DWLBC REPORT

Rocky River Catchment Water Resources Assessment

2005/34

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

Rocky River Catchment Water Resources Assessment

David Deane

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

June 2007

Report DWLBC 2005/34

Australian Government

Government of South Australia
Northern and Yorke Natural Resources Management Board

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ISBN 0-9758235-4-X

Preferred way to cite this publication
Deane, D 2005, *Rocky River Catchment water resources assessment,* Report DWLBC 2005/34, Department of Water, Land and Biodiversity Conservation, Adelaide.

FOREWORD

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

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

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

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

ACKNOWLEDGEMENTS

The author extends particular thanks to the following DLWBC colleagues: Bruce Murdoch, for guidance and assistance in hydrological data analyses; Paul Magarey for assistance in field investigations, consultations and groundwater analyses; Judy Tan for map preparation; and Andrew Love for advice and review of the groundwater section.

Ashley Greenwood contributed the additional rainfall statistical analyses presented in Appendix B and suggested a number of improvements to the structure and layout of the report during a comprehensive review of the draft, which was particularly appreciated by the author.

The assistance of the following people who contributed valuable time, knowledge, information, ideas and constructive criticism during the preparation of this report is also gratefully acknowledged.

Northern and Yorke Natural Resource Management Board and staff

Trudie Stanley, Kerry Ward, Phyllis Robinson, David Sloper, Saideh Kent, Dave Clarke.

Greening Australia

Anne Brown, Paul Slattery.

State Agencies

Mary-Anne Young (PIRSA Jamestown), Peter Harris (Goyder APCB), Gaby Swearse (Northern Areas Council), Ashley Greenwood, Theresa Heneker, David Cresswell, Kumar Savadamuthu, Steve Kotz, Doug McMurray and Tricia Williams (DWLBC).

Landholders and Community Members

Finally, a special thank you is extended to the many landholders and members of the community who gave their valuable time, and offered information relating to their experience of the water resources of the catchment in particular: Greg Pech, Bill Pech, John Wilson; and also: Alan Wilson, Paul Kretschmer, Ann Kretschmer, Greg Dick, Marie Johnson, Noel Curtis, Julianne Curtis, Peter Curtis, Jim Lynch, David O'Reilly, Jackie O'Reilly, Peter Trott, Lyell Woolford, Russell Lines, Kym Arbon, Pam Cockburn, Tom Cockburn, Arnold Borgas, Trevor Stevens, Peter Cockburn, Martin Jaeschke, Paul Marner and Mark Lange.

Funding

This assessment was commissioned by the Northern and Yorke Natural Resource Management (NYNRM) Board using resources obtained through the joint Commonwealth and state-funded National Action Plan for Salinity and Water Quality. It forms part of a NYNRM Board water resources assessment project in the Mid-North of South Australia entitled *Investigate the impacts of farm dams and irrigation in priority areas under threat*.

Photography

Unless noted otherwise all photographs used within this report were taken by the author during field surveys in June and September 2005.

Cover photographs (clockwise from top left) Appila Springs; Upper eastern catchment looking west; Rocky River near Thredgold’s Crossing; Rocky River downstream of Gladstone.

CONTENTS

FOREWORD .... **iii**

ACKNOWLEDGEMENTS .... **v**

EXECUTIVE SUMMARY **1**

1. INTRODUCTION **5**

2. APPROACH **7**

2.1 CONSULTATIONS 7
2.2 SPATIAL ANALYSIS 7
2.2.1 Groundwater 7
2.2.2 Farm Dams 7
2.2.3 Irrigation 8
2.3 SURFACE WATER MODELLING 8
2.3.1 Rainfall-runoff Modelling 8
2.3.2 Annual Catchment Yield 8

3. CATCHMENT DESCRIPTION **11**

3.1 TOPOGRAPHY 11
3.2 MAJOR RIVER SYSTEMS 11
3.3 CLIMATE 11
3.4 LAND USE 15
3.4.1 Land Use Classification 15
3.5 WATER-DEPENDENT ECOSYSTEMS 17

4. SURFACE WATER RESOURCES **19**

4.1 RAINFALL 19
4.1.1 Data 19
4.1.2 Analysis 21
4.2 EVAPORATION 27
4.3 STREAMFLOW 27
4.3.1 Data 27
4.4 RAINFALL-RUNOFF MODELLING 28
4.4.1 Model Calibration 28
4.4.2 Limitations 30
4.5 CATCHMENT YIELD 31
4.6 SURFACE WATER KNOWLEDGE GAPS 33

5. GROUNDWATER RESOURCES **35**

5.1 INTRODUCTION 35
5.2 RESOURCE STATUS 35

5.2.1 Groundwater Quantity 35
5.2.2 Groundwater Quality 35
5.2.3 Community Perceptions 38
5.3 RECHARGE ESTIMATES 39
5.3.1 Chloride Mass Balance 40
5.3.2 Regional Water Balance Estimates 40
5.4 DISCUSSION 43
5.5 GROUNDWATER KNOWLEDGE GAPS 45
6. WATER RESOURCE DEVELOPMENT 47
6.1 INTRODUCTION 47
6.2 FARM DAM DEVELOPMENT 47
6.2.1 Impacts of Farm Dams 47
6.2.2 Data Availability and Quality 48
6.2.3 Dam Development Levels 49
6.2.4 Benchmarking Dam Development 49
6.3 GROUNDWATER DEVELOPMENT 54
6.3.1 Benchmarking Groundwater Development 56
6.4 IRRIGATION 58
6.4.1 Irrigation Usage 58
6.5 STOCK AND DOMESTIC USE 59
6.6 WATER RESOURCES DEVELOPMENT KNOWLEDGE GAPS 60
7. CONCLUSIONS AND RECOMMENDATIONS 61
7.1 RISK ASSESSMENT 61
7.1.1 Surface Water 62
7.1.2 Groundwater 62
7.1.3 Water-dependent Ecosystems 63
APPENDICES 65
A. WATER-USE VOLUME METHODOLOGY 65
B. THE RECENT DRY SPELL 67
C. DISAGGREGATION AND INFILLING OF RAINFALL RECORDS — METHODOLOGY 71
D. RAINFALL RECORD HOMOGENEITY 72
E. SURFACE WATER MODELLING 74
F. TANH FUNCTION 77
G. MODEL PARAMETERS — SUB-CATCHMENTS 78
UNITS OF MEASUREMENT 79
GLOSSARY 81
REFERENCES 87

LIST OF FIGURES

Figure 1 Broughton River system showing the Rocky River Catchment.......... 6
Figure 2 Topography and rainfall distribution, Rocky River Catchment. 12
Figure 3 Sub-catchments, average rainfall and gauging stations used in modelling 14
Figure 4 Rocky River Catchment land use 16
Figure 5 Waterhole on Peter Trotts' property, Rocky River north of Wirrabara 17
Figure 6 Permanent pools identified in the Broughton River system during 1999 18
Figure 7 Long-term regional average rainfall, Rocky River Catchment 20
Figure 8 Annual rainfall variation, west to east and regional average of the Rocky River Catchment 22
Figure 9 Long-term regional average rainfall and residual mass of the Rocky River Catchment 22
Figure 10 Regional average rainfall trends and residual mass since 1970 for the Rocky River Catchment 23
Figure 11 Cross-decadal rainfall and 10 year moving average, Rocky River Catchment 24
Figure 12 Long-term regional mean monthly rainfall and standard deviation, Rocky River Catchment 25
Figure 13 Regional April and June rainfalls, means and trendlines, Rocky River Catchment 25
Figure 14 Regional September and October rainfalls, means and trendlines, Rocky River Catchment 26
Figure 15 Selected regional monthly and annual residual mass curves, Rocky River Catchment 26
Figure 16 WaterCress Model layout, Rocky River Catchment.......... 29
Figure 17 Observed versus modelled flows during late 2003, Rocky River Catchment 30
Figure 18 Annual rainfall-runoff curve for Hutt River Catchment 32
Figure 19 APP2 monitoring bore SWL and monthly rainfall at Wirrabara 36
Figure 20 Groundwater salinity as a function of well depth, Rocky River Catchment.......... 36
Figure 21 Groundwater salinity distribution, Rocky River Catchment 37
Figure 22 Estimated annual recharge by sub-catchment in the Rocky River Catchment 41
Figure 23 Well yields per metre of depth, Rocky River Catchment.......... 44
Figure 24 Dam size classes, Rocky River Catchment 49
Figure 25 Farm dam development levels by sub-catchment in the Rocky River Catchment 51
Figure 26 Current groundwater wells, Rocky River Catchment 55
Figure 27 Proximity of irrigation wells to Laura township 57
Figure 28 Irrigation water-use and irrigated area by crop type, Rocky River Catchment.......... 59
Figure 29 Frequency of regional annual rainfall totals, Rocky River Catchment 67
Figure 30 Kolmogorov-Smirnov test results, Rocky River Catchment 68
Figure 31 Rocky River regional annual rainfall frequency 69
Figure 32 Monthly double mass curve for 019001 versus regional average 72

LIST OF TABLES

Table 1 Rocky River sub-catchments and rainfall 13
Table 2 1999 land use in the Rocky River Catchment 15
Table 3 Rainfall stations used in analysis of the Rocky River Catchment 19
Table 4 Monthly averaged daily evaporation data for Beetaloo Reservoir Meteorological Station 021124 27
Table 5 Streamflow gauging sites in the Rocky River Catchment 28
Table 6 Runoff coefficients for selected catchments 32
Table 7 Salinity data from an irrigation well north of Wirrabara on Rocky River 38
Table 8 Selected groundwater salinity data provided by landholders 38
Table 9 Recharge rates and volumes by sub-catchment in the Rocky River Catchment 42
Table 10 Comparison of farm dam statistics within South Australia 50
Table 11 Selected farm dam and hydrological statistics for the Rocky River Catchment 52
Table 12 Status of all bores located within the Rocky River Catchment 54
Table 13 Drilling activity in the Rocky River Catchment since 1990 54
Table 14 Water-use and irrigated area by crop type 65
Table 15 Land use types and associated areas for grazing calculations, Rocky River Catchment 66
Table 16 Statistics for Rocky River regional annual rainfall, pre- and post-1975 70
Table 17 Slopes, % variation and correction factors, BoM Station 019001 73

EXECUTIVE SUMMARY

A water resources assessment of the Rocky River, a major sub-catchment of the Broughton River system in South Australia's Mid-North, was completed in 2004 for the Northern and Yorke Peninsula Agricultural Districts Natural Resources Management Board (NYAD). Estimates of the available surface water and groundwater resources and current levels of use are summarised below.

Rocky River Water Resources Summary

Surface water resources (median runoff)	8000–10 000 ML/y
Sustainable limit of farm dam capture (50% rule)	4000–5000 ML/y
Total farm dam capacity	2600 ML (966 dams)
Groundwater recharge	2500–24 000 ML/y
Sustainable limit of use	3600–6000 ML/y
Actual use	4200 ML/y
Total water resources	11 600–16 000 ML/y
Sustainable limit of use	5600–8500 ML/y
Actual use	5500 ML/y

As indicated by the values within the table, there are considerable uncertainties in estimating both the available resource and current usage levels for surface and groundwater. Improving these estimates will require the collection of considerable additional data and subsequent analysis.

Monitoring was found to be spatially adequate from a surface water perspective, but streamflow records are currently of insufficient duration to be of use in modelling. Existing stations need to be maintained to extend the record. There is no groundwater monitoring of the fractured rock aquifer system and this needs to be implemented across the catchment. High priorities include areas of intensive irrigation or high well density in the western central and northern sub-catchments.

Based on the available evidence, current use was within sustainable limits at a catchment scale but areas of unsustainable and highly intensive surface and groundwater development were located in specific areas. These areas warrant more detailed investigation supported by suitable additional monitoring where appropriate.

Surface water

Rainfall analysis showed a significant change in rainfall patterns between 1970–80. The seasonal onset of rains appears to have been delayed and persisted later, resulting in an effective loss of available water to the catchment's annual water balance. Extremes in annual rainfall appear to be decreasing, with annual rainfall generally around the long-term average. Large rainfall events were less frequent and annual patterns showed a marked reduction in variability. The multiple lines of evidence pointed toward an overwhelming picture of a drying landscape with correlates with other parts of the Mid-North and Mount Lofty Ranges.

Hydrological rainfall-runoff modelling was completed using the WaterCress platform and standard statistical methods, but the available streamflow data from recently constructed gauging stations was only representative of recent dry conditions and was thought to underestimate runoff in wetter periods of the historic rainfall record. An analytical Tanh rainfall-runoff function was used to estimate surface water resources to provide the preliminary estimates of catchment yield shown in the above table.

Farm dam development was the only method identified for harvesting surface runoff and streamflow. Total dam storage volumes were estimated using aerial photography to measure surface areas and a surface area–volume relationship, a technique with acknowledged uncertainties but increasing application in southeastern Australia. Uncertainties can be reduced if more accurate farm dam surface areas are available at full supply level and theoretical area–volume relationships are supported by groundtruthing. The average size of dams is small, and use of water from farm dams is apparently limited to stock and domestic purposes.

The sustainability of farm dam surface water harvesting was assessed using the State Water Plan 2000 50% rule. At catchment scale, Rocky River was found to be within South Australia's limit of sustainable development with total farm dam capacity around 30% of estimated long-term median annual runoff. This rule is intended for application at the paddock scale, and when used at larger scales it may not depict how sustainably the needs of all downstream users, including the environment, are being met. Some sub-catchments had dam development levels that had the potential to capture more than 100% of median annual runoff, putting all downstream users at risk. Hot spots were located in the low rainfall areas in the east and northeast of the catchment.

Groundwater

Groundwater recharge to the fractured rock aquifers of the catchment was estimated using a mass balance of chloride concentrations in rainfall and groundwater and found to be in the order of 2500 ML/y. Technical limitations of the method and the distribution of available data may mean that the figure would tend to be conservative.

A water balance approach using adjusted values based on those found in studies undertaken in the nearby Clare Valley was also applied. This method suggests that recharge may be almost a factor of 10 higher than that suggested by the chloride mass balance, but should be used with caution as it is purely theoretical. Adjusted for differences in rainfall, application of the Clare Valley water balance suggests that a sustainable groundwater yield might be of the order of 3600–6000 ML/y. Further investigation is required to reduce the uncertainty in the recharge estimate, and to develop an improved water balance for the catchment that will also improve understanding of surface–groundwater interactions and regional groundwater flow.

All irrigation activity in the catchment was dependent on groundwater. Volumetric use was assessed using Bureau of Rural Science (BRS 2001) land use survey data, field surveys and public consultation. Irrigation activity increased during the period 1999–2002, but no further development appears to have occurred in the period 2003–05.

Irrigation was estimated to consume a maximum of 3500 ML/y, and stock and domestic groundwater use was estimated at around 650 ML/y. This gives a total catchment-wide groundwater demand of around 4150 ML/y. Despite falling within estimated sustainable limits at a catchment scale, specific areas of concentrated development were identified that at local scales probably exceed sustainable limits. Of particular concern was the area around Laura township, where the concentration of irrigation wells is considered to be very high relative to the level of rainfall and estimated recharge.

Suggested management actions

- All water resources be considered fully developed until more substantial investigations can be undertaken. Future proposals for high water-use activities should be subject to an appropriate hydrological assessment to ensure it is sustainable and that it does not place other resource users, including the environment, at unnecessary risk.
- Develop preliminary sustainable groundwater development criteria and apply these to all future development applications. For example, based on the Clare Valley Water Allocation Plan, the following or similar criteria could be applied:
    - limit pumping of any individual well to 13 ML/y
    - limit total extracted volume to 0.6 ML/ha of the property concerned
    - limit the potential of new wells to interfere with existing wells or ecological assets by applying a modified Clare Valley Water Allocation Plan zone of influence equation.

Improving knowledge and understanding

- Consider more detailed technical assessments to fill necessary knowledge gaps to develop an improved catchment water balance and thereby refine sustainable use limits.
- Undertake suitable investigations to identify local and intermediate groundwater flow systems in order to develop suitable groundwater management units.

Farm dams

- Limit all farm dam development to the State Water Plan 2000 sustainability benchmark of no more than 50% of the median annual runoff generated at a property scale or an alternative more conservative measure.
- Avoid further farm dam development in highly stressed areas indicated in this report, and look for opportunities to restore a more natural hydrology, such as encouraging the installation of low flow bypasses.
- Encourage construction of dams greater than 5 ML capacity to be sited off-stream, and approval of such development to be subject to a hydrological assessment to ensure that no significant impacts will occur to downstream users, including the environment.

Monitoring

- Maintain the existing surface water monitoring network and consider additional project sites that can provide some insight into surface and groundwater interactions in the catchment.
- Develop a regional groundwater monitoring network to provide some understanding of natural and human influenced seasonal fluctuations in water level and water quality.

