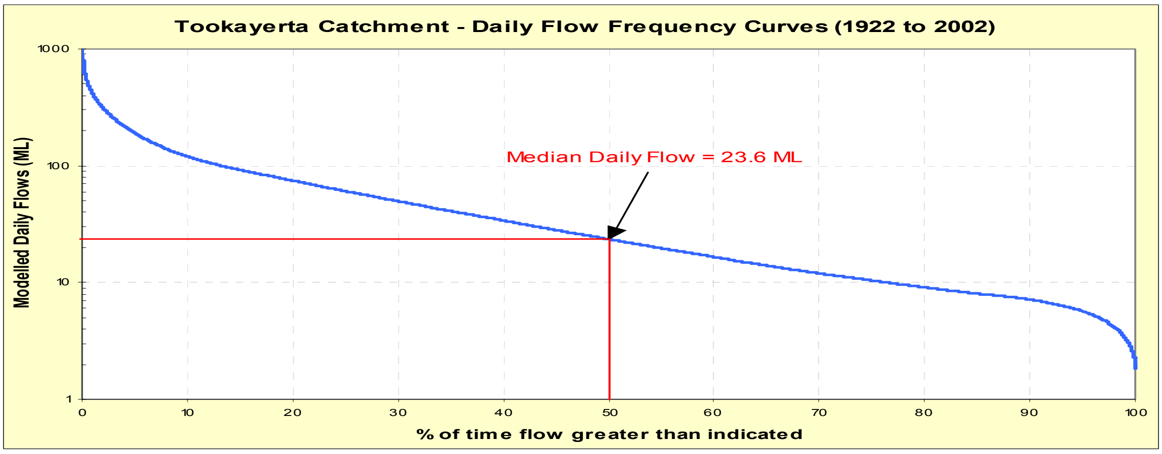


Figure 13. Monthly Streamflow from Tookayerta Catchment

Figure 13 shows the mean monthly streamflows and the corresponding rainfall data. The highest streamflow occurs during the month of august. On average, 80% of the annual rainfall occurs during the period between May to November, and 86% of the annual streamflow occurs during that period. This results in around 14% of the streamflow occurring during summer months (December to April). Summer flows of 14% are much higher in comparison to other catchments in the Mount Lofty Ranges, where they are generally less than 5% of the annual flows.

The comparatively higher summer flows are attributed to the groundwater discharge (baseflow) from Permian sand aquifers in the catchment (Harrington, 2004) rather than to high summer rainfall, as the neighbouring Finniss River catchment has a similar rainfall pattern but has less summer flows. The Finniss River catchment is characterised by more of fractured rock aquifers and does not have Permian sand aquifers.

Analysis of daily flows also indicates a high rate of summer flows in the catchment. Figure 12 shows the daily flow frequency curve for the Tookayerta catchment. This was plotted with modelled data for the period 1922 to 2000. Daily flow frequency analysis is a simple but effective method of analysing the flow regime of a catchment. Flow frequencies are defined as the percentages of time during the period of record the flows exceeded various rates. It can also be interpreted as, the percentage of time during an average year, different daily flows would occur. For example, as can be interpreted from Figure 14, daily flows of 10 ML or higher would occur for around 75% of the time (around 275 days) during an average year. The chart also shows a median daily flow of 23.6 ML for the catchment i.e., a flow of 23.6 ML would occur at least 50% of the time during an average year.



(modelled low/base flows to be used with caution. Refer text for further details)

Figure 14. Flow Frequency Curve of Modelled Daily Flows for Tookayerta Catchment

The flow frequencies of different flow ranges are tabulated in Table 8. The data presented in the table indicate that the catchment flows throughout the year and also, the number of days in a year different flow ranges could be expected. This plays a crucial role in assessment of impact of different development activities (like farm dam development) on different catchment flow regimes.

Table 8. Daily Flow Frequencies for Tookayerta Catchment

Flow Criteria	% of Year	No. of days
Cease to flow	0	0
Flow ≥ 1 ML/day	0	0
Flow ≥ 5 ML/day	97	352
Flow ≥ 10 ML/day	76	280
Flow ≥ 20 ML/day	55	200
Flow ≥ 50 ML/day	30	110
Flow ≥ 100 ML/day	13	48
Flow ≥ 200 ML/day	4.6	17
Flow ≥ 500 ML/day	0.6	2
Flow ≥ 1000 ML/day	0.03	3 hours

Caution is required when using the results of low/base flow analysis indicated in Figure 14 and table 8 due to the limitations in modelling the low flows. These limitations are further discussed in “4.4 Model Calibration” section of the report.

3.3 Baseflow

Baseflow is the portion of streamflow derived from medium to long-term groundwater storage. It also termed widely as “Base runoff”, “Dry Weather flow”, “Sustained flow” and “Delayed flow”. The hydrograph of discharge against time (Figure 15) has two main components, the area under the hump, labelled *surface runoff* (which is produced by a volume of water derived from the storm event), and the broad band near the time axis, representing the *baseflow* contributed from groundwater (Shaw, 1994). While notional separation of surface runoff and baseflow components of a stream hydrograph is conceptually simple, objective baseflow separation proves to be inordinately difficult in practice (Stanger, 1994).

While objective baseflow separation is difficult in practice, techniques have been developed for numerical separation of flow hydrograph into surface runoff and baseflow. Lyne and Hollick Filter method (Nathan and McMohan, 1990) is one widely used method of baseflow separation, and was used in this study (Appendix E).

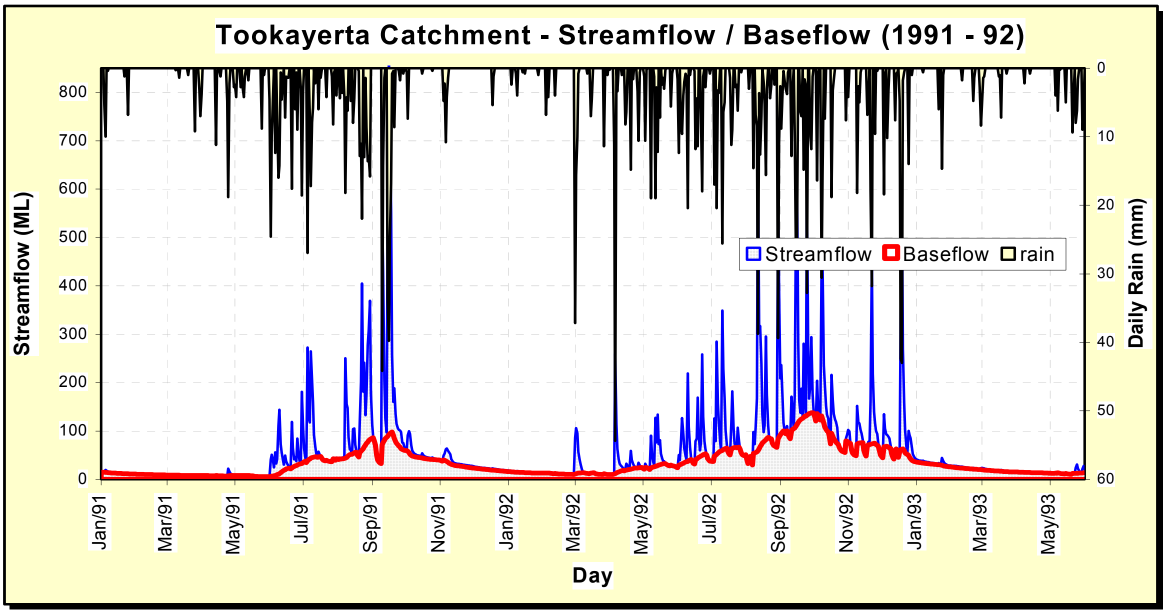


Figure 15. Baseflow Separation of Streamflow from Tookayerta Catchment

Figure 15 shows the daily streamflow (blue lines), baseflow (portion of the hydrograph enclosed by the red line) and rainfall (bars on the top) for the years 1991 and 1992. This exercise was carried out for the complete modelled data set for the period 1922 to 2000. Baseflow Index, which is the volume of baseflow divided by the total volume of streamflow, was estimated to be 0.56 for the catchment, by using the Lyne and Hollick filter method. A value of 0.56 or 56% of baseflow contribution is comparatively higher than the neighbouring catchments in the EMLR.

As discussed in the earlier sections, the comparatively high percentage of baseflow in the Tookayerta catchment could be attributed to the presence extensive Permian sand aquifers in the catchment.

3.4 Rainfall-Runoff Relationship

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

Runoff coefficient for a catchment is derived by dividing the average annual runoff by the average annual rainfall for the catchment. The runoff coefficient for the Tookayerta catchment is 0.25 for the period 1922 to 2000, or in simpler terms, on an average 25 mm of runoff leaves the catchment for every 100mm of rainfall. The coefficient was derived from the modelled average annual runoff of 19107 ML (191 mm) and the observed average annual rainfall of 770 mm. The runoff coefficient of 0.25 for the Tookayerta Creek catchment is higher than many other catchments in Eastern Mount Lofty Ranges (Table 9). This could be attributed to the high baseflows and the high rainfall in the catchment.

Table 9. **Runoff Coefficients for Catchments in the Eastern Mount Lofty Ranges (McMurray, 2001)**

No.	Catchment Name	Period of Record	Mean Annual Rainfall (mm)	Mean Annual Runoff (mm)	Runoff Coefficient
1	Finniss Catchment U/S of AW426504	1970-98	854	144	0.17
2	Marne Catchment U/S of AW426529	1973-96	535	33	0.06
3	Currency Creek U/S of AW426530	1973-96	726	108	0.15
4	Bremer River U/S of AW426533	1974-96	492	42	0.09
5	Mt Barker Creek U/S of AW426557	1980-96	703	82	0.12
6	Dawesley Creek U/S of AW426558	1976-96	642	76	0.12
7	Tookayerta Creek Catchment	1922-00	770	191	0.25

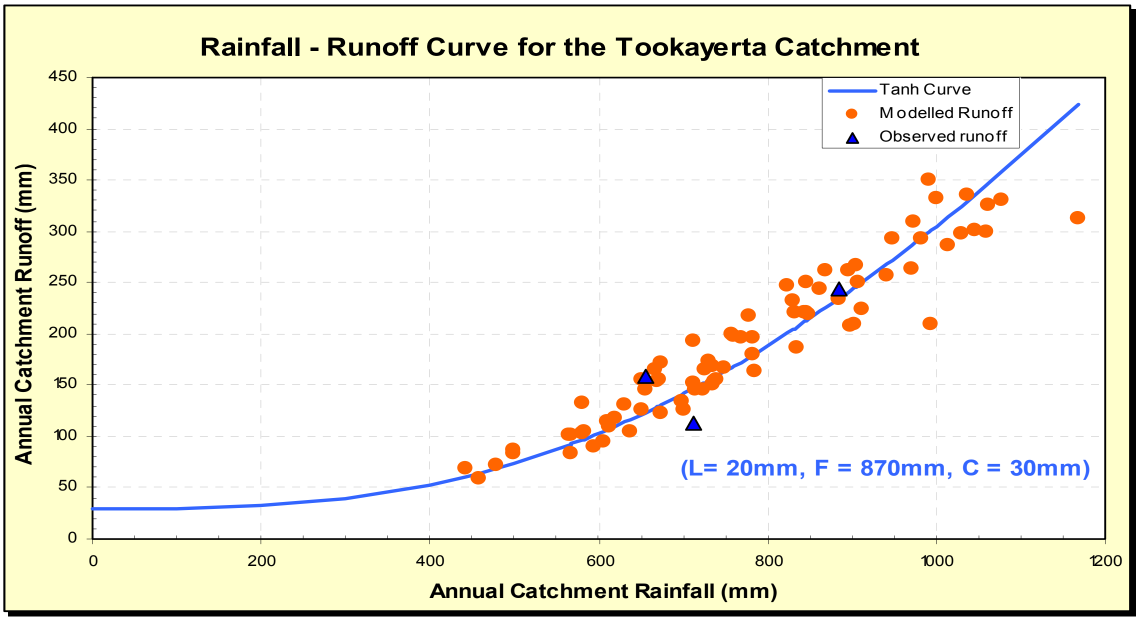


Figure 16. Rainfall-Runoff Curve for the Tookayerta Catchment

A rainfall-runoff curve and hence, a rainfall-runoff relationship for a catchment can be developed by plotting the annual rainfall versus the annual runoff values. Tanh is a standard hyperbolic function that can be used a simple rainfall-runoff relationship. The Tanh function was modified by addition of a constant (C) to represent the baseflow in the catchment. The function, its parameters and the modification applied to the function are described in Appendix A.