1. INTRODUCTION

Rocky River (Fig. 1) is the largest sub-catchment of the Broughton River, in South Australia's Mid-North. The water resources of the catchment support a diverse range of activities including irrigated horticulture, broadscale cereal cropping, grazing and forestry. The Rocky, along with the Hill and Hutt Rivers, contribute the majority of streamflow to the Broughton River system (Cresswell 1999).

As has been the case throughout the Mount Lofty Ranges, the Mid-North has experienced significant growth in the use of irrigation over recent years to diversify crop types or improve yields. Expansion of intensive irrigation developments including vineyards, olives and other high-value crops has been accompanied by an increasing level of groundwater abstraction and farm dam development, following trends seen across much of the higher rainfall areas of South Australia (Cresswell 1991; Cresswell & Verhoff 1991; Billington & Kotz 1999; Savadamuthu 2002).

Left uncontrolled, these developments can lead to unsustainable levels of capture, resulting in resource degradation, environmental impacts and negative social consequences. Sustainable development depends on healthy river systems, which are managed so that sufficient water is available for all downstream users.

In recent times, increases in development pressure have coincided with reductions in the availability of surface and groundwater resources as a consequence of drought or longer term climate variability. These issues have now gained greater prominence and the importance of sound assessment in managing water resources has become the focus of a number of significant national and regional initiatives to promote sustainability.

Through the creation of the Northern and Yorke NRM (NYNRM) Board, a regional natural resource authority is now in place in the Mid-North as a dedicated catchment management authority with the responsibility of managing water and other natural resources. To date, work by the board has necessarily focused on initiating projects to rapidly improve the available knowledge upon which to make informed decisions.

This report summarises the state of knowledge for water resources within the Rocky River Catchment, develops preliminary quantitative estimates of surface and groundwater resource capacity and compares these with current use levels. It contributes to the acquisition of a base level of knowledge regarding the water resources of the Mid-North region, an important first step in protecting existing users and ensuring that sustainable levels of development are achievable in the future.

Figure 1 Broughton River system showing the Rocky River Catchment

2. APPROACH

The Rocky River Catchment hydrological assessment was undertaken in three phases:

- A consultation phase was used to attempt to refine estimates of current water-use and assess community perceptions of resource condition.
- Desktop spatial analyses were performed to develop estimates for ground and surface water resources, and map and assess the pressure on the resource due to farm dam and irrigation development.
- Surface water modelling was completed to quantify the regional water resources and enable the impact of different development scenarios to be assessed.

2.1 CONSULTATIONS

Information on irrigation development was obtained from Bureau of Rural Sciences land use survey data from 1999, and consultation with members of local government, PIRSA, DWLBC and the NYNRM Board.

To develop an improved understanding of the degree of irrigation usage of water resources within the catchment, a round of community consultations was also undertaken. Landholders known to engage in irrigation were invited to attend a community meeting to discuss water-use. Surveys were handed out to irrigators both in person and by mail, and followed up by telephone interviews and in some cases site inspections.

2.2 SPATIAL ANALYSIS

2.2.1 GROUNDWATER

Spatial interpretation was conducted on the available data within the state drillhole database (SA Geodata) and used to develop recharge estimates, salinity and preparation of water-use distribution maps.

Groundwater recharge was estimated using chloride mass balance, based on data available in SA Geodata. Water balance information was adapted from the Clare Valley groundwater flow study (Love et al. 2002) to suit the study region and used to develop estimates of recharge and sustainable yield.

2.2.2 FARM DAMS

Farm dam volumes were calculated using a surface area to volume relationship developed by McMurray (1996, 2001). Surface areas were mapped using 1:40 000 ortho-rectified colour aerial photography and compared to the GIS spatial layer entitled 'Waterbodies' developed and maintained by the Department for Environment and Heritage.

The entire catchment was divided up into smaller sub-catchments to allow for the spatial distribution of dams and their relative impacts on local hydrology to be assessed. The results were used in mapping the level of farm dam development pressure (Section 9.2) and in surface water modelling.

The equation used for dams with a surface area of <2 ha was:

$$\text{Volume (ML)} = 0.000215 \times \text{surface area } (m^2)^{1.26}$$

2.2.3 IRRIGATION

Information collected on irrigation activity was consolidated into a single GIS ArcMap polygon feature class, representing known and suspected irrigated parcels to establish the distribution of irrigation throughout the catchment. Details on the methods employed in water-use calculations appear in Appendix A.

2.3 SURFACE WATER MODELLING

2.3.1 RAINFALL-RUNOFF MODELLING

The streamflow of the catchment was modelled using WaterCress, a modelling system that incorporates some of the most widely used rainfall-runoff models in Australia, including AWBM, SFB, HYDROLOG and WC-1.

WC-1 was used for the Rocky River assessment as it was designed specifically for use in dry environments where runoff is difficult to replicate. The model has been successfully employed in a number of surface water assessments in South Australia.

The individual steps involved in developing, running and calibrating the surface water model were as follows:

- review of existing literature and hydrological data including rainfall, evaporation and streamflow
- identifying development levels through spatial data analysis using Geographic Information System (GIS) ArcMap and field verification
- determining the location and volume of farm dams through spatial data analysis using ArcMap
- subdivision of the catchments through digitisation using ArcMap
- model construction and calibration.

2.3.2 ANNUAL CATCHMENT YIELD

The rainfall-runoff model simulated streamflow during periods of low rainfall but did not provide a reasonable representation of runoff over the full range of historic climatic conditions. Modelling will be improved once a dataset is available that is more representative of long-term conditions.

APPROACH

An analytical Tanh function was used to model annual streamflow volume and enable development pressures to be assessed. Tanh is a robust method that uses annual rainfall time series and estimates of initial and continuing loss to generate catchment yields (Grayson et al. 1996, App. F).

Long-term streamflow data from three gauging stations within the Broughton River system were used to fit parameters to the Tanh function on an annual timestep. The modified function was then applied to long-term rainfall records for the Rocky River Catchment to obtain a first order estimate of long-term annual catchment yield.

3. CATCHMENT DESCRIPTION

3.1 TOPOGRAPHY

The Rocky River Catchment rests between the southern Flinders Ranges and northern Mount Lofty Ranges. Its morphology is governed by a series of parallel north–south-trending valleys and ridges including the southern Flinders in the northwest and the Narien Range in the northeast; the White Cliff Range in the southwest and the Campbell Range to the southeast (Figs 1, 2).

The elevation of the catchment ranges from ~70 m above sea level near Crystal Brook to over 700 m near The Bluff which forms part of the western catchment divide. The maximum elevation occurs in the Narien Range at 730 m.

Landscape can generally be described as comprising gently undulating hills. The central regions of the catchment tend to be relatively flat, broken by north–south-trending ridges and hills (Fig. 2).

3.2 MAJOR RIVER SYSTEMS

Rocky River Catchment forms part of the Broughton River system, and adjoins two other catchments of the Broughton: Crystal Brook (incorporating the Beetaloo Reservoir sub-catchment) to the west, and Yackamoorundie Creek to the east. To the north, the Rocky adjoins the inland drainage system of the Willochra Creek, which flows almost due north eventually terminating at Lake Torrens.

The Rocky River Catchment covers an area of 1350 km^2 (Fig. 2). Major tributary streams include Ippinitchie, Pine, Appila, Pisant and Narridy Creeks. The river itself rises in the southern Flinders Ranges north of The Bluff. Flowing firstly northwards, it then turns through almost 180° around the footslopes of the ranges, turning southeast prior to converging with Ippinitchie Creek south of Wirrabara. The river then continues in a roughly southerly direction meeting Pine Creek immediately north of Laura. Pine Creek, along with Appila Creek, is the major drainage in the central north and eastern parts of the catchment.

The river then continues in a roughly southeasterly direction, picking up flows from Pisant Creek and its tributaries draining the central eastern catchment at Gladstone. Flow is then predominantly southerly before turning west to the north of Narridy, flowing in this direction past its confluence with Yackamoorundie Creek, and ultimately meeting the Broughton River close to Wandearah. The Broughton River discharges into Spencer Gulf at Port Davis.

3.3 CLIMATE

The climate of the catchment is predominantly Mediterranean with hot dry summers and cool wet winters. Winter maritime rainfall patterns dominate, with the majority of reliable rainfall occurring during June–October. Thunderstorm events may occur, particularly during summer, when tropical low-pressure systems and northwest cloud bands move down from

Localities
Isohyets
Streams
Rocky River Catchment

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Map Production: Resource Information Group
Department of Water, Land and Biodiversity Conservation

Map Projection: MGA Zone 54.
Map Datum: GDA94.

N W E S

0 1.25 2.5 5 km

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Figure 2 Topography and rainfall distribution, Rocky River Catchment

the north and northwest. Rain from these systems is highly unpredictable and may occur in isolated sections of the catchment but is capable of delivering large volumes of water in short periods of time.

Long-term average rainfall is highly variable, ranging from over 680 mm at Wirrabara Forest near to The Bluff, to less than 370 mm in the far northeast of the catchment near the Narien Range. Regional average rainfall is around 460 mm, and much of the catchment is semi-arid in nature. Though there are areas of relatively high rainfall in the central western part of the catchment, these are generally small in area. Rainfall inputs are moderated by average evaporation rates in the order of 2300 mm/y.

Rocky River sub-catchment adopted for use in this assessment are summarised in Table 1, which shows the area and variation in mean annual rainfall. The geographical location of the sub-catchments is shown in Figure 3.

Table 1 Rocky River sub-catchments and rainfall

Name	Area (km^2)	Average rainfall (mm/y)
Anglevale	19.17	400
Appila Creek	167.57	375
Bauer Creek	76.61	380
Emu Spring	41.93	545
Fairview	30.21	440
Huddleston	12.09	425
Ippinitchie Creek	66.42	592
Lower Rocky River	22.15	433
Mid Rocky River	61.35	438
Mt Herbert	23.48	442
Mt Mick	26.01	440
Pine Creek	102.60	439
Pisant Creek	42.40	435
Stone Hut	22.18	489
Upper Pine Creek	155.07	396
Upper Rocky River	67.53	493
White Cliff Hill	21.25	457
White Cliff Range	29.88	486
Wirrabara	39.80	482
Yangya Creek	92.28	434
Yarrowie Creek	104.01	416

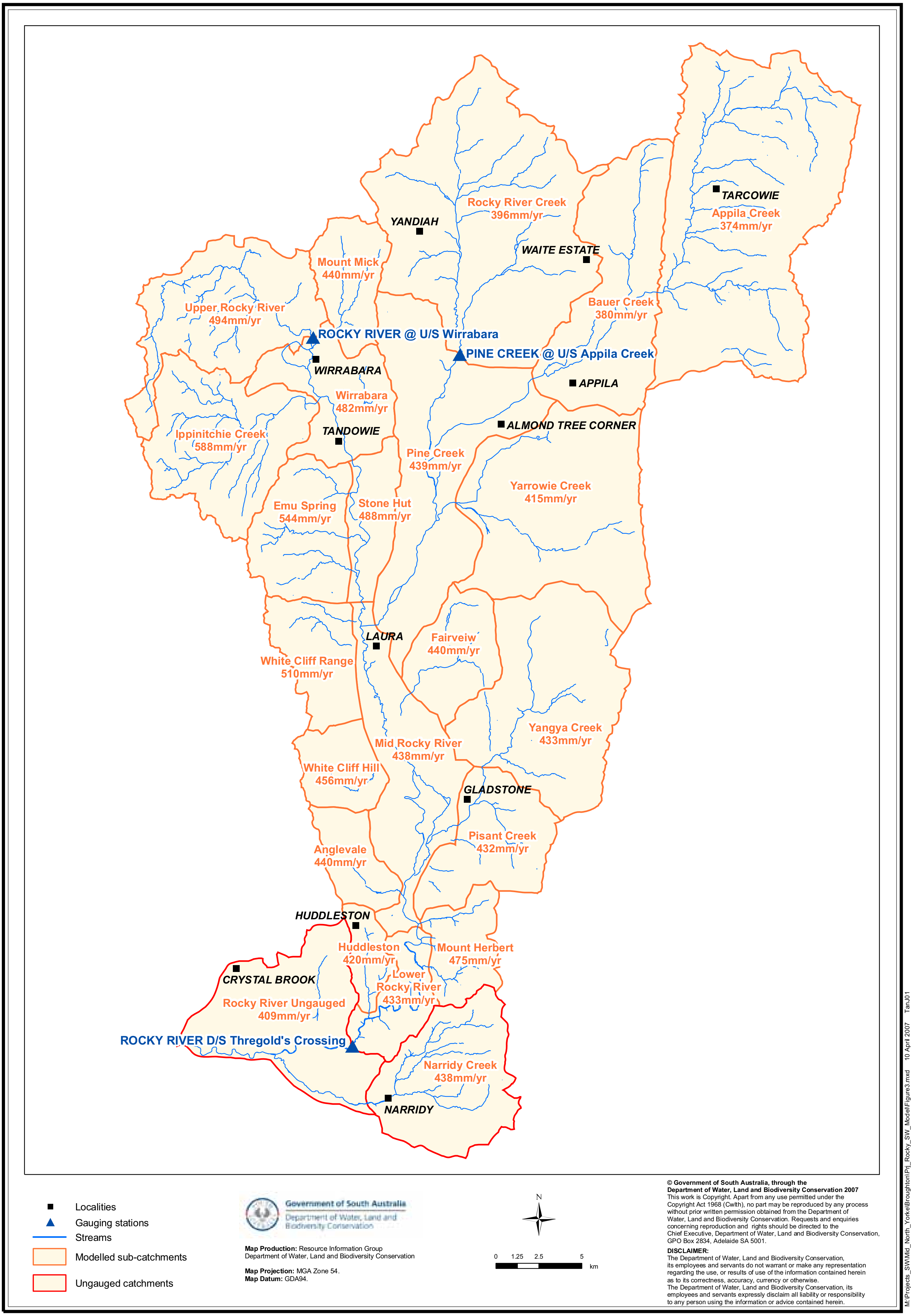


Figure 3 Sub-catchments, average rainfall and gauging stations used in modelling

3.4 LAND USE

Land use in the region is diverse, but broadscale cropping and grazing are dominant. Forested areas are also significant in the higher rainfall northwestern part of the catchment. Irrigation, while not a significant land use in the catchment, is reported to have been increasing over recent years (P. Robinson & K. Ward, NYNRM Board Members, pers. comm., 2004). A number of different crops are involved, but vines, lucerne and olives are easily the most common.

3.4.1 LAND USE CLASSIFICATION

Land use data for the catchment area, collected by the Bureau of Rural Sciences in 1999 (BRS 2001), were compiled using remote sensing, cadastre and ancillary data, and field verified before final land use maps were produced. The following land use groupings were employed in this study:

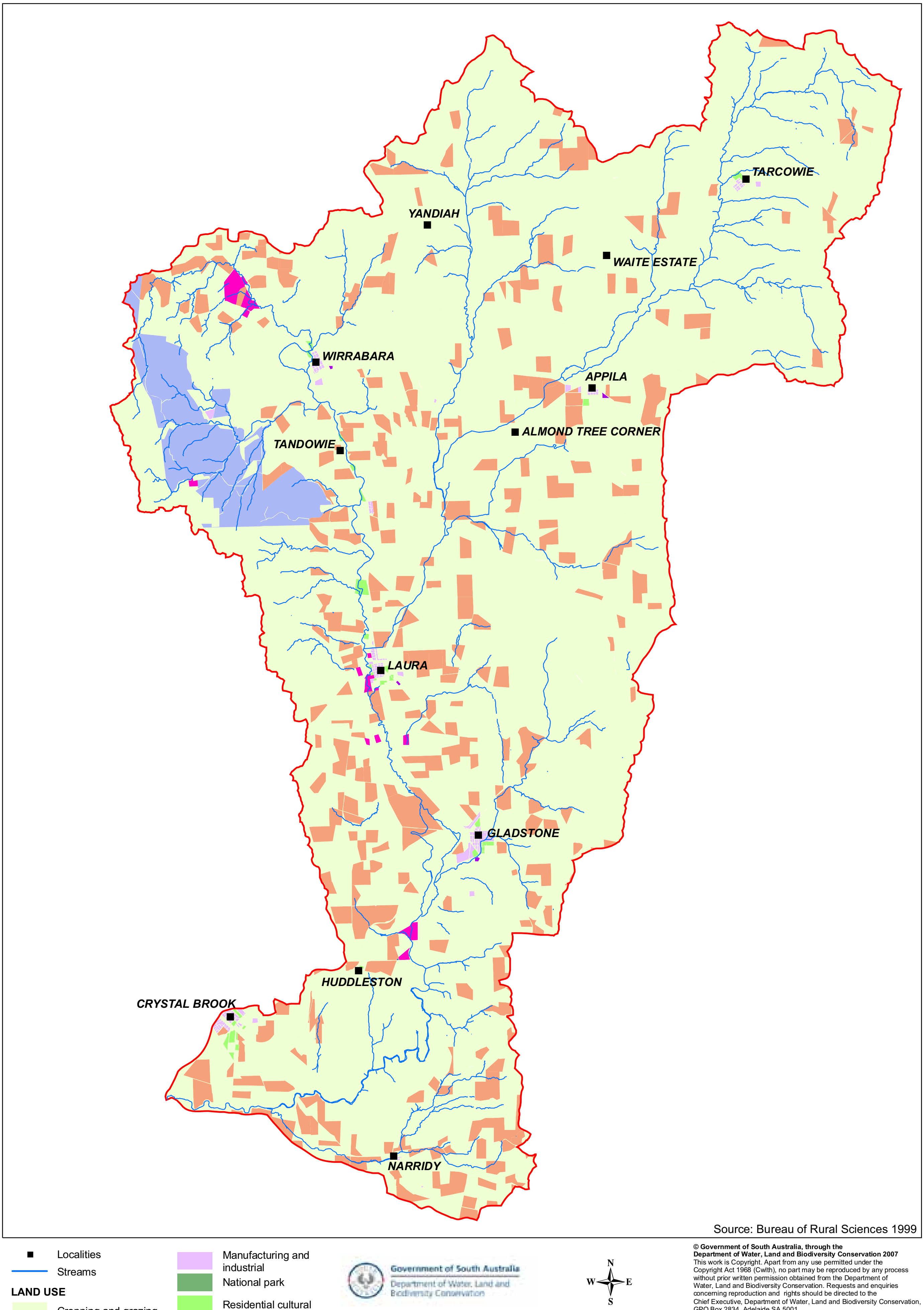
- crop and grazing rotation: land under cropping at time of mapping that may be in a rotation system; includes cereals, hay and silage, oil seed and legumes
- grazing modified pastures: land in a rotation system classed under the land use at the time of mapping; includes pasture and forage production
- legumes
- oil seeds and oleaginous fruit
- livestock grazing (vegetation): grazing by domestic stock on native vegetation with limited or no attempt to modify the pasture
- softwood plantation
- residential and industrial: includes manufacturing and industrial; residential; services; utilities; transport; communications; waste treatment and disposal
- irrigation (sown grasses, vines, tree fruits).