Figure 16 shows the rainfall-runoff curve for the Tookayerta catchment that was plotted using the Tanh function. The significant feature to note is that the curve crosses the Y-axis at around 30mm, which indicates the presence of high volumes of baseflow in the catchment. As baseflow is more dependent on catchment hydrogeology than catchment rainfall, a constant baseflow (C) of around 30 mm for annual rainfalls up to 200 mm can be noticed. Due to the high extent of saturation in the catchment (L=20 mm), even low annual rainfall years with around 200 mm would have baseflows leaving the catchment. A series of dry years in combination with high ground water extractions would gradually reduce this baseflow from the catchment. This is unique to this catchment as a minimum of around 400 mm of annual rainfall is required to generate any significant runoff in other in the Mount Lofty Ranges catchments.

4. SURFACE WATER MODELLING

4.1 Overview

Hydrologic models are conceptual models that represent the various components of the hydrologic cycle (viz, rainfall, interception, evaporation, infiltration, surface runoff, groundwater recharge and baseflow) and the links between them. The components and the links of the hydrological 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-runoff 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 Tookayerta Creek 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 runoff.

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 viz, rainfall, interception storage, evaporation, transpiration, infiltration, percolation, baseflow, etc.

Model Calibration: The iterative process of solving the above-mentioned 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 (eg, daily rainfall data set);
- Iteratively vary the other unobserved hydrological and catchment characteristics parameter sets (eg, interception storage, ground water discharge, etc.,) to mathematically simulate, generally one hydrological parameter that has been measured (eg, simulation of catchment runoff)
- Compare the simulated dataset to the measured dataset and continue the iteration process until a ‘good correlation’ is obtained between the simulated and measured datasets. 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 datasets.

Modelling Scenarios: The process of running the calibrated model with measured long-term hydrological dataset(s) to obtain long-term estimates of the other hydrological dataset(s) that were not measured (eg, to generate long-term streamflow from 100 years of measured rainfall data) to:

- provide a historical insight of the hydrological condition of the catchment,
- assess the probable impacts of various changes (natural & human-influenced) that had occurred in the past, on the catchment hydrology,
- assess the impacts of possible future developments and changes on catchment hydrology.

4.2 Methodology

WaterCress (Cresswell, 2000), 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 viz., AWBM, SFB, HYDROLOG, and WC1. WC1 (Appendix F) 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, which includes town and rural demands
- Catchment Components, which includes rural and urban catchments
- Storage Components, which includes reservoir, aquifer, tank, and off-stream dam
- Treatment components, which include sewage treatment works and wetlands
- Transfer Components, which 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 Tookayerta Catchment was divided (as explained in the earlier section on Catchment Sub-Division) into 3 major sub-catchments that were further divided into 70 minor 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 minor sub-catchment within the whole of Tookayerta catchment (Figure 17). Each off-stream dam node in the model represents an individual dam or accumulation of dams within that minor 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 dataset, rainfall factor and monthly evaporation dataset,
- Model to be used, which was WC1 in this case and the initial estimated values for the catchment parameter set, viz., median soil moisture content, interception storage, catchment distribution, ground water discharge, soil moisture discharge, pan factor, fraction ground water loss, storage reduction coefficient, ground water loss and creek loss, and
- Calibration file, which contains observed daily rainfall dataset and corresponding observed streamflow dataset 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 Tookayerta catchment model.

4.3.3 DAM NODE INPUTS

Each catchment node with farm dams was then linked to an off-stream dam node (Figure 17). 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 dataset, rainfall factor and monthly evaporation dataset,
- 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 runoff diverted to the dam. This is dependent on the location of the dam(s) and the probable catchment runoff captured by the dam(s). For example, this fraction was 1.0 if there were 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 runoff 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 Mt Lofty Ranges supports this figure of 30% as an average water use from farm dams. (McMurray, 2003)

The whole of Tookayerta catchment was hence 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 Appendix B 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. Spatially variability of rainfall within the Tookayerta catchment was accounted for by using a rainfall factor for each node derived from daily rainfall dataset from the BoM station at Mount Compass and the annual rainfall isohyets. The rainfall factor for each node was calculated as the ratio of value of the isohyet passing through the minor sub-catchment representing that node to the isohyet passing through the BoM station Mount Compass. Hence, the daily rainfall dataset for each node was obtained by multiplying the rainfall factor for that sub-catchment by the dataset from Mount Compass BoM station.

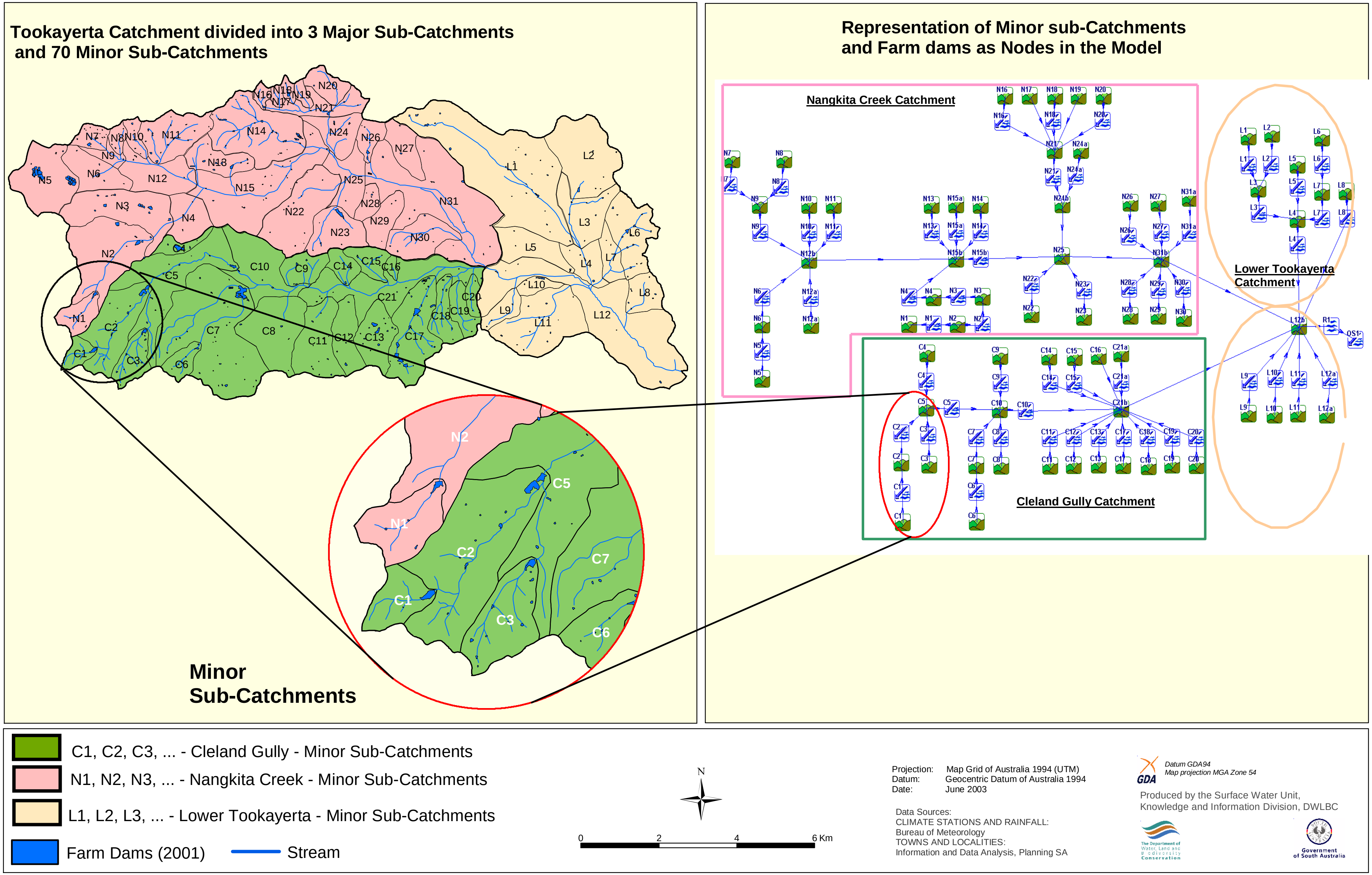
For example, the 800mm isohyet passes though the centre of the minor sub-catchments N23, N25 and N26. Hence, rainfall datasets for those sub-catchments were obtained as follows:

Rainfall data set for minor
sub-catchments N23, N25, N26 = 800/850 * Mt Compass Rainfall Data
= 0.94 * Mount Compass Rainfall Data

where, 850 is the isohyet passing through Mount Compass.

The rainfall factor used for all the sub-catchments are listed in Appendix B.

Figure 17. Tookayerta Catchment - Model Layout



4.4 Model Calibration

Long-term data generally provides 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-runoff modelling, long-term (10 to 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 landuse 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 Tookayerta catchment. Hence, the Tookayerta catchment model was calibrated to streamflow data available for just 5 years, which includes extended periods of missing data. 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 actual 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 the simulated datasets, which in this study were streamflow datasets.

'Good Correlation', in this study involved visual and statistical comparison of observed and modelled streamflow datasets on a daily, monthly and annual timescales, as well as comparison of their daily flow frequency curves. Statistical examination involved examining the correlation statistics, i.e., Correlation Coefficient (R^2) and the Co-efficient of Efficiency (Ce) for each iteration.

4.4.2 CALIBRATION RESULTS

The Tookayerta catchment model was calibrated to the daily runoff data for the period between 19/04/1997 to 15/04/2002. The values used for the parameters in the catchment model are listed in Appendix F and the correlation statistics are shown in Table 10.

Table 10. Model Calibration Results

Time scale	**R-Squared**	**Coefficient of Efficiency**	**Mean Flow (ML)** Measured / Modelled	**% Volume difference**
Annual	0.99	0.87	13744 / 14299	3.8
Monthly	0.96	0.91	1169 / 1211	3.5
Daily	0.88	0.78	32.1 / 33.1	3.2

The R^2 and Ce statistics for three different timescales shown in Table 10 indicate a good correlation between the observed and modelled data, given that only 5 years of streamflow data (with periods of missing data) was available for calibration.

Modelling the catchment response on a daily timescale that is, simulating the individual streamflow events, particularly the peaks and the recessions of every event is generally difficult. This results in correlation at daily timescale (R^2=0.88) being generally lower in comparison to monthly (R^2=0.96) and annual timescales (R^2=0.98). This difficulty is pronounced during summer, as the summer events are more rainfall-intensity driven while the data input is in daily time steps. Considering these difficulties, the model appears to have simulated daily flows to a satisfactory degree of representivity. A plot of the observed and modelled daily flows for the year 2000 is shown in Figure 18. As shown in the plot, the model has successfully reproduced almost all the events, with a good reproduction of the recessions and the peaks.