Table 2 categorises the land use of the catchment based on figures published by BRS (2001). Figure 4 shows simplified land use categories.

Table 2 1999 land use in the Rocky River Catchment

Land use category	Hectares	% of total
Crop and grazing rotation	61 676	45.7
Grazing modified pastures	41 745	30.9
Legumes	9 926	7.3
Oil seeds and oleaginous fruit	6 721	5.0
Livestock grazing (vegetation)	6 192	4.6
Softwood plantation	4 438	3.3
Residential and industrial	3 922	2.9
Irrigation	402	0.3
Total	**135 000**	**100**

Source: BRS (2001)



Map Production: Resource Information Group
Department of Water, Land and Biodiversity Conservation

Map Projection: MGA Zone 54.
Map Datum: GDA94.

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Figure 4 Rocky River Catchment land use

3.5 WATER-DEPENDENT ECOSYSTEMS

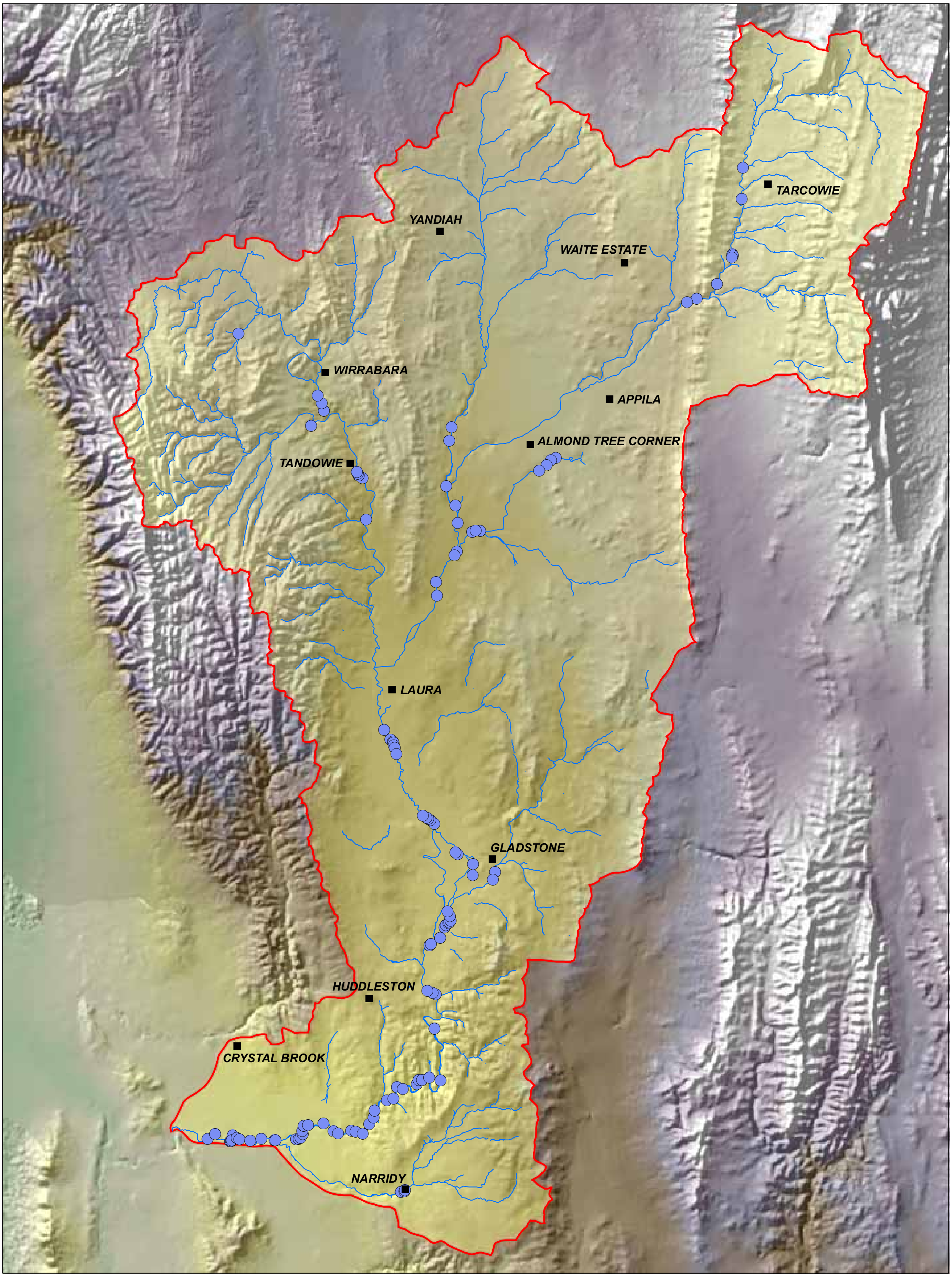
Favier et al. (2004) identified the significant water-dependent ecosystems in the Broughton River system associated with higher order streams, including those within the Rocky River Catchment. Permanent pools are a key ecological feature in an ephemeral river system, providing refugia for the survival of aquatic plants and animals during periods of no flow.

During 1999, an aerial survey of the Broughton River was undertaken and the location of permanent pools recorded (Fig. 6). Many of these pools were visited during September 2005 as part of the investigations for this report. Although some were found to have low water levels, most appeared to still have at least some water.

Many, but not all, landholders suggested that permanent waters are becoming less common. Others expressed concern over the declining levels in some pools. Figure 5 was taken during March 2005 and shows a permanent pool on Rocky River near Wirrabara. The landholder reported that the water level in the pool during the dry seasons has started to decline over the last 2–3 years, whereas formerly it maintained a minimum level near to that of the streambed.

These ecological assets need to be protected from direct pumping and groundwater extraction from nearby wells that could impact on water quality or quantity. In order to ensure the protection of these locally significant ecological assets, it is important that a monitoring program for water-dependent ecosystems be established as soon as practical.

Figure 5 Waterhole on Peter Trotts' property, Rocky River north of Wirrabara



Localities
Permanent pools
Streams
Rocky River Catchment

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

Map Production: Resource Information Group
Department of Water, Land and Biodiversity Conservation

Map Projection: MGA Zone 54.
Map Datum: GDA94.

N W E S

0 1.25 2.5 5 km

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Figure 6 Permanent pools identified in the Broughton River system during 1999

4. SURFACE WATER RESOURCES

4.1 RAINFALL

4.1.1 DATA

The Bureau of Meteorology (BoM) is the major source of daily rainfall data, and a number of stations with a long-term record are located throughout the Mid-North. In addition to this information, DWLBC also collects continuous rainfall data on behalf of SA Water at Beetaloo and Baroota Reservoirs, which are located immediately to the west and northwest of the Rocky River Catchment, respectively.

Data from 18 rainfall stations across the region were assessed for their suitability for use in modelling and analysis purposes. Rainfall-runoff hydrological modelling requires the highest quality data to generate reliable, sub-catchment-scale daily runoff estimates at specific locations within the system. Regional analysis is undertaken to produce broader catchment-scale assessments. Lower resolution, average parameters can be used to produce reasonable regional hydrological assessments that do not require the highest levels of site-specific accuracy.

Criteria used for rainfall data assessment were:

- current operational status of site
- length and period of record
- quantity of missing and aggregated data.

Table 3 shows the stations that met the above criteria and the various purposes for which they were used. Of the 18 available stations, three were considered suitable for hydrological modelling and four were suitable for regional analysis. The three DWLBC sites had a relatively short record compared to the BoM sites and were only used to infill missing data. Six stations were not used.

Table 3 Rainfall stations used in analysis of the Rocky River Catchment

Station	Name	Period of record	% Good	Used for
019011	Murray Town @ Doughboy Creek	1884–present	94	Not used
019052	Wirrabara	1884–present	94	Regional analysis
019053	Wirrabara Forest	1884–present	96	Modelling
021021	Gladstone	1884–present	90	Regional analysis
021016	Crystal Brook	1884–present	93	Regional analysis
019006	Booleroo Centre	1884–present	95	Not used
019001	Appila	1884–present	93	Modelling
019062	Yongala	1884–present	86	Not used
021013	Caltowie	1884–present	93	Regional analysis

Station	Name	Period of record	% Good*	Used for
021031	Laura	1884–present	91	Modelling
021027	Jamestown	1884–present	96	Not used
019005	Orroroo (Black Rock)	1884–present	95	Not used
019102	Pt Germein (Baroota Reservoir)	1922–1998	62	Not used
AW508500	Baroota Creek @ Baroota Reservoir	1979–present	22	Infilling data
AW508504	Baroota Reservoir @ Glenlossie	1989–present	13	Infilling data
021114	Beetaloo Reservoir (old)	1897–1982	72	Not used
021124	Pt Germein (Beetaloo Reservoir)	1981–present	19	Evaporation
AW507506	Beetaloo Reservoir Met Station	1989–present	13	Infilling data

4.1.1.1 Processing

Raw rainfall data from BoM was processed according to the procedure described in Appendix C, which is required to remove systemic errors that arise from routine BoM collection procedures.

The final individual daily rainfall datasets were used in modelling and to generate a regional average rainfall dataset, with areas apportioned to each station using the Theissen polygon method. This dataset, shown in Figure 7, was used in rainfall trend analysis (Section 4.1.2, App. B) and for runoff estimation in Section 4.5.

Contours of mean annual rainfall (isohyets) as shown in Figure 2 were used to generate area weighted rainfall estimates for each sub-catchment by summing the areas between 20 mm rainfall contours and assigning the corresponding average rainfall estimate for the

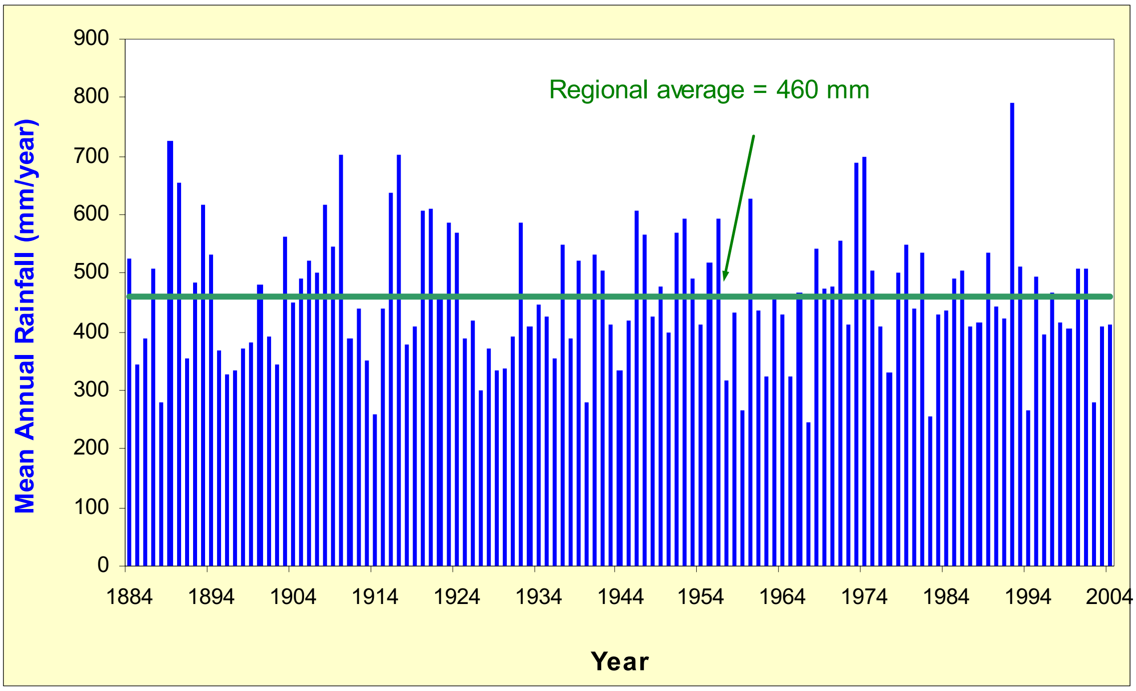


Figure 7 Long-term regional average rainfall, Rocky River Catchment

geographical area enclosed by the contour interval. The average annual rainfall values for each sub-catchments are shown in Figure 3, and this dataset was used for groundwater recharge estimation (Section 5.3).

4.1.2 ANALYSIS

Analyses were completed on both processed point data and the constructed regional average data. Rainfall spatial patterns and variability over time were assessed using a range of simple qualitative and quantitative methods that produced a picture of regional trends, cyclic patterns and randomness. The findings are discussed with regard to implications for current sustainability and future development.

4.1.2.1 Rainfall Distribution Across The Catchment

Patterns of annual rainfall in the Rocky River region are highly variable, typical of many dry regions in Australia. The regionalised average annual rainfall is 460 mm, but ranges from 380 mm/y in Appila in the northeast of the catchment, up to 680 mm at Wirrabara Forest in the northwest (Figs 2, 3).

The isohyets in Figure 2 closely follow the topography of the southern Flinders Ranges, showing increasing annual rainfall totals around topographic high points such as The Bluff, which has an elevation of around 700 m (Fig. 2). As moisture-laden oceanic weather systems encroach upon land, air is forced to rise and rainfall increases, tending to intensify over areas of high relief. This process is the driving influence on winter rain in southern Australia where seasonal frontal systems from the Southern Ocean bring significant rainfall across relatively modest orographic features such as the Darling Scarp in West Australia and the Mount Lofty Ranges (Gentilli 1971).

However, rainfall patterns in the Rocky River Catchment cannot be explained by elevation alone. The driest area around Appila is surrounded by the Pekina and Narien Ranges which, with peaks exceeding 730 m, have the highest relief in the catchment (Fig. 2).

Combined with prevailing regional weather circulation patterns, the geomorphology of the southern Flinders Ranges tends to restrict rainfall within the northeastern Rocky River Catchment. Areas to the east lie within a distinct rain shadow, and rain-bearing weather systems display a pronounced decrease in productivity as they move further inland. Prevailing winter rainfall patterns bring moisture from across the coast from the southwest and other regionally significant weather patterns, including northwest cloud bands and those associated with tropical low pressure systems, bring moisture from the northwest. Consequently, all significant weather systems are effectively intercepted by ranges along the west and south of the catchment and, despite having comparable elevation, the eastern sections remain relatively dry.

The rain shadow effect is shown in Figure 8. Rainfall nearly halves over a distance of ~20 km across the upper Rocky River Catchment, reducing in a marked average gradient of 15 mm/y/km. Rainfall decline of this magnitude is similar to many parts of the eastern Mount Lofty Ranges where small, relatively wet upper catchment areas generate the majority of available surface water resources for a much wider area. Wetter areas form limited zones of abundance that when developed can have a disproportionately significant impact on a much wider area of downstream users, including the environment.

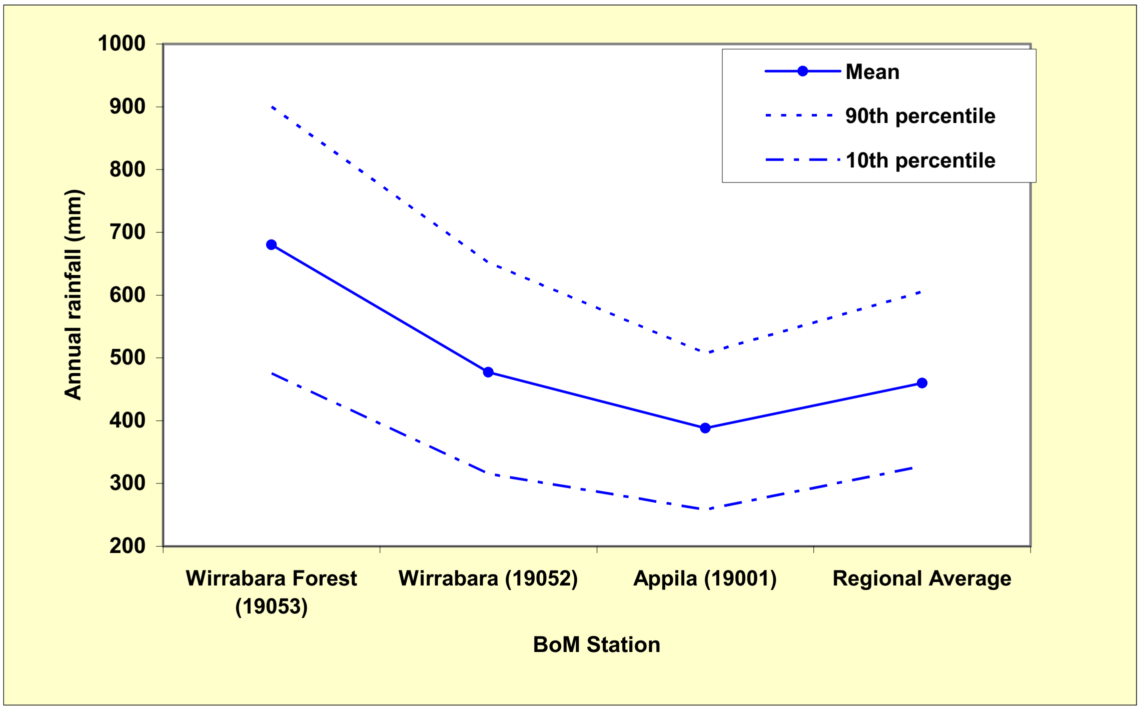


Figure 8 **Annual rainfall variation, west to east and regional average of the Rocky River Catchment**

4.1.2.2 Rainfall Variability Over Time

Figure 9 shows the regional average annual rainfall presented in Figure 7 fitted with a least squares regression linear trend line generated using MS Excel®. The slight downward trend exhibited by the entire annual rainfall record since 1884 was not significant ($p = 0.05$).

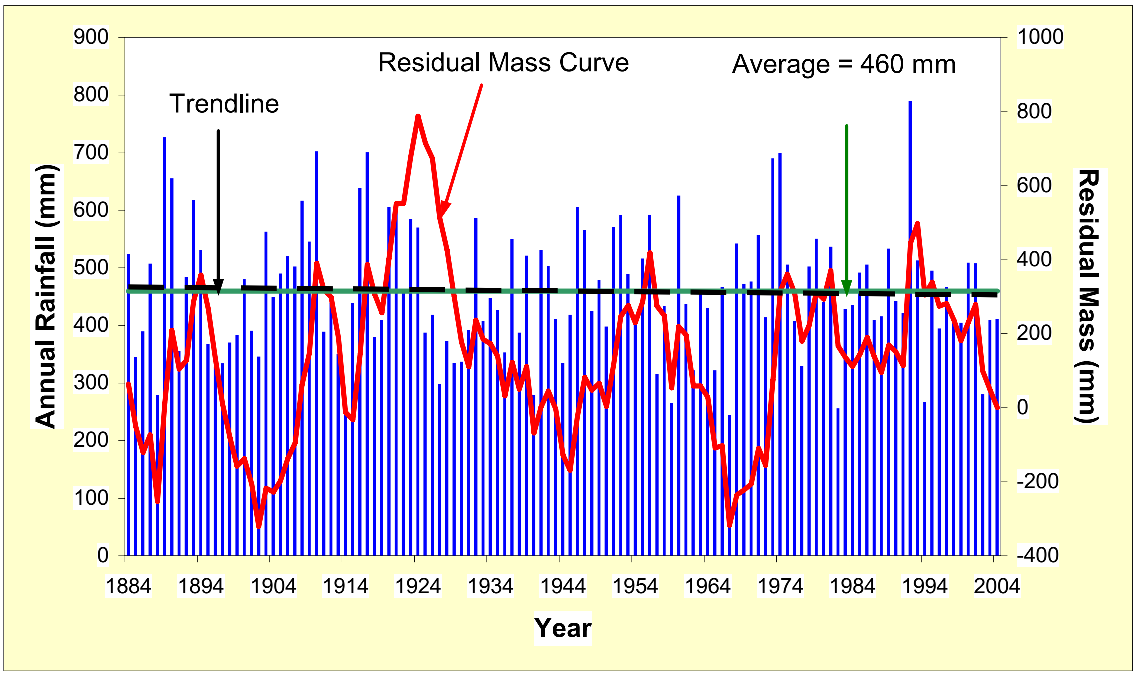


Figure 9 **Long-term regional average rainfall and residual mass of the Rocky River Catchment**

However, similar lines fitted to the data since 1950, 1955, 1960, 1965 and every ensuing five-year decreasing period until 1995 also show decreasing trends. Decreasing trends since 1970, 1980, 1985, 1990 and 1995 are all significant ($p = 0.05$), and an example of this is shown in Figure 10. This analysis provides a compelling picture of decreasing rainfall in recent years compared to the long-term average. The period of rainfall record is, however, too short to determine whether this comprises part of a long-term cyclical climatic pattern.

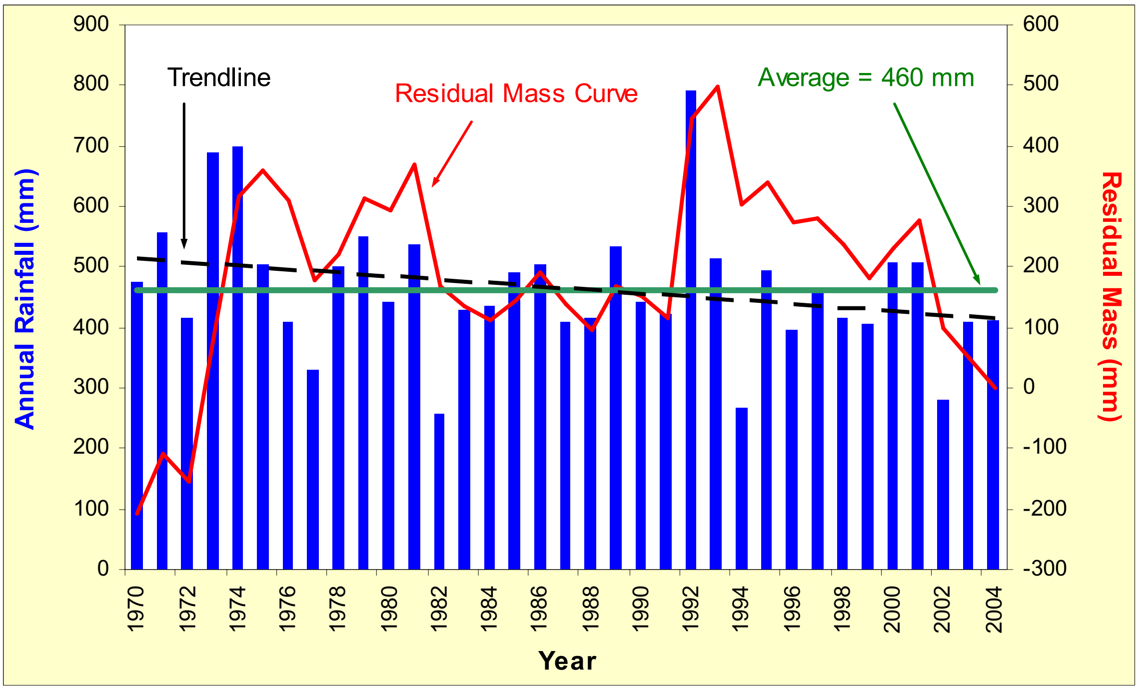


Figure 10 Regional average rainfall trends and residual mass since 1970 for the Rocky River Catchment

Figures 9 and 10 also show the cumulative deviation of the annual rainfall series from the mean, also known as the residual mass. This function provides a qualitative depiction of how rainfall has varied from the long-term mean over the length of record and gives a graphic impression of decadal-scale fluctuations in rainfall.

A positive (upward) trending slope indicates periods of above average rainfall, and a negative (downward) slope indicates periods of below average rainfall. Figure 9 shows that above average rainfall occurred during the years 1886–94, 1902–10, 1915–24, 1945–56 and 1967–75. Below average rainfall occurred in the periods 1894–1902 (the so called Federation Drought, http://www.bom.gov.au/lam/climate/levelthree/c20thc/drought1.htm), 1924–44, 1956–67 and from 1993 to the present.

The patterns of the residual mass plots give the impression of a distinct decadal periodicity. This was explored further by calculating 10 year moving averages as shown in Figure 11. The data seem to show a reduction in peak-to-trough amplitude since around 1980 and a flattening of the cyclic peaks. These features could be interpreted as a reduction in variability, where 10 year averages have rainfall closer to the long-term annual mean.

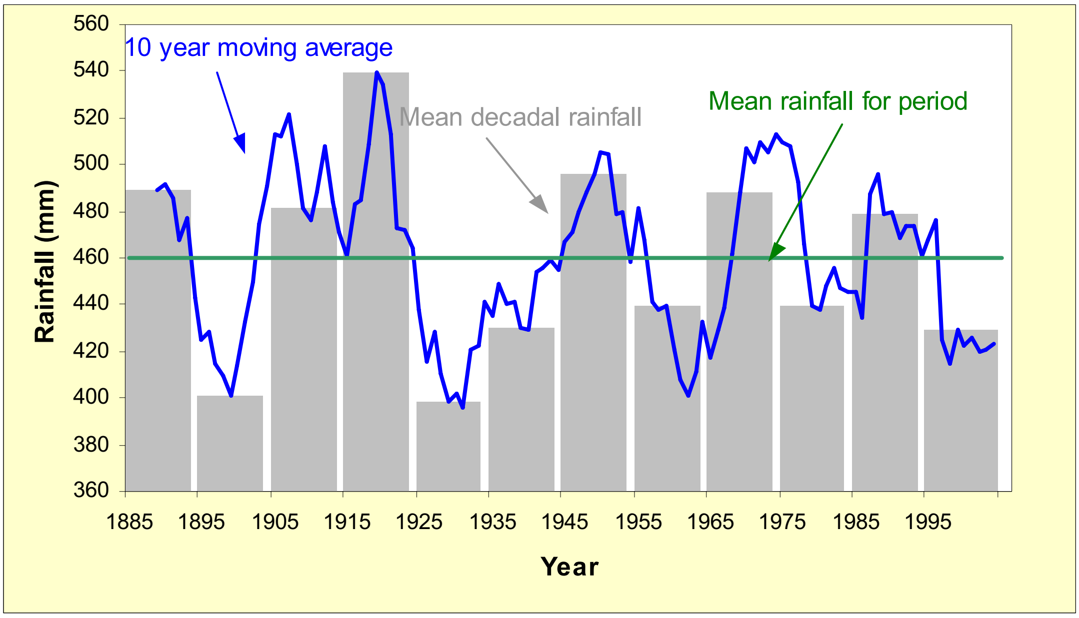


Figure 11 Cross-decadal rainfall and 10 year moving average, Rocky River Catchment

4.1.2.3 Seasonal Rainfall Variability

Regional monthly rainfall appears in Figure 12. The standard deviation from the mean is also plotted to give an indication of monthly variability in rainfall. The driest months are January to March. A distinct break in season occurs in April followed by the wettest months of May to October. Summer rainfall is relatively consistent but modest throughout the catchment. The most significant influence on total yearly rainfall is the variation in winter rain.

Monthly data for all rainfall stations were analysed to gain an insight into the variability of monthly and seasonal rainfall. A number of notable patterns emerged across all stations. Of most interest was the suggestion of a change in seasonality of rainfall, delaying the onset of winter rainfall.

Linear regression trendlines fitted to monthly rainfall totals from all individual stations and the regional average data showed consistent decreasing trends for April, May and June (Fig. 13) and slight increasing trends in September and October (Fig. 14). Trends for April and June were significant at 96% and 94%, respectively ($F = 4.63$; $F = 3.70$).

Regional residual mass curves for the months demonstrating the strongest trends are shown in Figure 15, with the annual data included for comparison. April rainfall has been below the long-term average since the mid-1980s. June data showed a continuing decline during the period between the mid-1920s and 1970s. It has fluctuated around average conditions since the mid-1970s, but has been below average since the mid-1990s. September rainfall has tended toward above average levels since the early 1970s, while October rainfall has remained around average since experiencing a period of above average years in the mid-1970s.

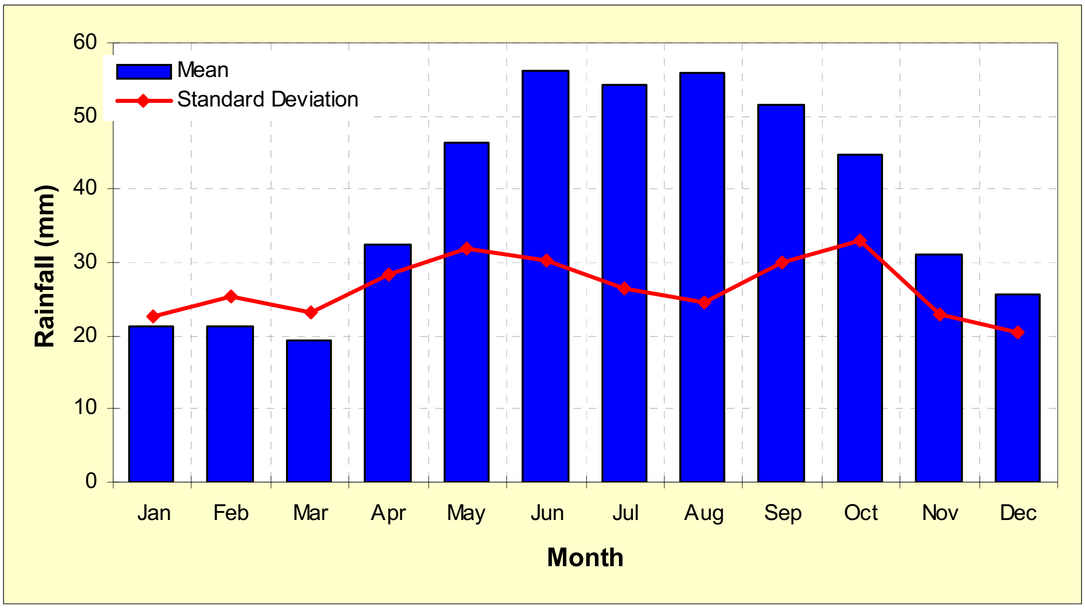


Figure 12 Long-term regional mean monthly rainfall and standard deviation, Rocky River Catchment

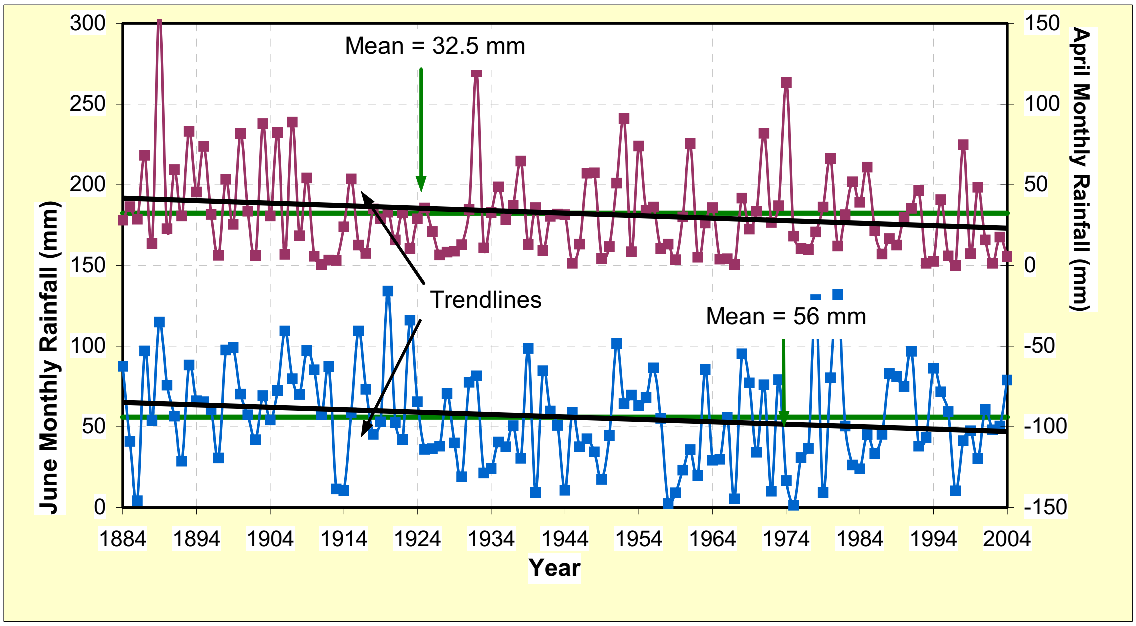


Figure 13 Regional April and June rainfalls, means and trendlines, Rocky River Catchment