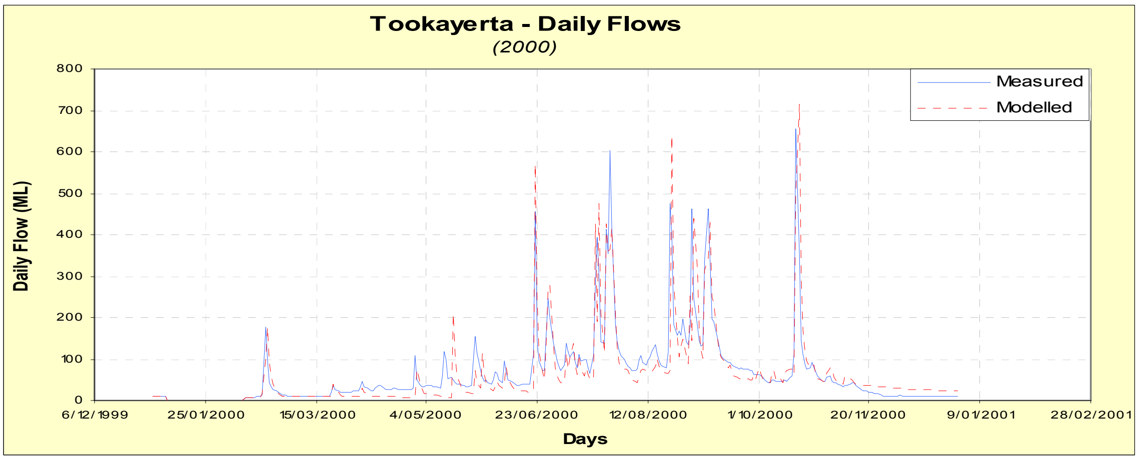


Figure 18. Observed and Modelled Daily Flows for the Tookayerta Catchment (2000)

The parts that could not be modelled as successfully as the others were some of the late autumn events as seen in the first few events in Figure 18 and the late spring events as seen in the end of the plots in Figure 18 and Figure 19. This is not uncommon in hydrological modelling, as the baseflow component is usually groundwater driven and quite complex to reproduce to a great degree of accuracy. This is also the case with late autumn events as they are more rainfall intensity driven, which cannot be accounted for as the rainfall data input is on a daily timescale.

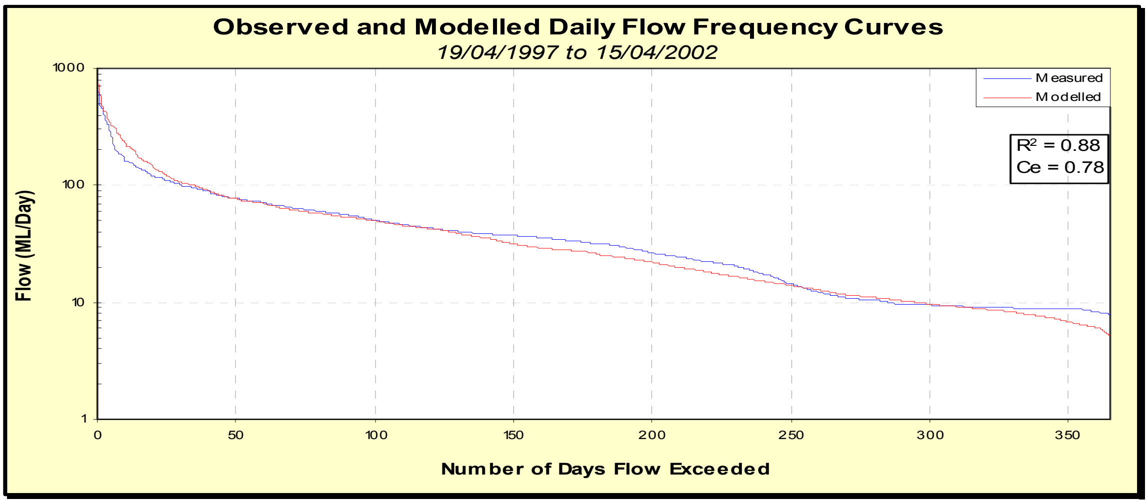


Figure 19. Observed and Modelled Daily Flow Frequency Curves for the Tookayerta Catchment (19/04/97 to 15/04/02)

Figure 20 shows the observed and modelled monthly flows for the Tookayerta catchment for the period 19/04/97 to 15/04/02 and the correlation (R^2) between them for each month. As discussed in the section above, and as shown in the figure below, the model reproduces the winter flows much better than the summer and the late autumn “break-of-season” events. The correlations (R^2) for the months June to November are in the high 0.9s and the lowest for months April and May, which once again confirms the ability of the model to satisfactorily reproduce catchment runoff for the majority of the year.

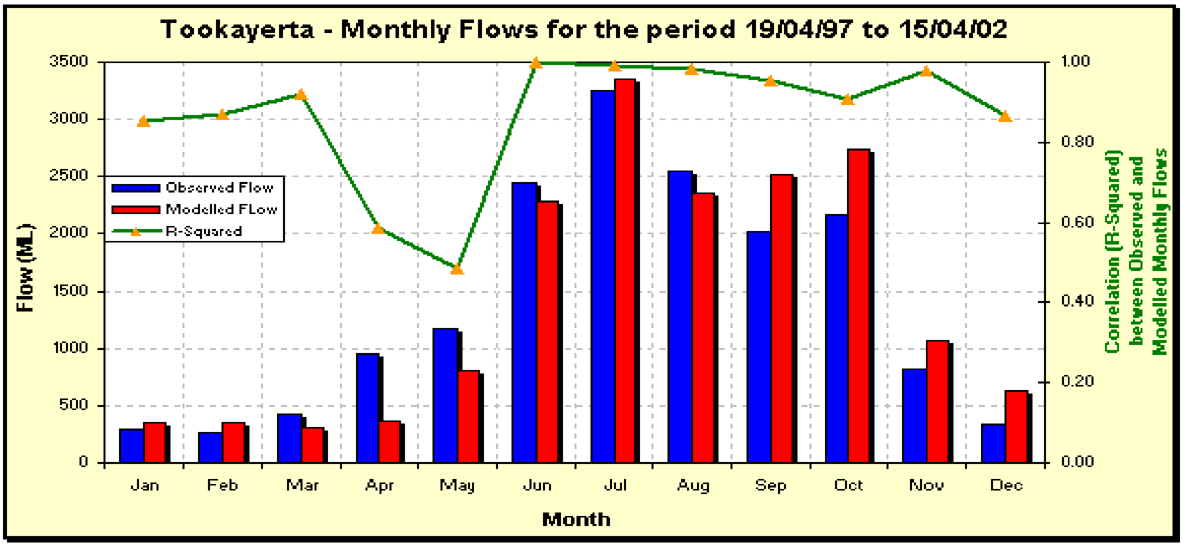


Figure 20. Monthly Flows - Correlation between Observed and Modelled Data

4.4.3 CALIBRATION IMPROVEMENT

As with most hydrological models simulation of late autumn “break-of-season” events, summer events and late season base flows could probably be improved by using:

- rainfall intensity data rather than daily rainfall data,
- Long-term and good quality gauged streamflow data, as the gauged streamflow data used in this study was for five years only and the quality of the data is also unknown,
- Daily evaporation data rather than mean monthly evaporation and
- A better understanding of the hydrogeology of the catchment and the surface-ground water interaction within the catchment.

These factors would lead to better-input data and hence, possibly better calibration of the runoff events. But such data, particularly rainfall and evaporation, are limited in availability, which in turn limit 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 sustainability of the overall surface water resources within the catchment, the potential errors at the extremes of the flow range are not seen as critical. Hence, the calibrated catchment model was considered suitable for further modelling of scenarios in this study, the results of which are presented in the next section.

5. SCENARIO MODELLING

The calibrated hydrological model of the Tookayerta Creek catchment was used to simulate different farm dam development scenarios. The purpose of simulating the scenarios was to quantify the current and future possible impacts of farm dam development on catchment hydrology. The scenarios modelled were:

- Current Scenario - Impact of current farm dams on catchment hydrology
- Future Scenarios - 1. Farm dam development to RMCWMP Limits
  - 2. Farm dam development with provision for free-to-flow areas

Estimation of impact of farm dams on catchment hydrology was carried out differently in this study in comparison 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 long-term streamflow records (10 – 20 years) were available for those catchments. Since long-term observed streamflow records are not available for the Tookayerta Creek catchment, the impacts in this study were determined using long-term modelled streamflow data (1922-2002). While this may not appear to be realistic, the results are still valid, as the long-term “mean” and “median” of modelled flows were used to assess the impacts, which are more hydrologically representative than using the short-term (5 years) observed streamflow records.

5.1 Current Scenario

This section looks at the possible impacts of the current level of farm dams (2001) on catchment hydrology. Farm dam development has been going on during the last two or three decades and their impact on catchment hydrology during this period would have been varied. But, since data for different periods and hence the actual growth rate of farm dams is unknown, data based on 2001 survey were used in this study. 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.

5.1.1 METHODOLGY

The methodology adopted for estimating the impacts of current levels farm dam development on catchment hydrology involved:

- generating long-term (1922-2002) streamflow data for the catchment with the current level of farm dam development. This was done due to the lack of observed long-term streamflow records for the catchment. Hence, the terms “current flow(s)”, “streamflow”, “runoff” ” in this report refer to “modelled streamflow/runoff”.
- removing farm dams from the model and then generating streamflow for the same period. This is termed as “pre-farm dam development flow”, which actually means “streamflow with impact of farm dams removed”.
- determining the variation in streamflows from the two modelled datasets, which is the runoff captured/trapped by the dams.

The analysis and results are presented on different time steps and on catchment and sub-catchment scales.

5.1.2 RESULTS & DISCUSSION

The streamflows generated from the scenario were analysed on annual, monthly / seasonal and daily time steps, the results of which are discussed in the following sections.

Annual flows

The current (2001) levels of farm dams in the Tookayerta catchment capture on an average 720 ML of the catchment's annual runoff. This accounts for around 4% of the catchment runoff if the farm dams did not exist. In otherworlds, the current farm dams have potentially reduced the mean and annual runoff from the Tookayerta catchment by 4%. This impact varies annually with rainfall, impacting higher during drier years and having a very minimal impact during wetter years. For example, a dry year like 1980 (with 480mm rain) will have annual flows reduced by 10%, while a wet year like 1992 (with 1275mm rain) will have annual flows reduced by 2%.

Analysis of estimated impacts of farm dams on a sub-catchment was also carried out and the results are presented in Table 11.

Table 11. Potential Impact of 2001 Dams on Sub-Catchment Annual Flows

Sub-Catchment	Annual Rain (mm)	Dam Density (ML/Km^2)	Modelled Mean annual Catchment Runoff (ML) (1922 – 2000)		Reduction in Mean Annual Runoff (%)
			With Dams	Without Dams	
Nangkita Creek	808	10.6	8785	9089	3%
Cleland Gully	806	17	6519	6846	5%
Lower Tookayerta	663	4	3803	3892	2%
Total Catchment	770	11	19107	19827	4%

Flow reductions due to farm dams do not vary significantly between the three sub-catchments, as shown in the table. The higher farm dam density of Cleland Gully sub-catchment is accounted for by a higher (but not significantly) flow reduction (5%) in annual flow. The low farm dam density of the Lower Tookayerta sub-catchment is reflected by the lower reduction (2%) in annual flow, once again not significantly lower than the 4% reduction for the whole catchment.

Monthly Flows

Analysis of flows on a monthly timescale provides a better understanding of the varying impacts of dams on a seasonal basis. Figure 21 shows the mean runoffs modelled with and without the dams, the potential percentage reduction in flows and the observed mean rainfall data on a monthly basis.

The farm dams do not have any impact on catchment flows during the period June to September (winter). The impact gradually increases from October onwards and the maximum impact is observed in the month of January. The impact starts decreasing slowly in the next few months until June when the impact is literally nil.