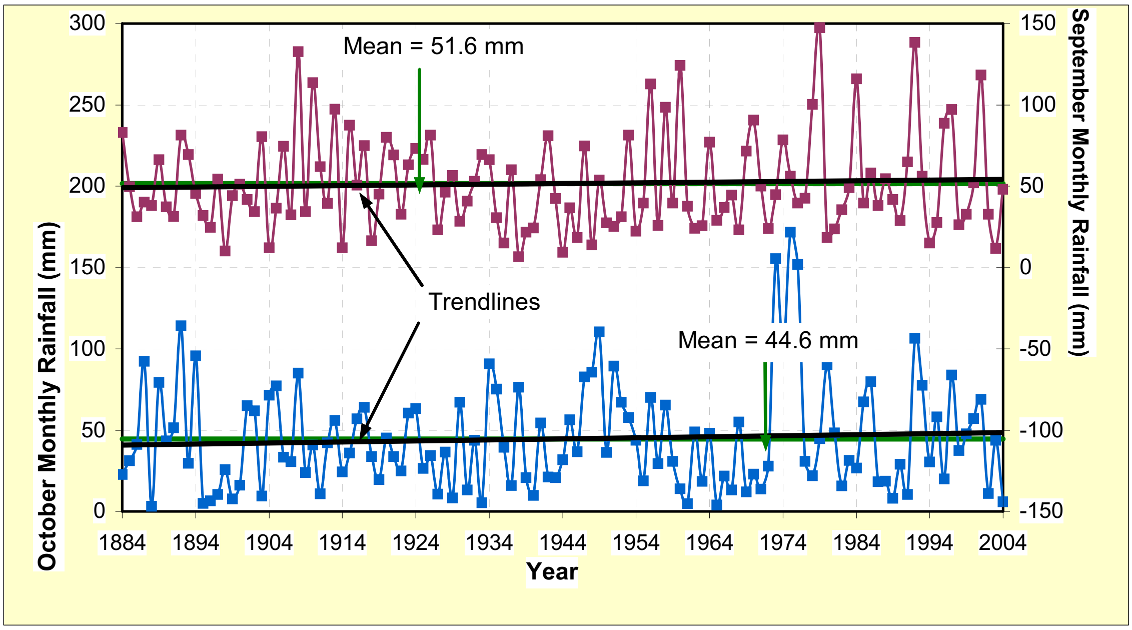


Figure 14 Regional September and October rainfalls, means and trendlines, Rocky River Catchment

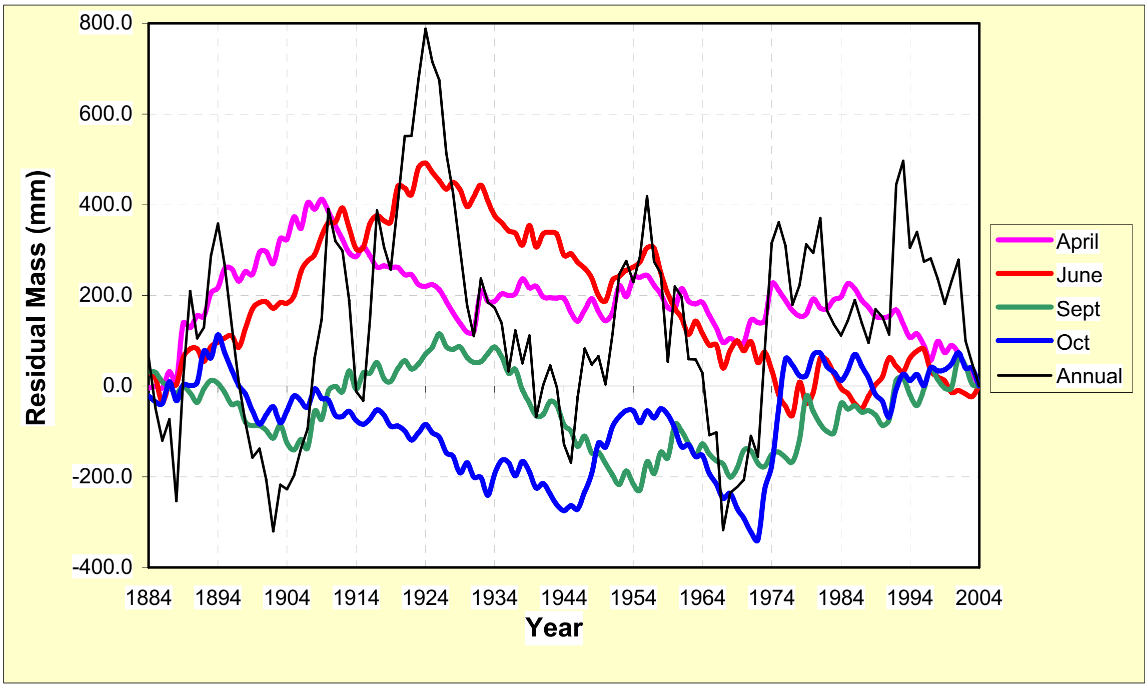


Figure 15 Selected regional monthly and annual residual mass curves, Rocky River Catchment

The tendency of April rainfall to be less than long-term averages in recent years would suggest a later break to the season and effectively a later onset of significant seasonal rainfall, while an increase in September rainfall would tend to result in its later end. These variations in seasonal rainfall are consistent with the findings of recent studies in the adjacent Willochra Catchment (Risby et al. 2003) and the southern Mount Lofty Ranges (Savadamuthu 2002, 2003; Teoh 2002; Heneker 2003), suggesting that the pattern is widespread in South Australia.

Early season rainfall infiltrates into dry soil stores after summer, gradually bringing catchments closer to the necessary saturation to produce runoff during winter. A delay in the onset of early season and winter rains produces a corresponding delay in the onset of streamflow in seasonal watercourses. Any such delay will compound that resulting from excessive on-stream farm dam developments, which prevent downstream flows until filled by seasonal rains. If less rainfall occurs in winter but is offset by more in spring, less is available to form runoff, as evapotranspiration losses rise with the approach of summer.

The net result is a delay and a decrease in streamflow volumes and a reduction in water available to recharge aquifers, reducing the total available water resource. These effects are compounded by farm dam developments, stream diversions and groundwater abstraction, increasing the pressure on available water and increasing risk to the shared resources of all users, including the environment. Further analysis of the recent dry period is provided in Appendix B.

4.2 EVAPORATION

Evaporation is an important parameter within the overall catchment water balance. The relative losses to interception and transpiration are affected by this rate, as is the loss from surface water storages such as tanks and dams.

Daily evaporation data suitable for use in hydrological modelling were not available for this study, necessitating the use of average monthly data collected from the adjacent Beetaloo Reservoir Meteorological Station (021124).

Average monthly data are not ideal for use in surface water modelling as it reduces the model's ability to realistically represent catchment responses using daily rainfall. The lack of daily evaporation data was not considered a major limitation in this study which suffered from a significant lack of streamflow record available for model calibration. Attempts to calibrate the model against a longer record of flow data in the future will increase the need for daily evaporation data.

Total average annual evaporation at Beetaloo Reservoir is 2300 mm. Monthly evaporation data are shown in Table 4.

Table 4 Monthly averaged daily evaporation data for Beetaloo Reservoir Meteorological Station 021124

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Apr	Sep	Oct	Nov	Dec
Average monthly evaporation (mm)	316	270	244	172	113	83	87	106	144	200	246	295

Source: BoM

4.3 STREAMFLOW

4.3.1 DATA

Streamflow data are collected in the Rocky River Catchment at three locations by DWLBC for the NYNRM Board. Summary information is provided in Table 5 and the location of all stations is shown in Figure 3.

Table 5 Streamflow gauging sites in the Rocky River Catchment

Station number	Location	Period of record	% Good data	Comments
A5071002	Rocky River @ D/S of Thredgold's Crossing	06/2003–06/2005	100	Measures flows out of the catchment. Rated structure.
A5071003	Rocky River @ U/S Wirrabara	06/2004–06/2005	100	Flows from upper Rocky River; provisional rating.
A5071004	Pine Creek @ U/S of Appila Creek	06/2004–06/2005	100	Flows from upper Pine Creek; provisional rating.

Source: DWLBC surface water archive.

All stations record continuous water level, allowing for flow volumes to be determined from a depth-discharge (streamflow) rating table. Thredgold's Crossing is a pre-calibrated hydrometric weir, meaning that the flow data derived from measured water levels within the structure's designed capacity are of high precision and accuracy. The sites near Wirrabara and on Pine Creek have ratings based on channel morphology and the direct measurement of water speed. As shown in the summary table, as at September 2005 none of these stations had a period of record in excess of two years.

4.4 RAINFALL-RUNOFF MODELLING

A rainfall-runoff model is a conceptual tool used to simulate catchment conditions for assessment of current, past and possible future condition. This is of use in planning and assessment and is capable of producing information on hypothetical streamflow and water balance scenarios. This allows for an informed assessment of the potential impacts on catchment hydrology resulting from changes whether natural (such as climate change) or induced (such as land use or vegetation change). Additional generic detail regarding the construction, calibration and running scenarios using a model is in Appendix E. A schematic of the WaterCress Rocky River model is shown in Figure 16.

4.4.1 MODEL CALIBRATION

The completed model was calibrated with daily rainfall data, monthly evaporation data and farm dam capacity and diversions as recorded inputs (App. E). Once the input data were finalised, the model was first run using the catchment parameter set developed for the Willochra Catchment (Risby et al. 2003). This was considered the best approach to adopt as the Willochra Catchment adjoins Rocky River to the north and has similar climatic and physiographic influences on its hydrology.

Running the model over 100 years with the Willochra model parameters produced a long-term median annual flow of 11 000 ML. This figure compared well with the estimates of catchment runoff developed for the NLWRA, which was 11 500 ML/y (NLWRA 2000).

However, when the output was compared to observed streamflow data from the Thredgold's Crossing station, the modelled streamflow was found to be overestimating the catchment yield. Flow events were generated where none occurred, the magnitude and duration of individual storm hydrographs was consistently over-estimated and the model generated baseflow for much of the year, which was not observed at the gauging station.

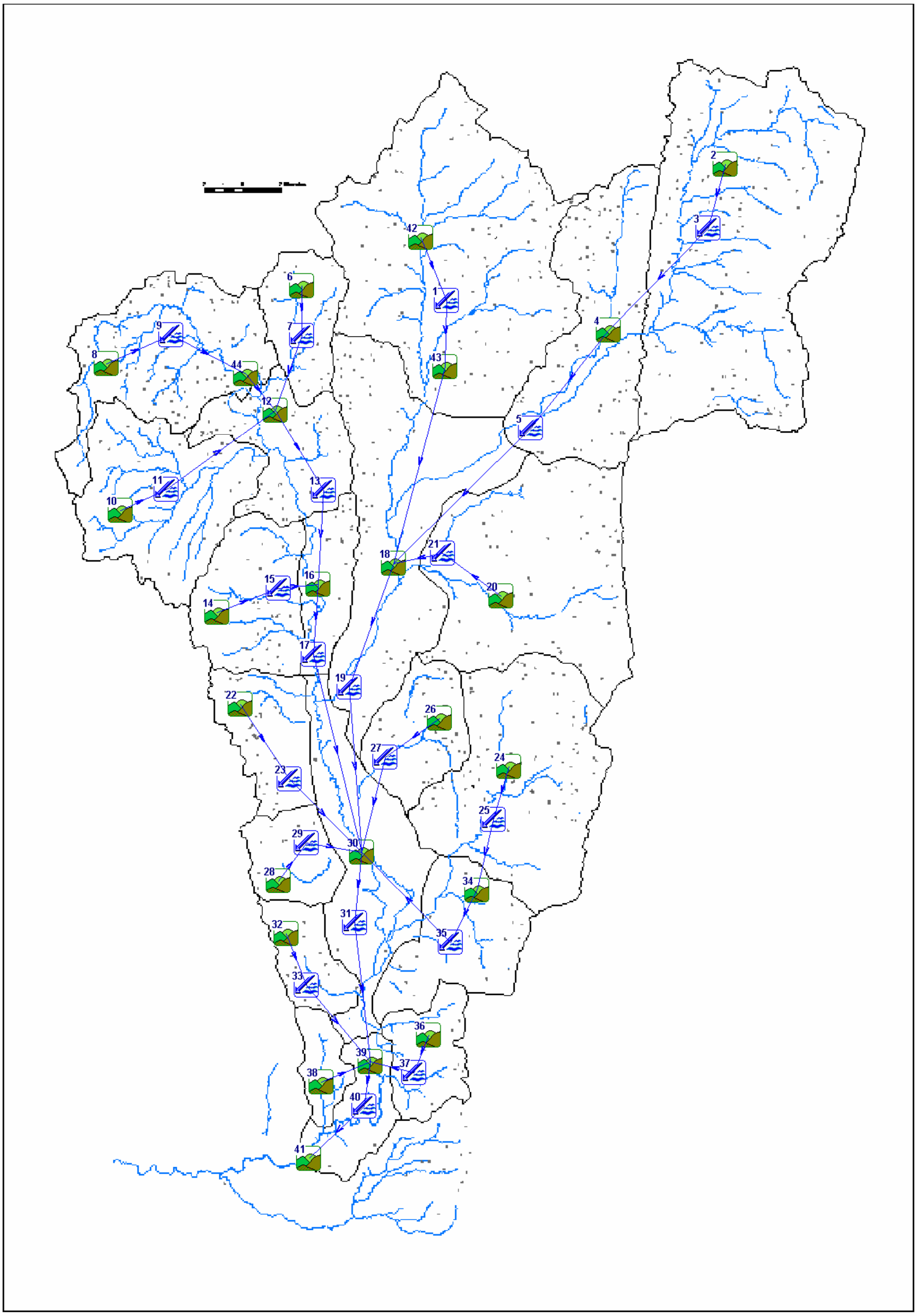


Figure 16 WaterCress Model layout, Rocky River Catchment

The catchment parameter set was then adjusted iteratively to obtain a closer representation of the observed data. The best calibration using the adjusted parameter set tended to underestimate the catchment yield. An example of the hydrographs generated during autumn 2003 are shown in Figure 17.

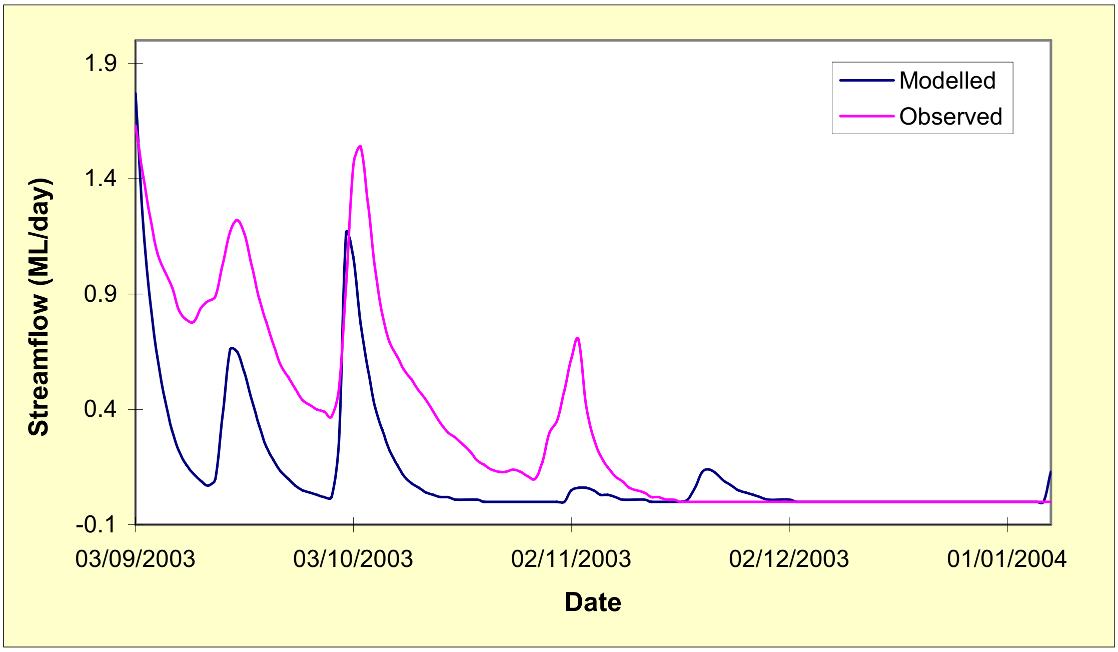


Figure 17 Observed versus modelled flows during late 2003, Rocky River Catchment

Here the measured peaks and baseflow appear to be underestimated by the model. When run using 100 years of daily rainfall data and this parameter set, the model generated median annual streamflows of 400–500 ML/y, which were much lower than the previous 11 500 ML/y estimate (NLWRA 2000).

This discrepancy in the modelled and expected yield was investigated by comparison with other catchments within the Broughton River system. Knowledge of rainfall-runoff relationships at several nearby gauged catchments provided an insight into what might be considered a reasonable estimate of the Rocky River surface water resources. The Hutt River in the Clare Valley has a catchment of only 280 km^2 (compared to 1350 km^2 for the Rocky River), yet since 1974 has produced a median annual runoff of around 4800 ML.

4.4.2 LIMITATIONS

The limitations of modelling are largely a result of the nature of the catchment, the recent dry conditions, and issues associated with the spatial and temporal characteristics of the available data on rainfall and streamflow.

Perhaps the greatest obstacle is the nature of the catchment itself. The runoff responses of semi-arid catchments to rainfall are extremely difficult to model. The relative importance of rainfall intensity in generating streamflow through Hortonian mechanisms is greatly increased (Dingman 2002). Rainfall intensity data are unavailable in the catchment, which necessitated the use of a daily timestep model. Models such as WC-1 rely upon simulated soil stores reaching saturation point during rainfall events to generate runoff. As a result, the model is incapable of producing runoff through this significant mechanism.

This issue may have been exacerbated by the dry conditions experienced in the catchment over recent years. Streamflow has only been collected since June 2003, a period which has been dominated by below average rainfall and which has been preceded by an extended period of unusually dry conditions. The resulting moisture deficit in the catchment is undoubtedly leading to a very high assimilative capacity for rainfall inputs. In attempting to reproduce these by calibrating the model to observed data from this period, the catchment response over the full range of climatic conditions is attenuated.

Calibrating the modelled response of the catchment to such conditions cannot be confidently extended to the entire length of climatic data and, when they are, tend to significantly underestimate runoff during average to wet periods. The model was unable to be calibrated with a level of confidence suitable to conduct scenario modelling in part due to the lack of representative calibration flow data across the required range of climatic conditions. With an improved data record over a range of conditions and flows, it will be possible to improve the performance of the model and conduct scenario modelling.

4.5 CATCHMENT YIELD

Despite the limitations of the WaterCress model, it was considered possible to use the regional data compiled and provide an improved understanding of annual catchment yield beyond the coarse NLWRA (2000) assessment. A Tanh function was used to generate an annual rainfall-runoff curve which enabled a reasonable estimate of catchment yield to be made for any annual rainfall total (Grayson et al. 1996).

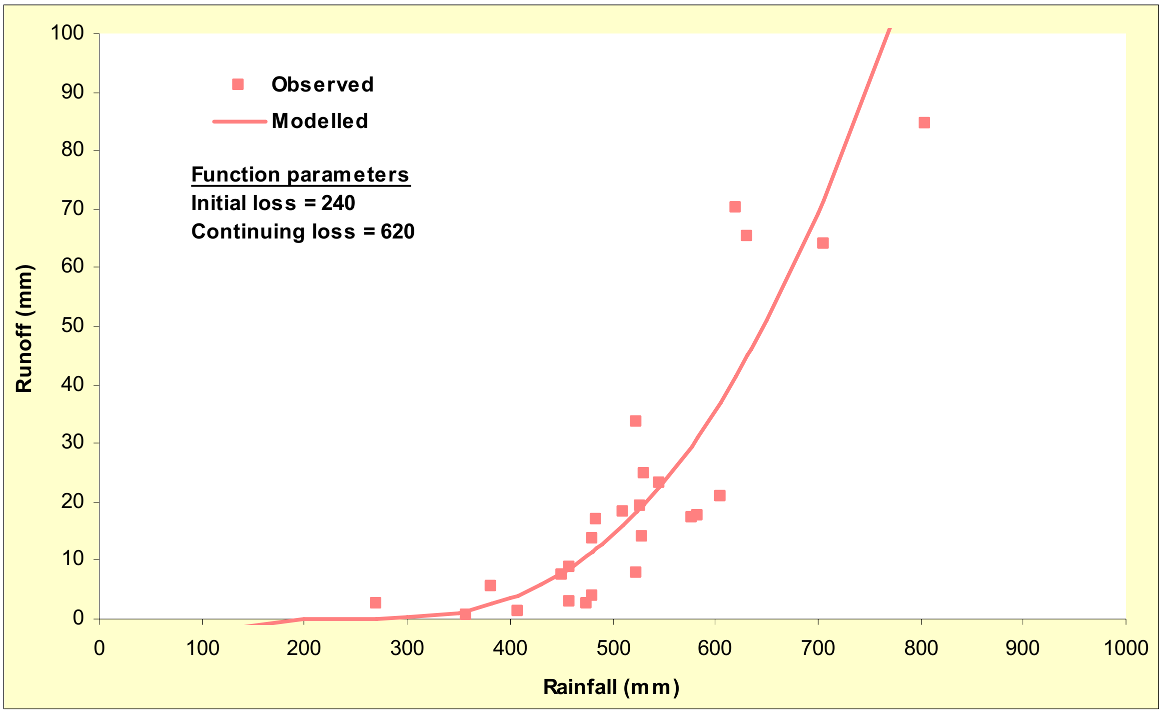
Three gauged catchments within the Broughton River system were reviewed to conduct this analysis — the Hutt and Hill Rivers, and the Broughton River at Mooroola. Tanh functions were fitted to annual rainfall and runoff totals in each catchment by adjusting parameters of initial and continuing loss to visually best fit the scatter of the recorded data.

Runoff data used were for the period 1974–2004 from the Hutt River gauging station at Spalding (AW507501). Annual rainfall data were proportionally distributed by catchment area, between BoM stations 021025, 021059 and 021069.

Hutt River parameters were also considered the most appropriate to extrapolate to the Rocky River Catchment since its land use was most similar to Rocky River; the Hill River features heavy dam development that would tend to generate parameters that would underestimate Rocky River runoff (D.J. Cresswell, DWLBC, pers. comm., 2005). Data from the Hutt River also had the closest match to the theoretical function (Fig. 18).

Final loss parameters values for the for the Tanh function were 240 mm for initial loss, and 620 mm for continuing loss. The resulting rainfall-runoff relationship indicates that little or no total annual runoff occurs for annual rainfall totals below 280 mm. Annual rainfall of 600 mm is predicted to produce 36 mm of runoff.

The regional annual rainfall for Rocky River for the 120 year record was used as the input to the rainfall-runoff, resulting in a median runoff estimated to be in the range 8000–10 000 ML. This range of values is comparable to, although 10–20% lower than, the estimate of 11 500 ML in NLRWA (2000).



Source: BoM (rainfall), DWLBC Hydstra (runoff)

Figure 18 Annual rainfall-runoff curve for Hutt River Catchment

Estimates of the median runoff from each sub-catchment were also required to allow for dam capture volumes to be assessed at this scale. This Tanh function was also used for this analysis with average sub-catchment rainfalls generated as described in Section 4.1 as the input.

Table 11 in Section 6 shows the predicted catchment yield by the sub-catchment divisions used for farm dam analysis, and also provides an indication of the variability of the rainfall-runoff response across the catchment.

The runoff coefficient is a commonly used measure providing a straightforward means of comparing catchment efficiencies in terms of producing runoff. The coefficient is calculated as the average annual runoff divided by the average annual rainfall for the catchment. Higher runoff coefficients indicate a more efficient catchment. Coefficients for Rocky River and other catchments in South Australia are shown in Table 6 for comparison. Rocky River runoff coefficient is 0.03, so for every 100 mm of rainfall received in the catchment an average of 3 mm leaves the catchment in runoff. This value compares closely with the adjacent Willochra Catchment, but is considerably lower than the Hutt River and Baroota Reservoir Catchments.

Table 6 Runoff coefficients for selected catchments

Catchment	**Area** (km^2)	**Runoff coefficient**
Rocky River	1 350	0.03
Hutt River	280	0.05
Baroota Reservoir*	236	0.06
Southern Willochra*	1 187	0.02

*Source: Risby et al. (2003)

4.6 SURFACE WATER KNOWLEDGE GAPS

Rainfall is the primary driver of runoff and the best indication of water resources distribution. The rainfall isohyet coverage was based on a limited number of stations and shows discrepancies between the rainfall stations analysed and the observed isohyet value. Long-term landholder rainfall records offer an opportunity to improve the understanding of surface water distribution and engage the local farming community in water resource management. Gaps typically include elevated areas as BoM sites tend to be located in valleys, close to populated centres.

Evaporation is a significant part of a catchment water balance, driving demand and limiting runoff, but no evaporation data for the Rocky River Catchment are available. Beetaloo Reservoir adjoining the catchment to the west provides an estimate of evaporation in higher rainfall areas, but little is really known of evaporation in the drier areas. Collection of evaporation data in the central or northeastern portion of the catchment would provide improved data to input to hydrological models.

The streamflow salinity monitoring network installed by DWLBC for the NYNRM Board is sufficient for catchment-scale ambient surface water quality assessment. However, the stations have only been operating since 2003 and do not yet have sufficient data to represent runoff in wetter periods. Once sufficient streamflow data have been collected, it will be possible to use the model developed in this study to run predictive scenarios relating to the potential impact of existing and future development levels on water quality.

Farm dam data generated for this study must be considered as preliminary and future assessments should look to improve on this. Of most importance is the capture of suitable imagery during a period when dams are at or near full supply level. The depth to volume relationship employed to develop dam storage volumes from digitised surface areas in this study was not groundtruthed, and future studies to improve dam capture estimates should consider this as a valuable addition to desk top methods of estimation. Although capture volumes have been estimated in this report, water-use from farm dams is not currently known. Although this is thought to be limited to stock and domestic uses, the relative importance of groundwater and surface storages needs to be clarified to improve future assessments. Information on all components of farm water-use is essential to improve both modelling and resource management.

Surface water – groundwater interactions are poorly understood and limit the certainty in conclusions that can be drawn from available data. Understanding this interface is critical to quantitative water balance studies and ecological assessments. Baseflow can make a major contribution to surface water yield for multiple years following major recharge events such as that which occurred in 1992 (D.J. Cresswell, DWLBC, pers. comm., 2005). This raises the potential of 'double accounting' in water resource planning, where shares of both surface and groundwater are allocated for use and a component appears in both water budgets. Water-dependent ecosystems in the region are dependent on surface expressions of groundwater to provide critical refuge habitats.

Favier et al. (2004) listed a range of predicted ecological responses to various flows within the Broughton River system. The report acknowledges that these responses are entirely based on expert opinions and have never been confirmed in the field. Knowledge of the relationship between ecology and hydrology for water-dependent ecosystems in the catchment is almost completely lacking. It is critically important that investigations are undertaken to address this gap.

A key issue is the development of an understanding of the structure, function and natural variability of aquatic ecosystems, requiring an assessment of the response of biota to a range of hydrological events. Knowledge gained will enable the design of meaningful integrated monitoring programs for water-dependent ecosystems, as mandated under NRM legislation.

5. GROUNDWATER RESOURCES

5.1 INTRODUCTION

The groundwater resources of the catchment are predominantly fractured rock in nature. Aquifers of this type are characterised by a high degree of spatial variability in observed hydraulic conductivity (Cook 2003). Fracture characteristics such as orientation, spacing and length are influential in this regard, but are also unique to each system, making predictions of their behaviour very difficult. The extent, connectivity and recharge processes of the various fractured rock systems found throughout the region are presently not known (Magarey & Deane 2004).

5.2 RESOURCE STATUS

5.2.1 GROUNDWATER QUANTITY

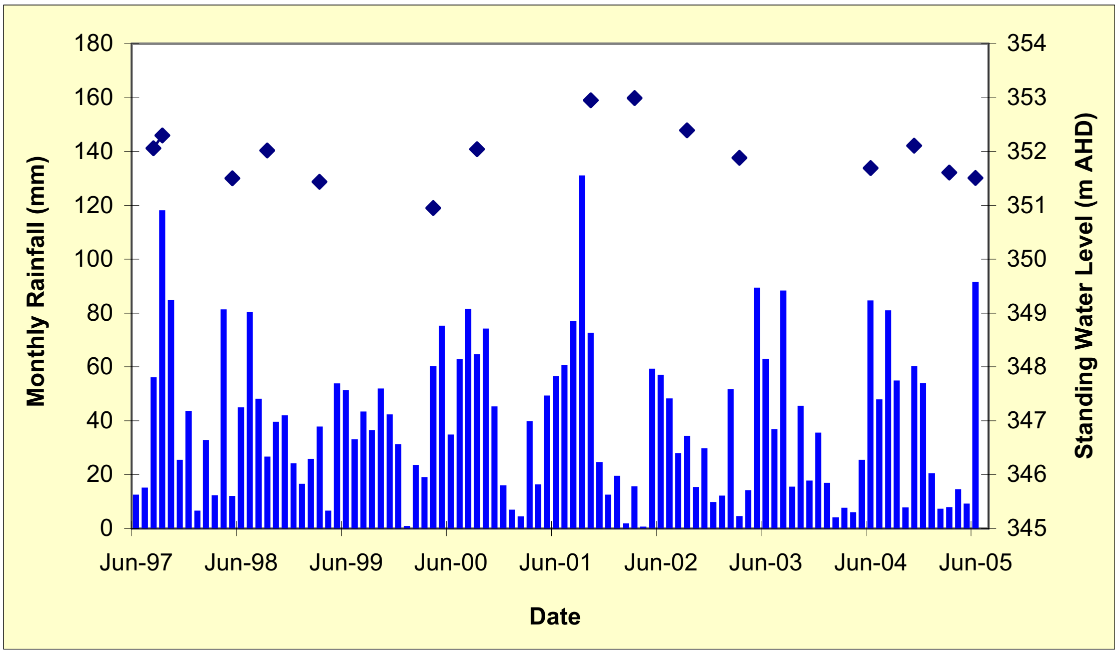
Understanding the condition of groundwater resources in the region is hampered by an almost complete lack of groundwater monitoring data. Only one monitoring bore is located in the catchment, just north of Wirrabara township, which actually forms part of the Willochra groundwater monitoring network. This bore has been monitored at roughly six-monthly intervals for standing water level since 1997. The monitoring record is shown in Figure 19, along with regional monthly rainfall.

No strong trend is apparent from the data, although there is some suggestion of a seasonal response. Unfortunately, the sampling frequency is too irregular, especially in the early record to indicate any marked seasonality in the recharge, although the highest water levels do correspond to high rainfall during winter 2001. Future monitoring should now be more regular, which will hopefully enable both seasonal recharge and any drawdown due to irrigation during the drier months to be determined. The lack of other information from the area or any pumping history from the bore means that the data can only be considered indicative.

Water level seems to remain fairly constant at 352±1 m AHD and shows no apparent trend or signs of being under stress. This evidence is supported by the landholders' observation that a nearby irrigation well has been a reliable source of water and shown no appreciable change in performance during use by the current owner (J. Wilson, Landholder and irrigator, Wirrabara, pers. comm., 2005). This experience supports anecdotal evidence from landholders in other areas of the catchment where 'strong' bores are reported to still be presenting a reliable source of water.

5.2.2 GROUNDWATER QUALITY

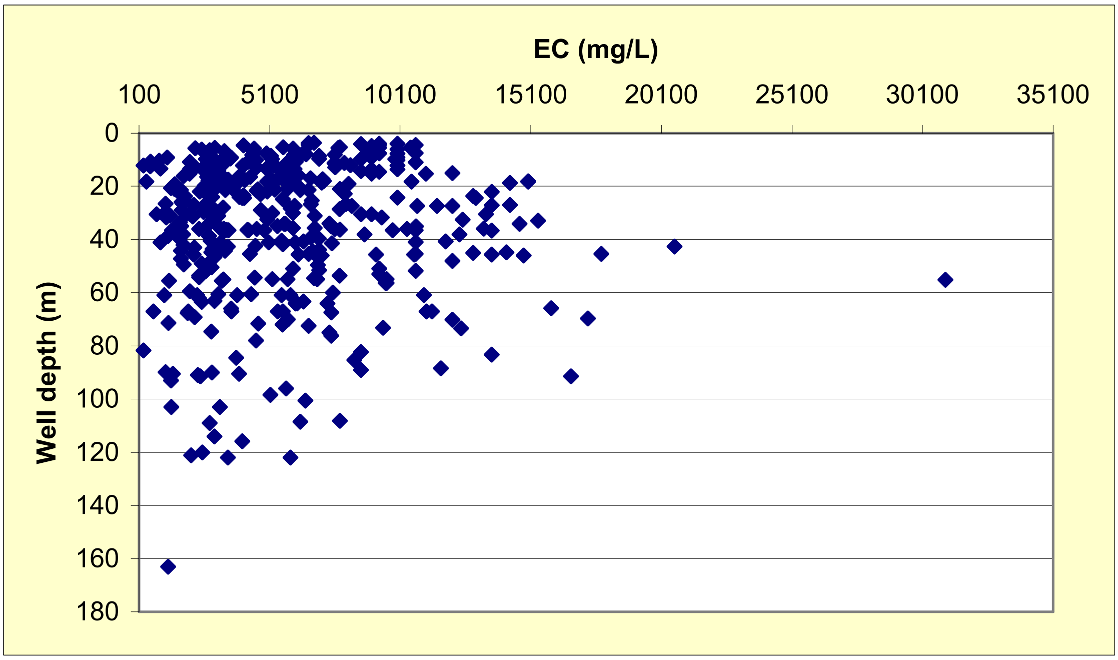
Although not monitored by any agency in the catchment, groundwater salinity is typically recorded when a bore is first drilled. The values of electrical conductivity (EC) recorded range from less than 300 to over 30 000 mg/L (SA Geodata 2004). Salinity values are plotted



Source: SA Geodata and BoM

Figure 19 APP2 monitoring bore SWL and monthly rainfall at Wirrabara

against well depth in Figure 20, which suggests that there is no definitive relationship between well depth and salinity. Figure 21 shows the distribution of groundwater salinity in the catchment based on the same readings.