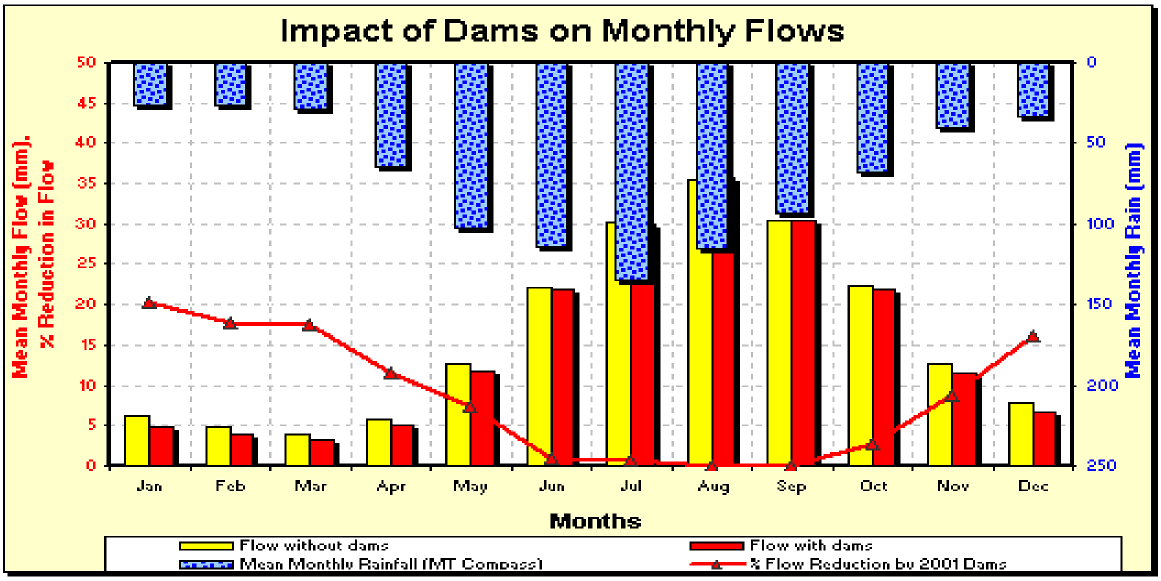


Figure 21. Impact of Dams on Monthly Flows

The impact of farm dams on seasonal basis can be described as:

- **Mid & 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 are not captured by the dams as they spill over them. Hence, the impact of dams is minimal during this season.
- **Spring & Summer** (late October to March) – This is the period when pumping from the dams for irrigation and evaporation from dams gradually increase and reach a peak by March. 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 runoff gradually increases from October onwards and reaches a peak by March.
- **Autumn & Early winter** (April to June) – this is the period when higher rainfall occurs (blue bars in Figure 21), with lower evaporation resulting in higher runoffs being generated after the wetting period and gradually the whole catchment starts contributing to the runoff. While the impacts of dams are higher earlier in this season it gradually reduces as the dams fill, starting with the smaller dams and progressively increasing with size happens and catchments gradually become free-to-flow. This is reflected by the impact of dams gradually reducing to almost nil effect in late June.

To summarise, the current farm dams potentially reduce the mean winter (May to November) runoff by 1% and the mean summer runoff by 17%. While the farm dams might have had a minimal impact on the overall water resources of the catchment, they might possibly have had more impact on flows during spring, summer and autumn. This could be crucial particularly to this catchment, as summer flows constitute 14% of the annual catchment flows, which is high in comparison to other catchments in the region.

Daily Flows

While changes in monthly flows are useful for examination of changes in seasonal flows, 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 frequencies of flows with and without dams.

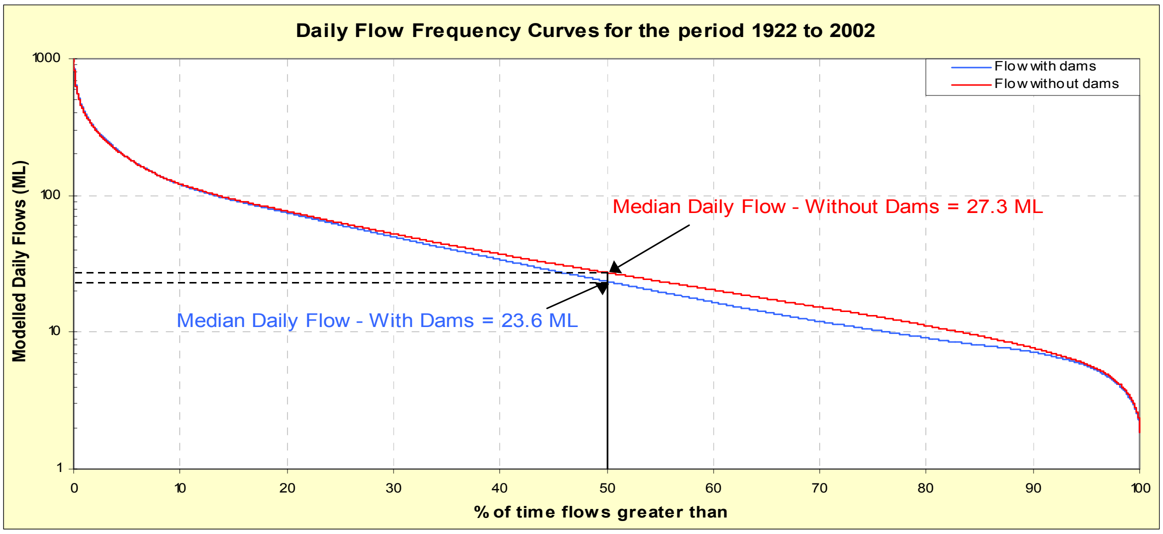


Figure 22. Comparison of Daily Flow Frequency Curves - With & Without Dams

Figure 22 shows the daily flow frequency curves modelled with and without dams. As shown in the figure, variation between the two curves is visible in the section between 40th and 90th flow percentiles. This section represents flows between 7 ML/day and 35 ML/day, which is the lower end of the medium flows and higher end of the low flows of the catchment. This implies that the farm dams have no significant impact on high flows, a major portion of medium flows and low flows. And, even where the impact is noted the flow differences are not large.

Further analysis and comparison of different flows ranges were carried out and results shown in Table 12. The results indicate that the dams have very little impact on flows greater than 50 ML/day and flows less than 10 ML/day. As discusses earlier this is the mid-flow section, or in other words the dams have very little impact on the high and low flows in the Tookayerta Catchment.

Table 12. Daily Flow Exceedance Values for – "With Dams" and "Without Dams" Scenarios

Flow Criteria	Number of days in a year of flow being equalled or exceeded		Difference in flow exceedance days
	"With Dams" Scenario	"Without Dams" Scenario	
Cease to flow	0	0	0
Flow ≥ 1 ML/day	0	0	0
Flow ≥ 5 ML/day	352	353	1
Flow ≥ 10 ML/day	280	304	24
Flow ≥ 20 ML/day	200	221	21
Flow ≥ 50 ML/day	110	114	4
Flow ≥ 100 ML/day	48	50	2
Flow ≥ 200 ML/day	17	17	0
Flow ≥ 500 ML/day	2	2	0
Flow ≥ 1000 ML/day	3 hours	3 hours	0

While the current level of farm dam development has not had a significant impact on the high flows in similar catchments in the region, they have had an impact on the low flows on other catchments in the region, which was not observed in the Tookayerta catchment.

The Tookayerta catchment, unlike most other catchments in the region, has a high percentage of baseflow, which forms a major portion of the low flows from the catchment. Since baseflows are groundwater-driven, and since there are no major on-stream dams in the lower sections of the catchment to capture them, the farm dams do not have a significant impact on them. This explains the result "dams not impacting low flows" for the Tookayerta catchment.

This raises an important issue of possible future development and its potential impact on catchment flow, and in particular the low flows (baseflows). As mentioned in the earlier section on farm dams, since the 2001 levels of farm dam development in all the three major sub-catchments have not exceeded allowable development limits set in the current Catchment Plan, further development might be considered during the water allocation planning process to be carried out for the catchment. In such case, it must be ensured that the plan does not allow for construction of new on-stream farm dams or for direct extraction of low flows from the streams. This will ensure that the current status of lows flows (base flows) are maintained and not allocated for other further developments. More importantly, groundwater extraction rates need to be maintained at sustainable levels to ensure the baseflows are not impacted, as

1. baseflows are primarily groundwater dependent, and

2. the quantity and quality of the groundwater resource in the Tookayerta catchment places it at a greater risk for over-extraction than surface water.

5.2 Future Scenario – RMCWMP Development Limits (based on best estimate of runoff coefficient (2004))

The River Murray Catchment Water Management Plan (2003) has set allowable limits for surface water development for all the major catchments and sub-catchments in the Eastern Mount Lofty Ranges ("EMLR"). The allowable development limits set in the catchment plan were developed using a runoff coefficient of 0.10 (10% of rainfall runs off) for the entire EMLR. While the runoff coefficient of 0.10 used in the catchment plan represents the estimated average runoff coefficient across the entire Eastern Mount Lofty Ranges, it varies widely with individual catchments, as does rainfall.

Runoff coefficient for the Tookayerta catchment (based on long-term rainfall records and streamflow data) was estimated in this study to be 0.25 (25%). This is much higher than the initial estimate of 0.10 (10%) that was used in the RMCWMP. The development limits (Table 13) based on the runoff coefficient of 0.25 was considered to be more current for the Tookayerta catchment in comparison to the development limits set in the catchment plan. Hence, as a future scenario, the catchment was modelled with farm dam capacities increased to the new development limits and their impact on catchment runoff was assessed.

The term "allowable development limits" in the following sections of this report means the "allowable development limit defined in the River Murray Catchment Water Management Plan's Allowable Limits, but estimated with a runoff coefficient of 0.25".

Table 13. Catchment Plan's Development Limits based on best estimate of runoff coefficient (2004) for the Tookayerta Catchment

Sub-Catchment	**Catchment Area (Km^2)**	**Average Annual Rainfall (mm)**	**Average May-November Rainfall (mm)**	**Average May-Nov runoff (25% of May-Nov Rainfall)(mm)**	**30% of May-Nov Runoff (mm)**	**Allowable Farm Dam Volume (ML)**	**2001 levels of estimated Farm Dam Volumes (ML)**	**2001 levels of development divided by allowable volume**
Nangkita Creek	42	808	646	162	49	2058	464	23%
Cleland Gully	33	806	645	161	48	1584	534	34%
Lower Tookayerta	25	663	530	132	40	1000	105	10%
Total	**100**	**770**	**616**	**154**	**46**	**4600**	**1103**	**24%**

As shown in Table 13, the total farm dam capacities were increased in the three sub-catchments to the allowable limits as per the RMCWMP. While in reality, farm dam development may or may not occur to the extent as shown in the table (for example, a ten fold increase in farm dam capacities in the driest sub-catchment (Lower Tookayerta)), it was considered useful to estimate the extent of possible impacts if farm dam development were allowed to occur to the RMCWMP's development limits.

5.2.1 METHODOLGY

The methodology adopted for estimating the impacts of possible future farm dam development involved:

- Establishing the allowable development limit for each minor sub-catchment. The limit as per the catchment plan is 30% of May to November runoff, which was calculated for each minor sub-catchment as follows:

  Allowable Development Limit = area of minor sub-catchment (Km^2) x average annual rainfall for the minor sub-catchment (mm) x 0.8 (Average May-Nov rainfall = 80% of average annual Rainfall, based on rainfall records for the period 1922 – 2002) x 0.25 (runoff coefficient for the Tookayerta catchment) x 0.3 (30% of May-Nov runoff is allowable development limit as per RMCWMP).
- Comparison of the allowable development level to the cumulative capacity of the existing dams in each minor sub-catchment. This resulted in either of the two cases, that is,
  (a) the existing cumulative farm dam capacity equals or exceeds the allowable limit for that sub-catchment. The minor sub-catchment was then considered saturated and hence the existing cumulative farm dam capacity was used for modelling, or,
  (b) the existing cumulative farm dam capacity is lower than the allowable limit for that sub-catchment. Hence, the cumulative farm dam capacity was increased to the allowable limit for that minor sub-catchment.
- Fraction of total catchment runoff diverted to the dam was made 1.0 for all the minor sub-catchments in which the exiting farm dam capacities were increased to the allowable limits. The sub-catchments that currently do not have dams ("free-to-flow" areas) were not altered, that is, no new dams were added to those nodes. The other dam node parameters were kept the same as in the calibration stage. (*Refer "Dam Node Inputs / Model Construction" section for further details on dam node parameters*)

The model was then run with the above-mentioned changes and streamflow data generated for the period 1922 to 2002. The data generated was then compared to the streamflow data generated with the "current dams" scenario and the "without dams" scenario for predicting future impacts if dam development was allowed to happen till the development limits are reached.

5.2.2 RESULTS & DISCUSSION

The streamflows generated for the scenario were then analysed in annual, monthly / seasonal and daily time steps, the results of which are discussed in the following sections.

Annual flows

The mean annual flow generated from the catchment was estimated to be 17185 ML under this scenario. This represents a further 10% reduction in flows generated from catchment under the current ("with dams") scenario. This impact would be much higher if new dams were added to the currently free-to-flow areas. The impact also varies annually with rainfall, with greater effect during drier years and less during wetter years. For example, a dry year like 1980 (with 480mm rain) would have 29% less annual flow in comparison to the current flow, while a wet year like 1992 (with 1275mm rain) would have 4% less annual flow in comparison to the current flow.

Table 14. Potential Impact of increasing farm dam capacities to RMCWMP Limits*

Sub-Catchment	Modelled Mean annual Catchment Runoff (ML) (1922 – 2000)		Reduction to Current Average Annual Flows
	With 2001 Dams	With Dam capacities increased to RMCWMP Limits*	
Nangkita Creek	8785	7943	10%
Cleland Gully	6519	5992	8%
Lower Tookayerta	3803	3249	15%
Total Catchment	19107	17185	10%

* RMCWMP Limits – River Murray Catchment Water Management Plan Limits calculated with a runoff coefficient of 0.25. Refer "Methodology" section for further details.

The impact also varies on a sub-catchment level as indicated in Table 14. The table lists the model annual runoffs from the sub-catchments under the current scenario and under the scenario with farm dam capacities increased to RMCWMP Limits estimated with a runoff coefficient of 0.25. The data indicates that the highest impact (15% reduction in average annual flows) would be in the Lower Tookayerta sub-catchment and lowest in the Cleland Gully sub-catchment (8% reduction). This is due to the low level of current (2001) farm dam development in the Lower Tookayerta sub-catchment and hence the highest increase in total farm dam capacity, to reach its allowable development limits. As shown in Table 13, the current (2001) farm dam development in the in the Lower Tookayerta sub-catchment is 105 ML. This was increased to its allowable limit of 1000 ML, which is almost ten times the current level of development and hence the high impact.

Monthly Flows

While an additional 10% reduction in average annual flows is estimated when farm dam capacities were increased to RMCWMP limits, there is literally no additional impact observed on flows during the months of July, August and September. As shown in Figure 23, the estimated future flow reduction is quite high during the period between November and May, and follows a similar pattern as the flow reduction caused by the current dams. The major difference observed between the flow reductions under the two scenarios (red and brown lines in Figure 23) is that while the current dams have had negligible impact on June flows, a 10% reduction in future June flows was observed when the farm dam capacities were increased to RMCWMP limits. The higher impact during June is probably due to more runoff required to fill up the larger dams. This results in longer filling-up period of larger dams that cause the delay in catchments becoming "free-to-flow".

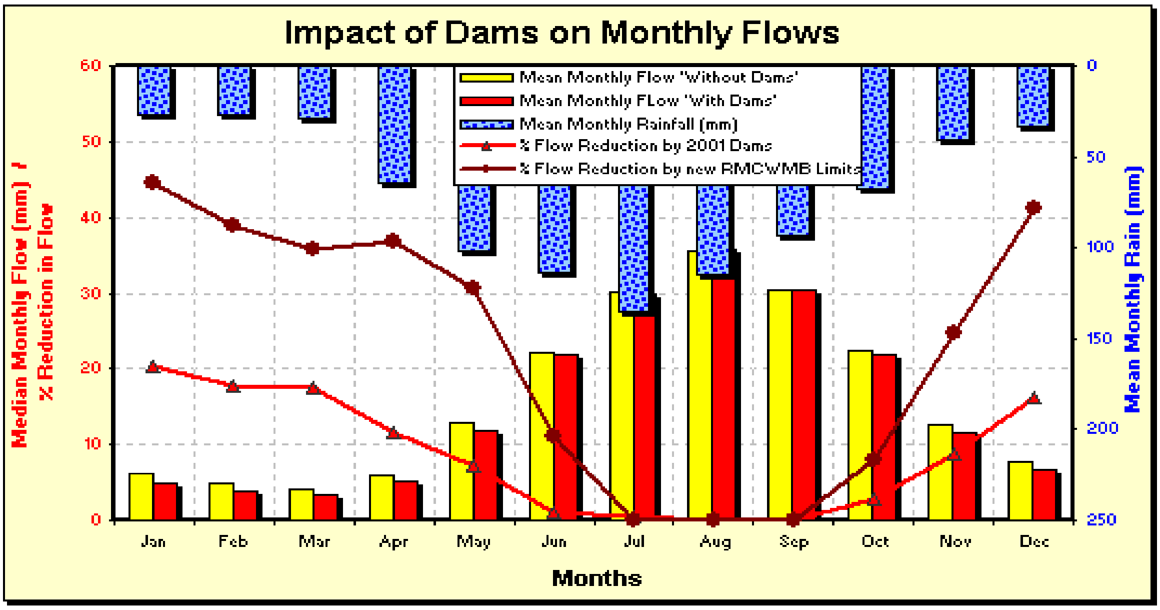


Figure 23. Future Scenario (RMCWMP Limits) - Impact of Dams on Current Monthly Flows

The impacts of increasing the farm dam capacities to the RMCWMP limits on runoff on a sub-catchment level on a seasonal basis are listed in Table 15.

Table 15. Impact of Dams on current Seasonal flows – Dam Capacities at RMCWMP Limits*

Sub-Catchments	**WINTER – Median Flows (ML)**			**SUMMER – Median Flows (ML)**		
	Current Scenario[1]	**RMCWMP Limits Scenario**[2]	**Flow Reduction** Volume *(%)*	**Current Scenario**	**RMCWMP Limits Scenario**	**Flow Reduction** Volume (%)
Nangkita Creek	7116	6591	525 *(7%)*	991	605	386 *(39%)*
Cleland Gully	5318	5070	248 *(5%)*	683	372	312 *(46%)*
Lower Tookayerta	2989	2631	359 *(12%)*	402	216	187 *(46%)*
Total Catchment	15520	14203	1317 *(8%)*	2075	1204	871 *(42%)*

* RMCWMP Limits – River Murray Catchment Water Management Plan Limits calculated with a runoff coefficient of 0.25. Refer “Methodology” section for further details.

To summarise, farm dam development up to the RWMCMP limits* would potentially further reduce the median winter (May to November) runoff by 8% and the median summer runoff by 42%.

Daily Flows

Figure 24 displays the flow frequency curves generated under three different farm dam scenarios. Comparison of current daily flows and daily flows expected if further farm dam development was allowed to the development limits, indicate that allowing farm dam development to that limit would have a significant impact on the catchment’s flow regime. As indicated in the chart, all flows less than around 100 ML/day would be impacted. The current median daily flow of 23.6 ML would possibly be reduced by 45% to 13.7 ML/day.

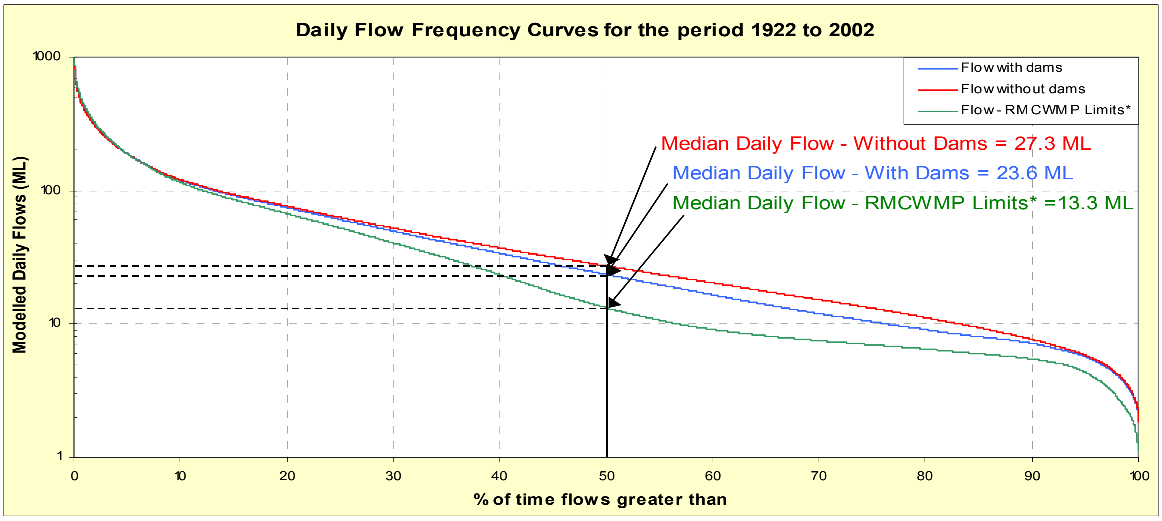


Figure 24. Comparison of Daily Flow Frequency Curves - Current & Future Scenarios

(** - RMCWMP allowable limits calculated with a runoff coefficient of 0.25*)

Comparison of different flow ranges for the different flow scenarios are tabulated in Table 16. The results indicate that, except for baseflows and high flows (> 100 ML/day) there would be a significant flow reduction if farm dam capacities were allowed to increase to RMCWMP's allowable limits.

In summary, increasing the dam capacities in the Tookayerta to the RMCWMP's allowable limits (based on a runoff coefficient of 0.25) would have a significant impact on the catchment's flow regimes less than 100 ML/day. This is indicated by the results of modelling, which predicts reduction in flows on an annual, seasonal and daily time steps.

Table 16. Daily Flow Exceedance Values for Current and Future Scenarios

Flow Criteria	**Number of days in a year of flow being equalled or exceeded**			**Difference in flow exceedance days between Current & Future Scenarios**
	"Without Dams" Scenario	**"With Dams" Current Scenario**	**"RMCWMP Limits*" Future Scenario**	
Cease to flow	0	0	0	0
Flow ≥ 1 ML/day	0	0	0	0
Flow ≥ 5 ML/day	339	352	339	13
Flow ≥ 10 ML/day	304	280	208	72
Flow ≥ 20 ML/day	221	200	156	44
Flow ≥ 50 ML/day	114	110	95	15
Flow ≥ 100 ML/day	50	48	44	4
Flow ≥ 200 ML/day	17	17	17	0
Flow ≥ 500 ML/day	2	2	2	0
Flow ≥ 1000 ML/day	3 hours	3 hours	3	0

5.3 Future Scenario – Farm Dam development with Provision for Free-to-Flow Areas ("Free-to-Flow Areas Scenario")

In addition to the two scenarios required for the assessment of impact of farm dams on the surface water resources of the Tookayerta catchment, an additional scenario was modelled using the development limits similar to those used in the Clare Valley Water Allocation Plan (WAP). This was chosen as the Clare WAP includes "limits for diversion" to new dams apart from "maximum development limits", while the RMCWMP sets allowable limits only on the level of development. Rules similar to those in the Clare WAP was used as a scenario in this study solely for the purposes of gaining further understanding on the impacts farm dams with diversion conditions applied to them.

For this scenario a rule was adopted that in any region (major sub-catchment in this study) 50% of the area should be under "free-to-flow" conditions, and of the runoff generated from the remanning area only 50% can be diverted to dams. This, in other words works out to:

- The allowable development limit for a sub-catchment is limited to 25% of the mean May to November catchment runoff, and

- Only 50% of the catchment runoff can be diverted to the dams, that is, one half of the catchment must always be left free to flow.

5.3.1 METHODOLGY

The methodology adopted for estimating the possible impacts if farm dam development were allowed under this scenario:

- Establishing allowable development limit for each minor sub-catchment. The limit as per the catchment plan is 25% of May to November runoff, which was calculated for each minor sub-catchment as follows:

  Allowable Development Limit = area of minor sub-catchment (Km^2) x average annual rainfall for the minor sub-catchment (mm) x 0.8 (Average May-Nov rainfall = 80% of average annual Rainfall, based on rainfall records for the period 1922 – 2002) x 0.25 (runoff coefficient for the Tookayerta catchment) x 0.25 (25% of May-Nov runoff is allowable development limit as per RMCWMP).