Source: SA Geodata

Figure 20 Groundwater salinity as a function of well depth, Rocky River Catchment

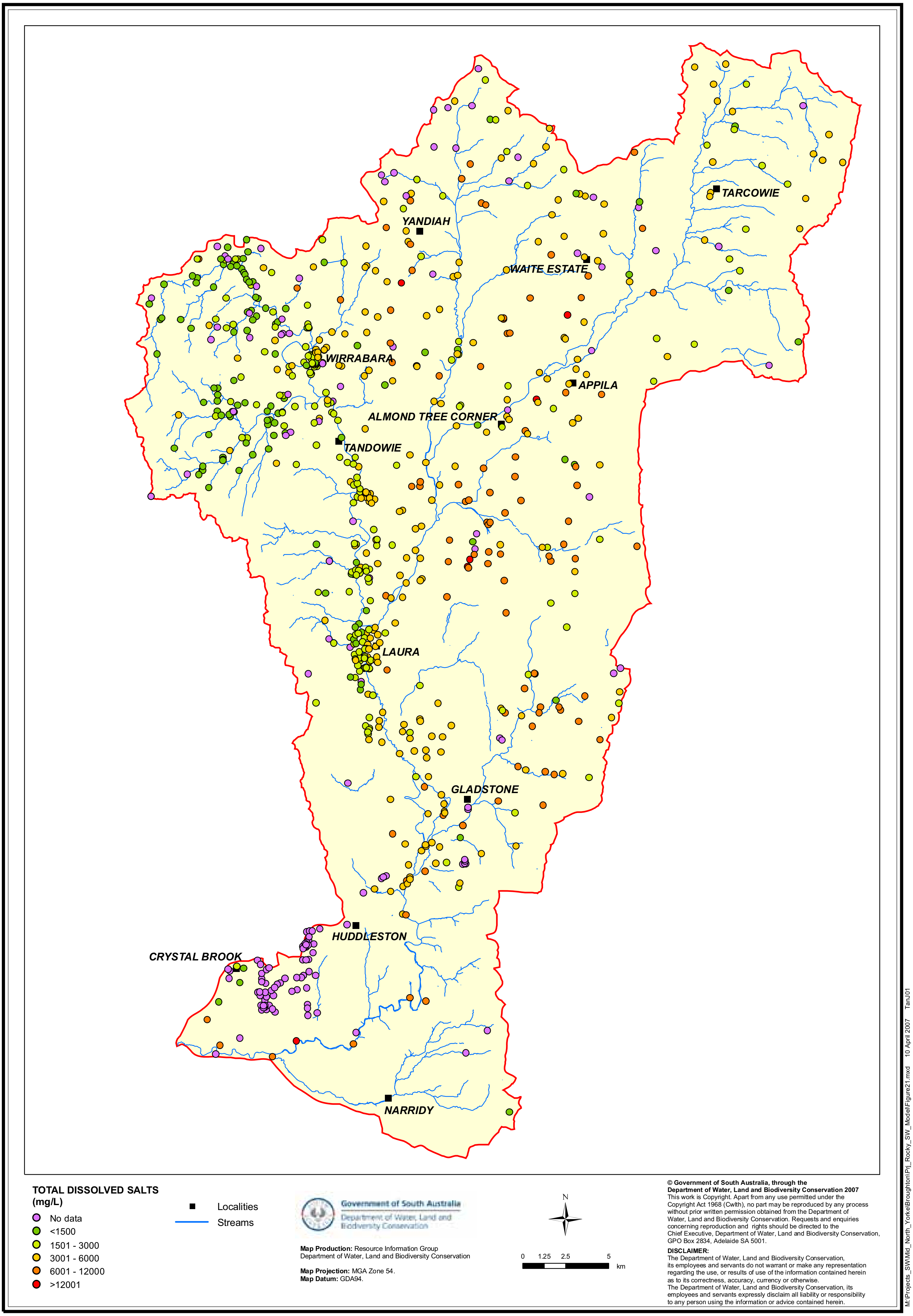


Figure 21 Groundwater salinity distribution, Rocky River Catchment

Salinity trends are difficult to determine with data such as these because it is a comparison of salinities measured during different seasons over a large span of time. Additionally, single data points provide no indication of seasonal trends. Despite this, Figure 21 suggests that the higher quality water is generally found in close proximity to watercourses, especially the upper reaches of Rocky River and Ippinitchie Creek.

More recent and reliable salinity data for two bores near Wirrabara were provided by local landholders and are shown below. Table 7 shows data from an irrigation bore adjacent to the monitoring bore discussed above. Salinity data for an additional bore located ~2 km downstream are shown in Table 8, along with some concurrent readings taken from pools and ephemeral springs in Rocky River. None of the data in Tables 7 and 8 show any appreciable trend in salinity over the monitoring period.

Table 7 Salinity data from an irrigation well north of Wirrabara on Rocky River

Date of test	Observed salinity (mg/L)
May 1983	1210
Feb 2000	1459
Mar 2005	1340

Table 8 Selected groundwater salinity data provided by landholders

Bore location	Sample	Date of test	Observed salinity (ppm)
Kanagra (north of Wirrabara)	Rocky River (spring?)	1991	2688
	Rocky River	May 1996	4032
	Permanent pool	Apr 2005	3184
	Windwill bore	1991	3014
		May 1996	3328
		Apr 2005	2864
	Irrigation bore	May 1996	2176
		Apr 2005	2092

Source: Greg Pech, Landholder and irrigator, Wirrabara.

5.2.3 COMMUNITY PERCEPTIONS

The lack of any lowering trend associated with the water levels in monitoring bore APP2 contrasts with other areas of the catchment that have experienced significant and widespread lowering of watertables. This has been most serious around the Stone Hut area where residents have had their bores, typically 30 m deep, totally dry up over the last few years. Mr Peter Trott, a local bore and mill contractor, reports that in addition to the reduced levels around Stone Hut, areas from around Appila through to Jamestown have all observed falls in water level typically around 2 m.

Additional supporting anecdotal evidence was recounted during the consultation phase of the project:

- A number of landholders indicated that groundwater levels in the Laura region have dropped 3–4 m over the last two years.
- Only two out of 10 wells located on the Laura Blocks to the north of the township are functioning properly.
- Bores perceived as being reliable sources of water with strong flow are maintaining supply, but marginal supplies are being seen to fail or have suffered reduced standing water levels.
- Formerly permanent waterholes within the Rocky River near Stone Hut and Laura are reported to be drying up.

While the drier than average conditions over the last few years are recognised as playing a role in the recent trends, clearly the resource is under major stress, particularly in the Stone Hut – Laura region. Several people interviewed expressed concern that water was not only being overused, but in some instances wastefully used.

5.3 RECHARGE ESTIMATES

First-order estimates of regional groundwater recharge using two desktop methods were employed in this study.

The relative concentrations of chloride found in groundwater and rainfall can be analysed to determine recharge volumes based on the conservation of chloride mass, and this method was used initially to give a lower end estimate of recharge.

In addition, comparisons were drawn with the nearby Clare Valley region, which appears to have a similar hydrogeology (see Section 5.4). Significant investigations in recent years have led to a relatively good understanding of the water balance components including groundwater recharge in the Clare Valley (see Love et al. 2002). These values were proportionally applied to the focus region using a number of assumptions to provide an indicative value for both recharge and sustainable use.

Of the two methods, the chloride mass balance is the most reliable but is prone to be conservative in the results produced. The most difficult aspect of the analysis is the scaling of point to areal recharge estimates. In this regard, analysis was limited by the spatial extent of the available data. This method should provide a good estimate of the likely lower limit of recharge. Applying proportional water balance values determined for the Clare Valley is less robust as it is not based on data collected within the catchment. Unlike simple recharge estimates, which do not provide a clear indication of safe extraction volumes, it did allow for preliminary sustainable use limits to be developed.

5.3.1 CHLORIDE MASS BALANCE

The chloride mass balance is a commonly used method to determine recharge and relies on the relationship:

$$P.C_P = R.C_G$$

where P is the mean annual precipitation, C_P is the mean concentration of chloride in precipitation, R is the mean annual recharge rate, and C_G is the mean concentration of chloride in groundwater.

The method has some limitations in fractured rock environments. In particular, the equation assumes steady state conditions and negligible contributions of chloride in groundwater from rock weathering (Love et al. 2002). Additionally, steady state conditions assume the movement of chloride stored in the matrix of the aquifer is in equilibrium with the existing groundwater flux. Any change in this equilibrium may take decades or longer to re-balance. Where recharge and groundwater storage is likely to have increased, as with widespread land clearing, increased recharge will result in a flushing of stored chloride from the matrix into the groundwater. This will have the effect of reducing the recharge estimate (Love et al. 2002). The resulting rates are still considered to be indicative of a low-end estimate of mean annual recharge (A. Love, DWLBC, pers. comm., 2005).

A review of water well data identified that groundwater from 188 wells within the catchment have had full chemical analysis completed, but the spatial distribution of these was not fully representative. Large areas of the eastern and southern portions of the catchment were without data, and this required an estimation based on the distribution of the chloride concentrations observed in surrounding areas.

The range of chloride concentrations in groundwater were generally lower in the higher rainfall areas of the catchment but did exhibit considerable variation both locally and regionally. For convenience of analysis, sub-catchments and rainfalls already calculated for the farm dam analysis were used. Chloride concentrations were taken from as many wells as possible within a given sub-catchment to give a representative recharge rate for the particular sub-catchment.

Precipitation chloride concentrations were determined following the method developed by Hutton and Leslie (1958), which uses the distance of the catchment centroid to the coast. This gave a value for the precipitation concentration of chloride of 6 mg/L.

All values were substituted into the rearranged equation to solve for recharge. Resulting values were then multiplied by the catchment area to convert depth of recharge to volume. Results are collated in Table 9, and Figure 22 illustrates the spatial variation in calculated sub-catchment recharge. The total volume of recharge in an average rainfall year for the catchment estimated using the chloride mass balance method was 2500 ML.

5.3.2 REGIONAL WATER BALANCE ESTIMATES

Developing a catchment groundwater balance requires quantification of all inputs and outputs. Recharge, as a proportion of rainfall, is the only input to the balance, with outputs being a combination of extractions, discharge to streams or springs, and lateral flow of water out of the catchment (Love et al. 2002).

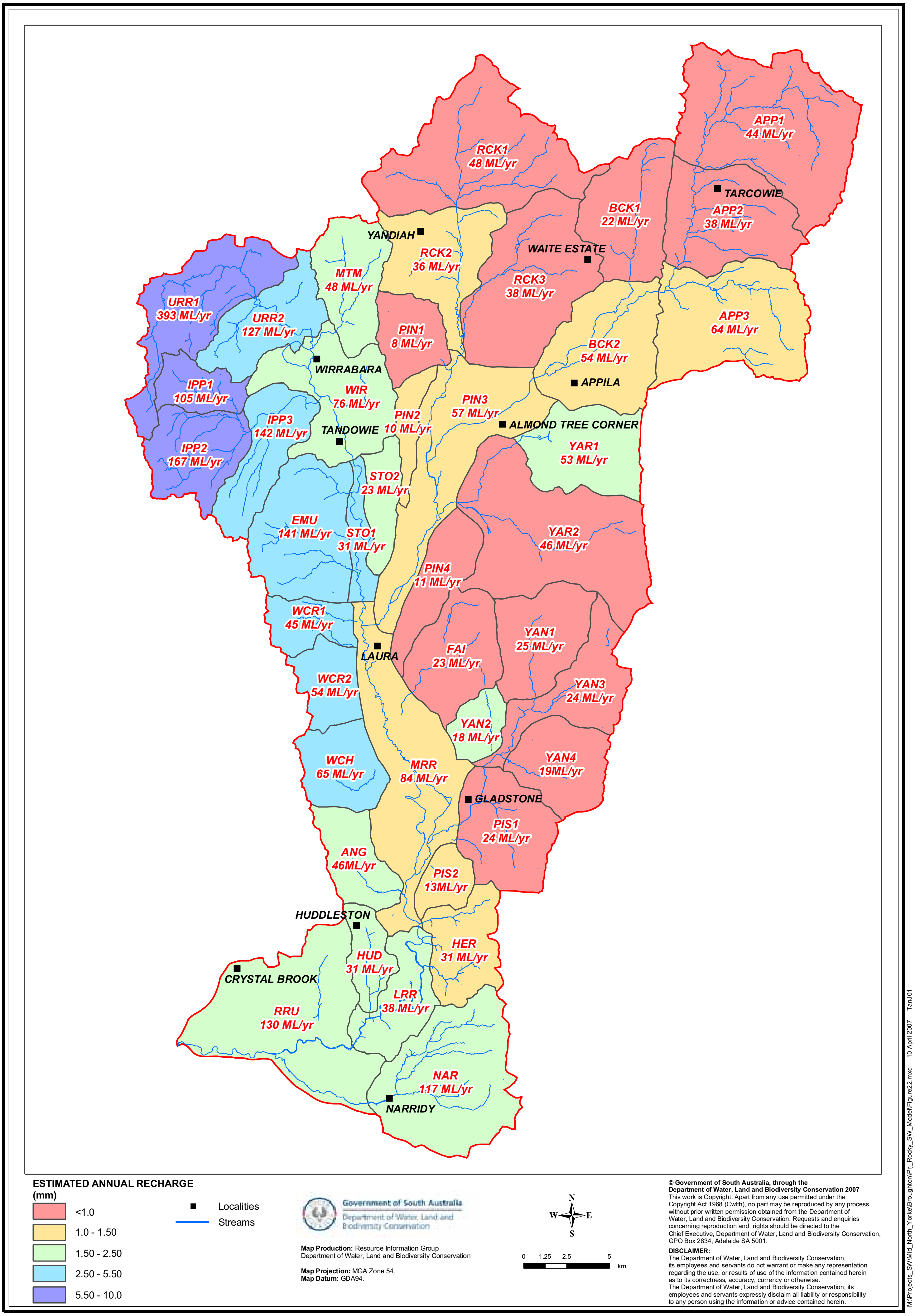


Figure 22 Estimated annual recharge by sub-catchment in the Rocky River Catchment

Table 9 Recharge rates and volumes by sub-catchment in the Rocky River Catchment

Code	Average rainfall (mm/y)	Chloride in groundwater (mg/L)	Chloride method*	GW recharge (ML/y)	GW recharge (mm/y)
ANG	400	1 000.00	Est	46.01	2.40
APP1	355	3 500.00	Est	44.49	0.61
APP2	380	2 500.00	Est	37.60	0.91
APP3	400	2 000.00	Est	63.87	1.20
BCK1	380	3 500.00	Est	22.03	0.65
BCK2	380	1 812.10	Ave	53.85	1.26
EMU	545	975.30	Ave	140.58	3.35
FAI	440	3 500.00	Est	22.79	0.75
HER	446	2 000.00	Est	31.10	1.34
HUD	425	1 000.00	Est	30.83	2.55
IPP1	582	450.13	Ave	104.74	7.76
IPP2	621	601.90	Ave	167.23	6.19
IPP3	568	620.56	Ave	142.25	5.49
LRR	433	1 500.00	Est	38.36	1.73
MRR	438	1 922.04	Ave	83.88	1.37
MTM	440	1 440.80	Ave	47.67	1.83
NAR	439	1 300.00	Est	116.70	2.03
PIN1	430	5 257.80	Ave	8.42	0.49
PIN2	450	2 500.00	Est	9.73	1.08
PIN3	436	2 601.79	Ave	56.62	1.01
PIN4	452	4 999.87	Ave	10.92	0.54
PIS1	432	3 518.50	Ave	24.04	0.74
PIS2	436	2 000.00	Est	13.08	1.31
RCK1	391	3 195.13	Ave	48.10	0.73
RCK2	411	2 338.53	Ave	36.49	1.05
RCK3	393	3 415.00	Ave	37.95	0.69
RRU	409	1 304.20	Ave	129.95	1.88
STO1	500	903.15	Ave	31.25	3.32
STO2	481	1 579.35	Ave	23.34	1.83
URR1	497	308.04	Ave	392.51	9.68
URR2	488	619.93	Ave	127.43	4.72
WCH	457	900.00	Est	64.76	3.05
WCR1	529	968.85	Ave	45.32	3.28
WCR2	449	798.90	Ave	54.09	3.37
WIR	482	1 509.34	Ave	76.27	1.92
YAN1	433	3 001.60	Ave	25.17	0.87
YAN2	420	1 449.40	Ave	18.33	1.74
YAN3	435	3 000.00	Est	24.09	0.87
YAN4	440	3 500.00	Est	18.84	0.75
YAR1	400	1 407.25	Ave	53.41	1.71
YAR2	423	4 051.00	Ave	45.54	0.63

*'Ave' refers to an average chloride concentration from well data; 'Est' refers to an estimated concentration.