- Comparison of the allowable development level to the cumulative capacity of the existing dams in each minor sub-catchment. This resulted in either of the two cases, that is,
  (a) the existing cumulative farm dam capacity equals or exceeds the allowable limit for that sub-catchment. The minor sub-catchment was then considered saturated and hence the existing cumulative farm dam capacity was used for modelling, or,
  (b) the existing cumulative farm dam capacity is lower than the allowable limit for that sub-catchment. Hence, the cumulative farm dam capacity was increased to the allowable limit for that minor sub-catchment.

- Fraction of total catchment runoff diverted to the dam was made 0.5 for all the minor sub-catchments. The other dam node parameters were kept the same as in the calibration stage. (*Refer "Dam Node Inputs / Model Construction" section for further details on dam node parameters*).

  It should however be noted that the diversion rate of 0.5 (50%) was set to all the dams in the modelling exercise, including existing and future dams, while in reality the 50% diversion limits applies only to new developments.

The model was then run with the above-mentioned changes and streamflow generated for the period 1922 to 2002. The data generated was then compared to the streamflow data generated with the "current dams" scenario for predicting future impacts if dam development was allowed to happen till the development limits are reached.

5.3.2 RESULTS & DISCUSSION

The streamflows generated for the scenario were then analysed in annual, monthly / seasonal and daily time steps, the results of which are discussed in the following sections.

Annual flows

The mean annual flow generated from the catchment was estimated to be 17631 ML under this scenario. This is around 450 ML higher than the mean annual flow generated under the "RMCWMP Limits" scenario. The reduction in mean annual flow under this scenario is 8%, which is 2% lower than 10% flow reduction estimated under "RMCWMP Limits" scenario. The is possibly due to the lower development limit of 25% set in this scenario in comparison to the 30% limit in the RMCWMP scenario. While the reductions in annual runoffs are not considerably different between the two scenarios, there is considerable difference in the impacts on monthly flows, which is discussed below in the next section.

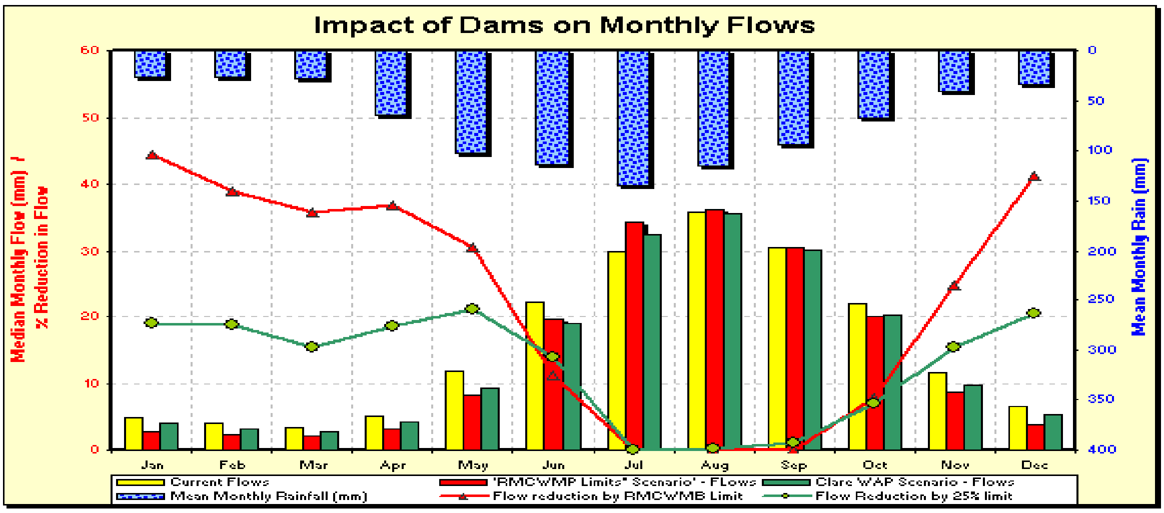


Figure 25. Impacts on Monthly Flows – Future Scenarios

Monthly Flows

Figure 25 shows the monthly flows generated under the two scenarios, and the predicted reduction of current monthly flows. As shown by the green line in the figure, future farm dam development under the "Free-to-Flow Areas" scenario would have considerably less impact on summer and autumn flows (November to May) in comparison to the flows under "RMCWMP Limits" scenario. The reason is, under this scenario only 50% of the flow generated is allowed to be diverted to dams and hence, all catchment runoff generated would not be captured by dams.

Under the "RMCWMP Scenario", there are no diversion rules and hence all runoff generated would be captured by the dams until they get filled-up and spill. It can also be observed that it takes more time for the dams to fill-up and for catchments to become "free-to-flow" under this scenario and hence, a higher impact is observed during June and July in comparison to the "RMCWMP Limits" scenario.

Once the dams are full, the catchments are "free-to-flow" with farm dams having literally no impact on flows, under both scenarios, until pumping starts, evaporation increases and the dams are not full anymore, starting from late spring (late October / November).

The overall impact on a seasonal basis is tabulated in Table 17.

Table 17. Impact of Dams on a Seasonal Basis - Different Scenarios

Scenarios	Summer (December to April)		Winter (May to November)		Annual	
	Mean Flow (ML)	Flow Reduction (%)	Mean Flow (ML)	Flow Reduction (%)	Mean Flow (ML)	Flow Reduction (%)
"Current (2001 Dams) " Scenario	2393		16714		19107	
"RMCWMP Limits" Scenario	1440	40%	15775	6%	17185	10%
"Provision for Free-to-Flow Areas" Scenario	1946	19%	15685	6%	17631	8%

As discussed earlier, under the "Similar to Clare WAP" scenario the impact of farm dams on summer flows is considerably less in comparison to the impacts under the "RMCWMP Limits" scenario. While the mean winter flow is lower (due to the longer filling-up period of dams – as discussed earlier) under the "Free-to-Flow Areas" scenario the percentage reduction is almost the same as the "RMCWMP Limits" scenario.

Daily Flows

Daily flow frequency curves for the different scenarios are plotted in Figure 26. Comparison of the curves for "RMCWMP Limits" scenario and the "Free-to-Flow Areas" scenario indicate the higher impact if farm dam development was allowed under the "RMCWMP" scenario. While, future development adopting the "Free-to-Flow Areas" scenario would have impact on the daily flows, it would be much lesser than the impacts of development under the "RMCWMP" scenario. For example, the current median daily flow would be reduced by 5 ML (23.6 ML/day to 18.6 ML/day) if development were allowed to occur adopting “Free-to-Flow Areas” scenario limits, while development adopting “RMCWMP” limits would reduce the current median daily flow by 10 ML (double the impact!). As discussed in the earlier section, the lower impact of farm dam development under the “Free-to-Flow Areas” scenario is due to the fact that only 50% of the flows can be diverted to off-stream dams.

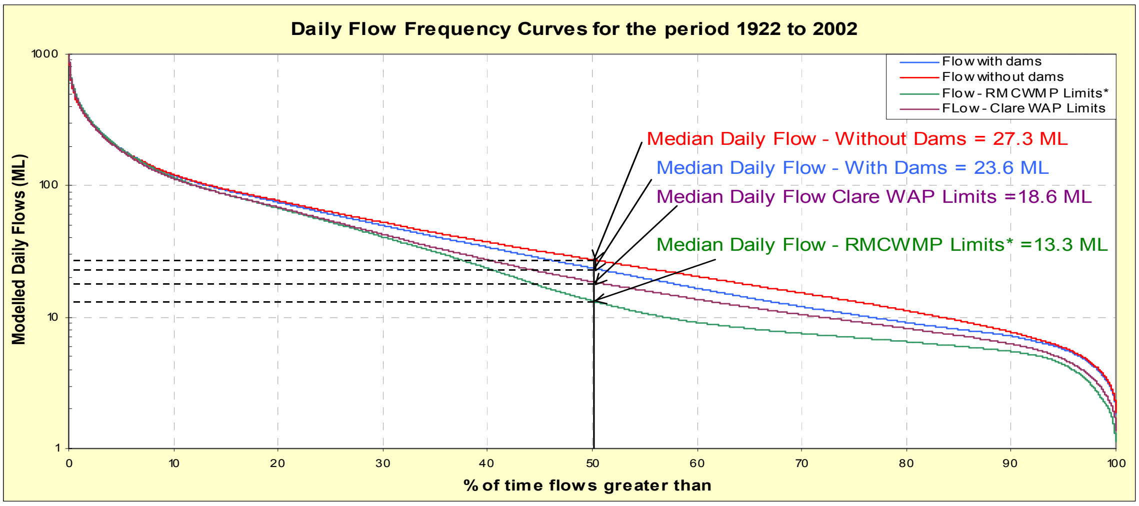


Figure 26. Impact of Farm Dams on Daily Flows - Various Scenarios

While the extent of impacts of future farm dam development under the “Provision for Free-to-Flow Areas” scenario might be higher in reality due to the fact that 50% diversion limits under the scenario was applied to both, existing and new dams, it still highlights the fact that incorporating “diversion limits” in addition to “development limits” would ensure all low flows not being captured.

6. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

6.1 Hydrological Data

The hydrological data used in this study, their spatial and temporal representivity for analysis purposes and future data requirements are summarised in this section.

Rainfall Data: Daily-read rainfall records are available from one Bureau of Meteorology site within the catchment. Rainfall records at this site are available from 1922 onwards, which provides a good temporally distributed rainfall data set. However, since the site is in the north-west corner of the catchment, data from the site represents neither the spatial variability of rainfall within the catchment nor the average rainfall for the catchment. Hence, rainfall isohyets in conjunction with rainfall records from the site were used in this study to obtain a spatial distribution of rainfall data within the catchment.

Streamflow Data: Streamflow data collected by THATCH Environmental Consultancy (for the Compass Creek Care Inc., a local community group) was used in this study, as there are no DWLBC streamflow gauging stations in the Tookayerta catchment. This data set includes data from 8 different sites, for varied durations, the maximum period for which good quality continuos data is available is for 5 years at one site. Since five years of streamflow data if too small a data set for hydrological analysis purposes, long-term streamflow data generated from modelling was used for analysis in this study.

Evaporation Data: Monthly evaporation data from Myponga reservoir was used in this study, as it was the only site closest to the Tookayerta catchment with long-term data. Data from a site within the catchment would better represent the catchment characteristics than from a station in a nearby catchment. Furthermore, due to lack of daily data, monthly evaporation data was used in this study. Use of daily evaporation data would probably enable better calibration of the catchment model.

6.2 Catchment Modelling

A rainfall-runoff catchment water balance model was constructed for the Tookayerta catchment in this study using the WaterCress modelling platform. The model was calibrated to five years of streamflow data, which was then used to generate long-term streamflow data using rainfall data from the catchment. The model was then used to simulate catchment scenarios to study their impacts on catchment runoff, the results of which are summarised in this section.

6.2.1 MODEL CALIBRATION

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

The rainfall-runoff model used in this study provided a good calibration of streamflow data on annual, monthly and daily time steps, given that only 5 years of streamflow data (which includes periods of missing data) was available for calibration. On a monthly basis, a good correlation was obtained for all months except for April and May, which represent the "break-of-season" events i.e., wetting-up period followed by start of catchment runoff being generated.

This difficulty in calibrating the "break-of-season" flows is common with most hydrological models. However, since flows during this season represent only a very small percentage of the annual flows, it does not affect the main outcome of this study, which is to assess the overall surface water resources of the catchment.

Calibration of the model can further be refined by using 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 evaporation data, and more importantly,
- Good quality long-term observed streamflow records and
- Better set of isohyets

6.2.2. SCENARIO MODELLING

The rainfall-runoff model constructed and calibrated for the Tookayerta catchment was run for three different scenarios to study the impact of farm dams on catchment hydrology.

The results of the case scenarios are:

i. **Pre-Farm Dam Development Scenario:** The model was run, first with the 2001 levels of farm dam development ("Current Scenario"), and next with the impact of farm dams removed ("Pre-Farm Dam Development Scenario"). The runoff data from the two scenarios were compared, the results of which indicate:
   - The farm dams, at 2001 level of development intercept on average 720 ML/year of runoff generated from the catchment. This represents 4% of the mean and median annual runoff generated from the pre-farm dam development scenario. The impact of farm dams on annual runoff varies in individual years, the reduction in annual flow being marginal during wet years (2% reduction during 1979 and 1992) and higher during drier years (10% reduction in 1980).
   - On a sub-catchment level, the estimated average flow reductions due to 2001 farm dams are 3%, 5% and 2% for the Nangkita Creek, the Cleland Gully and the Lower Tookayerta Creek sub-catchments respectively. These do not vary much from the average flow reduction of 4% for the whole Tookayerta catchment.
   - On a seasonal basis, the impact of dams is higher during summer months (an estimated average runoff reduction of 17%) in comparison to the minimal average runoff reduction of 1% during winter (May to November).

- On a daily basis, the dams appear to have impacted flows ranging between 10 ML/day and 50 ML/day. The dams appear to have no significant impact on low flows or baseflows, on the higher end of medium flows and on high flows.

ii. **Future Scenario – Farm dams developed to RMCWMP Limits:** The 2001 level of farm dam development in the Tookayerta catchment (1100 ML) is only 24% of the RMCWMP's allowable development limit [1] of 4600 ML. On a sub-catchment level the current farm dam developments in the Nangkita Creek, Cleland Gully and Lower Tookayerta sub-catchments are 23%, 34% and 10% of their allowable development limits. Since none of the sub-catchments have equalled or exceeded their allowable development limits, the capacities of the existing farm dams were increased to the allowable development limits and modelled as a future scenario. The runoff generated from this scenario was then compared to the runoff generated from the "Current Scenario", to estimate the impacts if farm dam development was allowed to the development limits. Hence, if farm dam development was allowed to the RMCWMP's development limits, the probable future impacts on catchment runoff would be:

- The farm dams would capture annually on average of 1920 ML of the catchment runoff. This represents 10% of the current mean annual runoff from the catchment. The runoff reduction varies annually, with an estimated reduction of current runoff by 30% during a dry year like 1980 (with 480 mm rain) and 4% during a wet year like 1992 (with 1275 mm rain).
- On a sub-catchment level the highest impact (15% reduction in annual flows) would be in Lower Tookayerta catchment due to the low level of current development and hence the highest increase in farm dam capacity if development were allowed to the allowable limit.
- On a seasonal basis the impacts would be higher during summer, with a possible reduction to the current mean summer runoff by 40% and a much lower reduction of 6% during winter.
- On a daily basis, the impacts would be on a wider range of daily flows and to a much higher extent. For example, while the current dams have potentially caused a 13% reduction (27.3 ML/day to 23.6 ML/day) to the pre-development median daily runoff, increasing the dam capacities to the RMCWMP's allowable limit would possibly cause a 42% reduction (23.6 ML/day to 13.3 ML/day) in the future.

iii. **Future Scenario – "Provision for Free-to-Flow Areas":** The Clare Water Allocation Plan (WAP) sets diversion limits to new off-stream dams in addition to setting development limits. In brief, the Clare WAP sets the following limits: 50% of any region (major sub-catchment) should be allowed to be under "free-to-flow" condition; and only 50% of the flow from the remaining area can be diverted to dams. This results in the allowable development limits for a region to be 25% of its catchment runoff, with a diversion limit of 50% to dams. The Tookayerta catchment model was run with similar conditions and the data generated was compared with other scenarios, the results of which indicate:

- While the impact of farm dams on annual basis would be similar in both cases, that is, under the "RMCWMP Limits" and "Free-to-Flow Areas", the impacts on seasonal flows would be different. Development as per the "Free-to-Flow Areas"

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[1] RMCWMP's allowable limits calculated with a runoff coefficient of 0.25

scenario limits would have considerably lower impact on summer (May to November) flows, with the estimated further reduction in average summer flows under this scenario being 19% in comparison to the 40% reduction caused by development under "RMCWMP" limits. The lower reduction of summer flows under the "Free-to-Flow Areas" scenario is attributed to the 50% diversion limits to dams that results in less flows being captured by dams during summer. The leads to dams filling slower and later in winter in comparison to the "RMCWMP Limits" scenario.

- The advantage of setting diversion limits is again reflected in the impact on daily flows, with lesser impact under "Free-to-Flow Areas" scenario. For example, the current median daily flow would be reduced by 5 ML/day (23.6 ML/day to 18.6 ML/day) under the "Provision for Free-to-Flow Areas" scenario, while this reduction would be doubled (23.6 ML/day to 13.3 ML/day) if development were allowed to happen under the "RMCWMP Limits" scenario.

This scenario was used in this study solely for the purpose of illustration of the advantages of applying "diversion limits" to farm dams and hence, the results of this scenario should be used for comparison purposes only. This is due to the reason that in this study the 50% diversion limit was applied to both, existing and new dams, while in reality this might be applied only for new developments as in the Clare WAP. Applying diversion limits to only new developments will give different results (higher impacts) than the ones in this study. However, it should be understood that setting diversion limits to new development would have a much lower impact on low flows as against having no diversion limits at all.

6.3 Technical Recommendations

The primary input parameters to the catchment model used in this study were rainfall, streamflow, evaporation and farm dam data. While the data available at the time of the study sufficed the needs, more data (reliable, long-term and recent) would further refine the model and its outcomes. Some of the monitoring requirements to collect the required data are:

- Streamflow is currently not gauged in the Tookayerta catchment and hence, establishment of a streamflow gauging station in the catchment needs to be considered. The hydro-geological and ecological uniqueness of the Tookayerta catchment further enhances this need for long-term streamflow gauging.

  The perennial nature of the stream with baseflows throughout summer necessitates the need for measuring low flows to a higher degree of accuracy, in addition to medium and high flows. This needs to be considered when designing the streamflow gauging station.

- Ground water (quantity and quality) monitoring is also essential given the occurrence of high baseflow in the catchment and the presence of extensive and unique ecosystems that are dependant on it. It is also essential for further understanding the interaction between the ground and surface water systems in the catchment.

- The current Bureau of Meteorology rainfall station is located in the north-west corner of the Tookayerta catchment, and hence, data from the site does not represent the average rainfall for the catchment. Rainfall measurement at more sites within the catchment would provide the appropriate data to represent the spatial distribution of rainfall within the catchment.

  Establishment of two rainfall stations, one in the Cleland Gully sub-catchment and one in the lower rainfall Lower Tookayerta sub-catchment would provide for this spatial representivity of rainfall within the catchment.

The above monitoring requirements have been recommended in the DWLBC's "Eastern Mount Lofty Ranges Surface Water Monitoring Review", which is currently being finalised.

6.5 Environmental Considerations

While this report provides a brief insight into the unique and significant water dependent ecosystems in the catchment, it is beyond the scope of this study to assess or quantify the direct impacts of farm dams on them. However,

- the main outcomes of the study, that is, the impact of farm dams on the different flow regimes in different catchment scenarios will be an useful tool to assess the impact of farm dams on ecosystems dependent on those flow regimes, and

- the model constructed in this study will be a useful tool in designing future scenarios to assess possible impacts on the ecosystems.

Furthermore, due to the high inter-dependability between groundwater, baseflow and water dependant ecosystems, assessment of the status of the ground water resources in the catchment would play crucial role, as the health of its extensive water dependant ecosystems are primarily baseflow dependant.

Further studies are required to identify the catchment's water dependent ecosystems and estimate their flow requirements, which will enhance the future water allocation planning process.

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APPENDIX A. TANH FUNCTION

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

Calculation

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

where

Q	is runoff [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. This 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 20.

APPENDIX B. TOOKAYERTA CATCHMENT – SUB-CATCHMENT AND DAM NODES DETAILS

Tookayerta Catchment - WaterCress Details

Nangkita Creek Sub-Catchment

No.	Sub-Catchment	Catchment Area (SqKm)	Dam Capacity (ML)	Dam Surface Area (m2)	DamDensity (ML/SqKm)	Avg Ann Rain* (mm)	Rainfall Factor#	Diversion Rate@
1	N1	0.740	19.25	10778.8	26.0	837	0.985	100
2	N2	2.691	37.9	22110.8	14.1	830	0.976	90
3	N3	2.500	42.91	29219.9	17.2	825	0.971	90
4	N4	1.070	0.8	880.6	0.7	850	1.000	80
5	N5	2.230	151.86	87896.0	68.1	787	0.926	100
6	N6	1.200	3.95	3758.5	3.3	810	0.953	80
7	N7	0.442	12.79	10078.2	28.9	800	0.941	90
8	N8	0.260	2.67	2802.8	10.3	812	0.955	80
9	N9	0.310	0.38	426.8	1.2	810	0.953	100
10	N10	0.350	2.71	2478.5	7.7	820	0.965	40
11	N11	1.680	15.38	13548.4	9.2	830	0.976	90
12	N12a	0.157	1.67	1803.8	10.6	830	0.976	100
13	N12b	1.143	0	0.0	0.0	830	0.976	0
14	N13	1.040	25.2	17714.0	24.2	830	0.976	90
15	N14	3.160	31.92	26608.1	10.1	837	0.985	95
16	N15a	2.760	4.8	4808.9	1.7	837	0.985	50
17	N15b	1.780	1.4	2061.0	0.8	837	0.985	100
18	N16	0.210	4.4	3604.2	21.0	837	0.985	100
19	N17	0.160	0	0.0	0.0	834	0.981	0
20	N18	0.170	13.29	7949.3	78.2	831	0.978	70
21	N19	0.200	0	0.0	0.0	829	0.975	0
22	N20	0.670	3.08	2648.6	4.6	820	0.965	50
23	N21	1.050	7.68	5463.5	7.3	825	0.971	100
24	N22	2.510	3.59	4024.4	1.4	812	0.955	50
25	N23	1.360	40.9	20070.8	30.1	800	0.941	70
26	N24a	0.200	3.48	3551.3	17.4	812	0.955	100
27	N24b	0.810	0	0.0	0.0	812	0.955	0
28	N25	1.160	0	0.0	0.0	800	0.941	0
29	N26	0.520	10.4	7196.8	20.0	800	0.941	100
30	N27	0.850	2.53	2144.1	3.0	775	0.912	50
31	N28	0.400	2.17	2057.4	5.4	787	0.926	80
32	N29	0.850	0.78	916.2	0.9	780	0.918	90
33	N30	1.400	3.81	3739.5	2.7	762	0.896	60
34	N31a	1.800	12.08	11306.4	6.7	750	0.882	100%
35	N31b	4.000	0	0.0	0.0	750	0.882	0
	Total	**41.833**	**463.78**	**311647.5**	**11.1**			

Cleland Gully Sub-Catchment

No.	Sub-Catchment	Catchment Area (SqKm)	Dam Capacity (ML)	Dam Surface Area (m2)	DamDensity (ML/SqKm)	Avg Ann Rain* (mm)	Rainfall Factor#	Diversion Rate@
1	C1	0.470	26.04	12408.6	55.40	850	1.000	100
2	C2	2.240	55.79	29265.0	24.91	850	1.000	100
3	C3	0.890	25.27	16272.0	28.39	837	0.985	100
4	C4	0.400	52.39	25035.1	130.98	850	1.000	50
5	C5	3.150	19.03	12921.2	6.04	850	1.000	90
6	C6	0.550	6.62	5226.3	12.04	820	0.965	100
7	C7	6.000	135.54	72188.8	22.59	820	0.965	100
8	C8	2.330	4.15	3480.9	1.78	812	0.955	50
9	C9	0.780	6.48	5136.8	8.31	812	0.955	20
10	C10	2.030	2.8	2759.9	1.38	825	0.971	60
11	C11	1.830	5.22	5432.0	2.85	790	0.929	80
12	C12	1.120	5.66	4599.2	5.05	785	0.924	20
13	C13	1.300	40.78	24883.0	31.37	775	0.912	80
14	C14	0.500	2.89	2323.0	5.78	790	0.929	90
15	C15	0.630	2.21	2195.1	3.51	785	0.924	10
16	C16	0.140	0	0.0	0.00	770	0.906	0
17	C17	2.510	130.17	72311.8	51.86	760	0.894	90
18	C18	0.850	8.02	7061.7	9.44	737	0.867	90
19	C19	0.660	0.8	922.9	1.21	730	0.859	5
20	C20	0.300	0.53	706.4	1.77	720	0.847	5
21	C21a	0.300	3.93	4255.0	13.10	775	0.912	100
22	C21b	2.700	0	0.0	0.00	775	0.912	0
	Total	**31.680**	**534.32**	**309384.7**	**16.87**			

* - Average annual rainfall for sub-catchments – calculated using rainfall isohyets.

- Rainfall Factor – Average annual rainfall for the sub-catchment divided by the average annual rainfall at the BoM station at Mount Compass. The factor was applied to the rainfall data set from Mount Compass for each sub-catchment.

@ - Percentage of flow diverted to the dam node from the catchment node upstream.

Lower Tookayerta Sub-Catchment

No.	Sub-Catchment	Catchment Area (SqKm)	Dam Capacity (ML)	Dam Surface Area (m2)	DamDensity (ML/SqKm)	Avg Ann Rain* (mm)	Rainfall Factor#	Diversion Rate@
1	L1	7.190	25.75	20784.1	3.6	725	0.853	80
2	L2	2.810	10.99	7461.6	3.9	662	0.779	100
3	L3	1.480	4.13	4123.7	2.8	650	0.765	50
4	L4	0.860	5.45	4423.0	6.3	637	0.749	75
5	L5	1.200	2.42	2681.6	2.0	675	0.794	100
6	L6	1.880	24.83	18631.9	13.2	600	0.706	90
7	L7	0.610	0.7	783.5	1.1	612	0.720	10
8	L8	0.820	5.45	5340.1	6.6	575	0.676	90
9	L9	0.550	1.98	1953.6	3.6	700	0.824	80
10	L10	0.350	8.72	6092.9	24.9	675	0.794	100
11	L11	2.880	9	8545.1	3.1	662	0.779	70
12	L12a	1.076	5.8	5129.1	5.4	625	0.735	100
13	L12b	4.284	0	0.0	0.0	626	0.736	0
	Total	**25.985**	**105.22**	**85950.3**	**4.0**			

APPENDIX C. TREND TEST (GRAYSON, 1996)

Mann's Test (Kendall, 1970)

Given a time series (X_1, X_2, X_3, …..X_n), Mann's test statistic 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:

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

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.

APPENDIX D. METHODOLOGY USED FOR DISAGGREGATION OF ACCUMULATED RAINFALL RECORDS

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

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

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

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

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

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

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

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

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

APPENDIX E. BASEFLOW SEPERATION (GRAYSON, 1996)

Lyne and Hollick filter (Nathan and McMahon, 1990, pp 78,79)

The Lyne and Hollick filter is used for seperation of hydrograpgh into components representing stormflow and baseflow. It has been widely applied to daily data and there is a body of regionalised information available, based on its use. The equation used is as follows:

$$q_f(i) = \alpha q_f(i-1) + (q(i) - q(i-1))\,(1+\alpha)/2$$

for $q_f(i) \geq 0$

where

$q_f(i)$	filtered quick flow response for the i^{th} sampling instant
$q(i)$	original streamflow for the i^{th} sampling instant
α	filter parameter for which a value of 0.925 is recommended for daily data.

Base flow (q_b) is therefore $q_b = q - q_f$

When coding the algorithm into a spreadsheet or computer program, a conditional equation should be used where if the computed value of q_f is less than zero, q_b is set to q, otherwise q_b equals q-q_f.

APPENDIX F. WC1 – MODEL DESCRIPTION (CRESSWELL, 2002)

WC-1 is water balance model developed by David Cresswell based on experience with South Australian rainfall / run-off calibration in the Mt 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 most of the existing models tried were not able to reproduce the recorded runoff of South Australia's drier catchments. When annual rainfall lies in the range 450 to 650mm the estimation of run-off becomes a tricky exercise.

Model Concept

The model is a 10 parameter model using 3 storages as shown in Figure 27 to track interception, soil moisture and groundwater. The soil store is generally the main runoff producing component requiring 4 parameters for calibration.

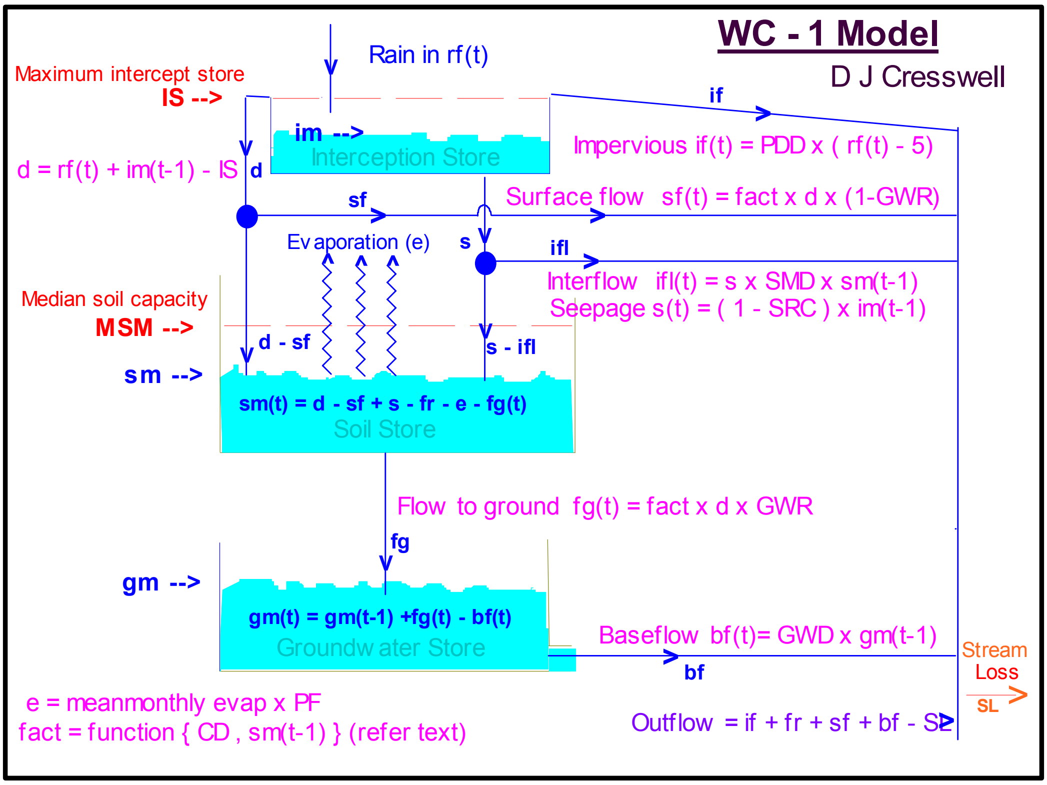

Figure 27. Concept of WC-1 Model

Surface runoff (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 runoff 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 by calculating the saturated surface area of the catchment. To do this, the model 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 28.

To calibrate such a model, two parameters are required, the median soil moisture of the catchment (MSM) and the catchment standard distribution (CD). Typically these values are found to lie between 150 to 250 mm (MSM) and 20 to 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 toward the fully saturated catchment which occurs at median soil moisture plus 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 28 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 runoff. From normal distribution tables this is 5.5% of the catchment.

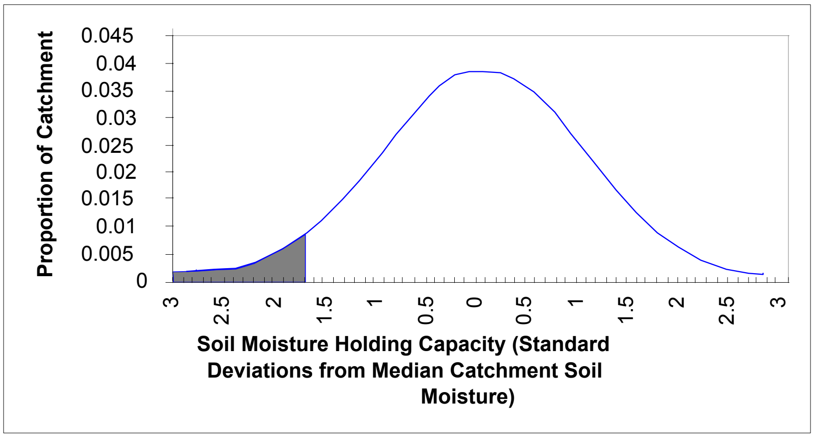

Figure 28. Contributing Catchment calculated from Soil Moisture

When the median soil moisture is reached the catchment contributing is 50% as shown in Figure 29.

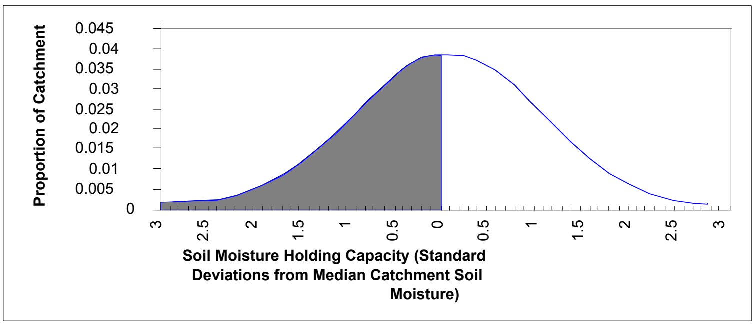

Figure 29. Contributing Catchment calculated from Soil Moisture

The shape of this relationship, (Figure 30), 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 silled at 1.0.

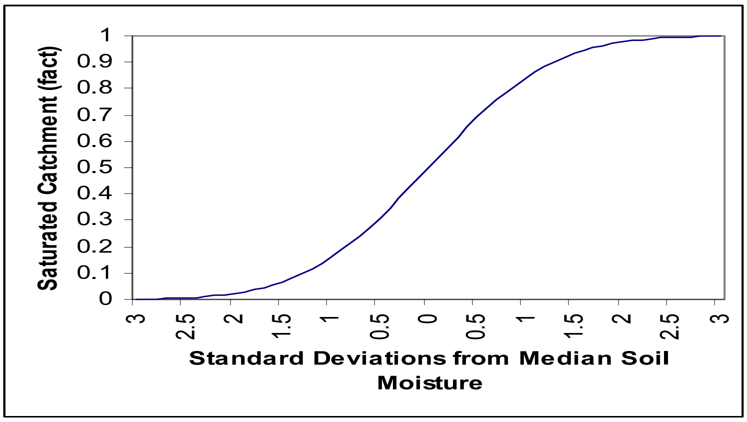

Figure 30. Contributing Catchment calculated from Soil Moisture

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 zero 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 is calculated equal to

- S = (1 – SWM) x im(t)

During the wet season the baseflow of the streams are seen to rise but the duration of such flow remains dependent on relatively continuous rainfall 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 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 runoff and was discarded for the simpler constant model. Here evapo-transpiration is assumed to equal the pan factor times recorded daily evaporation. Typically a value of 0.6 to 0.7 is 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 GWF is used to define the proportion passing to ground and often this may be up to 20 to 30 percent.

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. Usually in the range 150-300 mm. Increasing this value delays the early season initiation of runoff, decreases runoff by providing greater opportunity for evapo-transpiration and assist in keeping late season groundwater flows up.

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

Catchment distribution (CD) - sets the range of soil moisture values about MSM. Usual values are 25-60 mm. A larger value will initiate runoff earlier and more often.

Ground Water Discharge (GWD) - is 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 0.001 to 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 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 to 1.0. The higher the value, the less the runoff. The higher the value, the earlier runoff 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 5mm, 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) - is the proportion of rainfall that recharges the groundwater store. Usual values are 0.05 to 0.3 indicating that 5% to 30% of the flow running off the catchment is entering the groundwater system.

Creek Loss (CL) - is a reduction factor used to decrease runoff. It is generally set to zero.

<u>Values for the parameters used for calibrating the Tookayerta Catchment Model</u>

MSM	-	65
IS	-	10
CD	-	55
GWD	-	0.01
SWD	-	0.002
PF	-	0.60
FGL	-	0.55
SWM	-	0.9
GWR	-	0.7
ROUTING COEFFICIENTS	-	300, 0.8