Code refers to the sub-catchment codes, with the sub-catchments shown in Figure 22.

Estimates of regional groundwater recharge developed by Love et al. (2002) for the Clare Valley were of the order of 50–75 mm/y. For the Clare region, with an annual rainfall of 600 mm, this equates to 8% of total rainfall. 10 mm were found to discharge to surface watercourses and the remaining 40–65 mm were either extracted for irrigation or left the valley as lateral groundwater flow (Love et al. 2002).

Whilst ultimately dependent on rainfall, the relationship between rates of recharge and rainfall are not linear, especially in low rainfall areas. The rate of recharge was reduced according to the proportional difference in annual rainfall totals (0.75) to account for this non-linearity.

Adopting the lower value for recharge from the Clare Valley and local average rainfall, then recharge to groundwater in the Rocky River Catchment would be of the order of 6%, or 28 mm. Insufficient streamflow records are available to provide an estimate of baseflow, but assuming this stream discharge of groundwater is similar to the Clare Valley at 10 mm, this leaves around 18 mm of recharge, and a proportion of this should be available for irrigation and other uses.

In the water balance model of the region, proportional groundwater use averaged over the Clare Valley was thought to be 10 mm of an estimated 40–65 mm. This represents 15–25% of recharge that does not discharge to streams or leave the catchment as regional flow (Love et al. 2002). A sustainable yield for Rocky River might then equate to 2.7–4.5 mm, or 3600–6000 ML/y. Note that both of these values are above the recharge estimated using the chloride mass balance, which does not allow for stream discharge or lateral flow.

This figure is purely speculative and should be used with caution as the assumptions supporting it are yet to be evaluated quantitatively. It is also emphasised that these values would correspond to recharge during an average rainfall year. Recharge during below average years will again not be related in a linear manner. Half of average annual rainfall will not produce half the recharge volume produced in an average rainfall year. Due to evapotranspiration losses, it is quite possible that below average years will produce little to no significant recharge on a regional scale.

The volume is, however, the best available with current information and is used in a comparison with current use levels in Section 6.3.

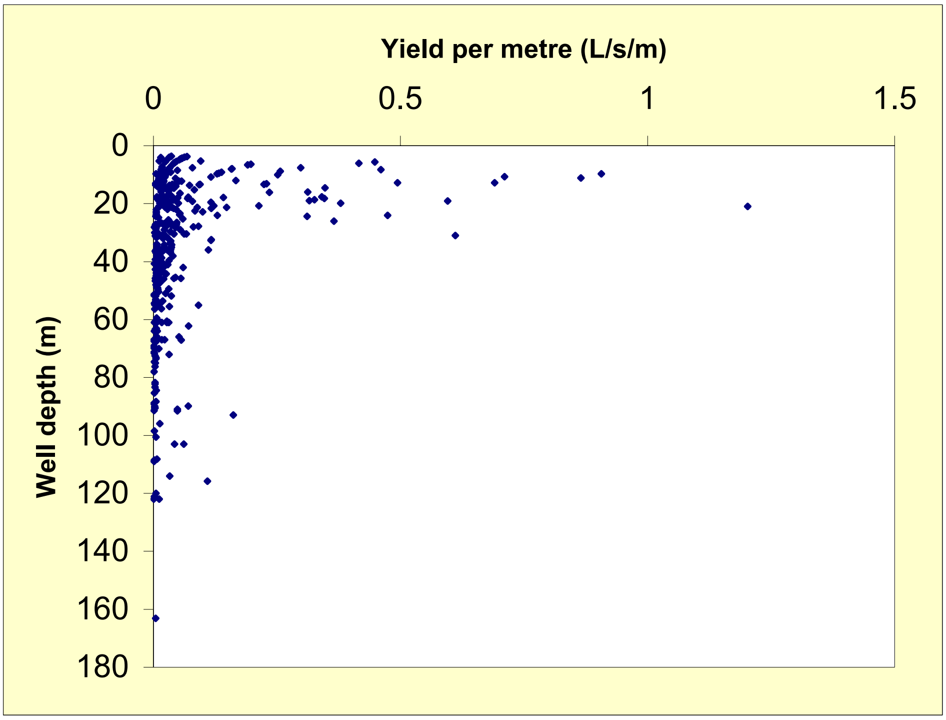
5.4 DISCUSSION

The water balance and sustainable yield estimates for the Clare Valley Water Allocation Plan (Love et al. 2002) were based on a broad range of investigative work. A finding of this work was the presence of a decrease in fracture intensity with depth, which is attributed to increased rates of weathering closer to the surface, a pattern commonly associated with fractured rock aquifers.

The highly fractured upper zone of aquifers in the Clare Valley are considered important in maintaining hydraulic connectivity at a regional scale. Where watertables fall below the level of the highly transmissive surface fracture zone, regional flow will decrease markedly irrespective of a favourable hydraulic gradient (Love et al. 2002). This is one example of how fractured rock systems differ from porous media type aquifers in their predictability.

Figure 23 illustrates the relationship between well yield and total depth for all wells with available information within the Rocky River Catchment. The same analysis appeared in Love et al. (2002) for wells in the Clare Valley, and the trends observed are similar, although the average well depth is apparently greater in the Clare Valley. The figure shows that higher yielding wells are generally associated with shallower depths, suggesting that an analogous fracturing pattern may be present in the Rocky River Catchment area.

Recent below average rainfall and recharge have resulted in the lowering of watertables, which in places may now be below the level of the highly fractured zone. As the watertable falls, wells will intercept fewer fractures that are capable of transmitting regional groundwater flow. This will decrease the capacity of the resource in low recharge areas, and potentially lead to the complete drying of shallow wells that are entirely within the highly fractured zone.



Source: SA Geodata

Figure 23 Well yields per metre of depth, Rocky River Catchment

Such impacts are likely to be felt most strongly in lower rainfall and hence recharge areas as local flow systems come under pressure. Figure 22 shows that Stone Hut receives only a modest amount of recharge, and the drying of shallow wells from this area may be due to reliance on local flow systems. Shallow wells are less likely to be in connection with regional groundwater flow systems where watertables have fallen below the more transmissive upper fracture zone.

It should be noted that only the probability of intercepting more and larger fractures decreases with depth (Love et al. 2002) and, as shown in Figure 23, a number of relatively high-yielding wells can be found at depths of over 80 m. Wells that have retained a constant supply through recent dry periods may simply intercept a greater number of larger and more extensively connected fractures that are in better hydraulic connection with regional groundwater flow systems.

5.5 GROUNDWATER KNOWLEDGE GAPS

There is currently insufficient baseline information about the hydrogeological environment to undertake any analysis to support the theories and resulting assumptions within this report. The lack of understanding of groundwater flow systems and connectivity means that currently the entire catchment is effectively considered as a single hydrogeological unit. A more strategic approach to management of groundwater resources would divide the catchment into groundwater management units with similar hydrogeological characteristics.

The absence of groundwater monitoring data compounds and contributes to the lack of understanding of the hydrogeology of the catchment. It is recommended that suitable monitoring bores be identified and a program of groundwater monitoring be implemented as soon as possible.

Monitoring wells should focus on areas of higher extraction rates, but wells outside of these areas are also required to monitor regional groundwater characteristics for comparison. Ideally, all included wells would be surveyed for elevation to allow for a potentiometric surface analysis that would enable broad groundwater flow systems to be elucidated. Wells should be monitored at the beginning and end of the irrigation season to indicate the state of recharge and indicate any inter-annual trends in water levels.

A research program to undertake a detailed water balance for groundwater is required in order to place the current pressure being exerted on the resource into a meaningful context. In particular, groundwater flow systems and the interaction between surface water and groundwater must be adequately quantified to improve management decisions.

In the absence of further technical investigations, it is suggested that a precautionary approach be adopted towards future development involving the use of groundwater, and savings be made wherever possible through improvements in efficiency of use and eliminating wastage.

6. WATER RESOURCE DEVELOPMENT

6.1 INTRODUCTION

This section provides an indication of the current levels of pressure being exerted on the water resources of the catchment, and considers both surface and groundwater use. Where possible, comparison of current levels with sustainable use benchmarks have been made. It should be noted that, in general, information is very limited in the catchment and this analysis relies heavily on the application of general principles developed during work undertaken in other parts of the Mid-North and on the assistance of the community. The important contribution made by landholders through provision of first-hand information cannot be overstated. Continuous communications should be fostered between landholders and regional NRM authorities at all opportunities. The more effectively that information can flow in both directions the better placed the community as a whole will be to respond to challenges such as drought and climate change.

The major demands on water resources identified in the region are from farm dam development, irrigation, and stock and domestic use.

6.2 FARM DAM DEVELOPMENT

6.2.1 IMPACTS OF FARM DAMS

Farm dams are an important aspect of water resource management in rural catchments and contribute to this in a variety of ways. These include collection of surface runoff or streamflow for stock or irrigation water, storages for water sourced from low-yielding wells via windmills prior to pumping at higher efficiencies to where it is required on a property, as an aid in reducing water erosion (often in conjunction with contour banking), and for domestic and recreational uses.

Surface water dams can be positioned directly on a drainage line (on-stream) or collect overland, often roadside, runoff or diverted streamflow (off-stream). Both dam types will have an influence on the way water moves through a catchment, but the impacts of these on streamflow patterns can be quite different. In general, off-stream dams, or on-stream dams with effective low-flow bypasses, will minimise any changes to the seasonality of flow, which is an important factor from the perspective of a downstream user.

Location within a catchment is also a critical factor in determining the impact of any particular dam on overall hydrology. The lower a dam is located in a given catchment, the greater the proportion of catchment runoff controlled by the dam (Beavis 1996).

On the other hand, a large number of small on-stream dams may effectively control a similar area of a catchment to a single large dam, but in fact will have a higher loss rate through increased evaporation from the increased surface area (Meigh 1995).

Irrespective of position within a catchment, for any flow to be felt downstream of an on-stream dam it must first fill to overflow level. This introduces a time delay in the first seasonal flow events for downstream areas. Sequentially located on-stream dams will each introduce a similar delay. Both the length of the delay and the overall impact of an on-stream dam will increase with capacity.

Champion et al. (1999) found that low flows such as groundwater baseflows and episodic summer rainfall events were highly impacted by excessive levels of dam development. Such flows are important ecologically as they provide pool level and water quality maintenance, improving the ability of aquatic ecosystems to survive dry periods. In addition, early seasonal flows, such as can occur during late autumn and early winter, were greatly reduced or removed (Philpott et al., 1999; Pikusa, 2000).

Delays in streamflow seasonality can be to the detriment of all downstream water users, particularly the environment. Life cycle phases such as reproduction can be intricately linked to natural hydrological cycles and how these relate to other seasonal variables such as temperature. Changes to flow regime can therefore lead to catastrophic consequences for local biodiversity.

Martin (1984) and Neil and Srikanthan (1986) found that semi-arid areas with highly variable rainfall are particularly susceptible to reductions in the length of season during which flow passes downstream, and increases in the frequency of low-flow events and no-flow periods.

Recently in areas of South Australia, especially the southern Mount Lofty Ranges, the construction of farm dams has progressed at alarming rates in the absence of regulatory control. Savadamuthu (2002) found that farm dam storage capacity in the upper Marne River Catchment increased by over 50% during 1991–99. An even greater level of development (140%) was noted by Cresswell (1991) during 1980–89 within the Barossa Valley.

Further studies in the Mount Lofty Ranges have indicated that the evaporative losses alone from dams in this much higher rainfall area of the state were of the order of 20% and could possibly reach 35% in a dry year (McMurray 2004). Water lost through evaporation would, prior to dam development, have left the catchment as streamflow, a proportion of which would have recharged groundwater systems. Water lost through evaporation from dams is lost to all users in the catchment.

6.2.2 DATA AVAILABILITY AND QUALITY

The analysis undertaken for this study was limited to the use of existing aerial photography. As the imagery was captured during summer 2002, the levels of dams were well below the full supply level. Best estimates of the area that a full capacity dam may cover were made, but only limited accuracy and precision is possible with such imagery.

The average size of dams is also small, adding to the potential relative size of errors. McMurray (2004) undertook a detailed error analysis on the results of a comparable farm dam study and found that errors greatly increased when smaller dams were considered. In that work, maximum errors in digitising were considered to be of the order of 6–8% for dams smaller than 1 ML.

Based on these values and given the relatively poor suitability of the imagery available for this study, errors of ±20% could be possible on individual dams. These errors should be largely random rather than systematic in nature. Hence, rather than consistently over or underestimating capacities, the positive and negative errors should be approximately equal and to some extent should cancel each other. It is not possible to refine this error estimate without extensive field survey work at this time, which is beyond the scope of this report.

Despite any shortcomings relating to accuracy, this work should still provide a good indication of the relative levels of dam development, provide reasonable estimates of total volumes and highlight areas where capture is above a sustainable level. In order to improve on this work significantly it will be necessary to acquire high-quality imagery at a period of time when all dams are close to full capacity, or alternatively survey every dam in the catchment.

6.2.3 DAM DEVELOPMENT LEVELS

The total number of farm dams identified during the analysis was 966. These are estimated to have a total storage capacity of ~2600 ML. The vast majority of dams have a capacity below 5 ML; size classes are shown in Figure 24.

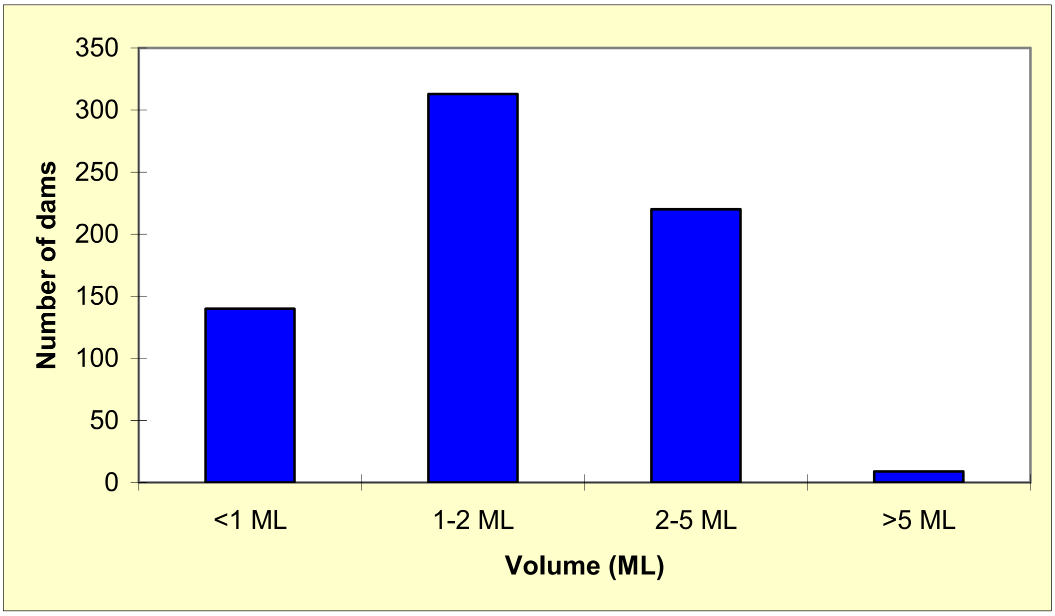


Figure 24 Dam size classes, Rocky River Catchment

The average dam volume is 2.6 ML and the dam density, defined as the total dam volume divided by the catchment area, is 1.90 ML/km^2.

6.2.4 BENCHMARKING DAM DEVELOPMENT

In South Australia, a number of sustainable development limits have been established to provide direction as to what constitutes an acceptable harvest of the total catchment yield. In the case of a prescribed water resource, the limits for major farm dam storages will be determined as part of the prescription process. Guidance should then be sought from the particular water allocation plan as to whether development levels are appropriate.

Outside of prescribed water resources, the State NRM Plan provides guidance as to a limit of sustainable diversions for surface water usage. This is set at 25% of the long-term median annual runoff and relates to direct extraction only and, as far as farm dam capture is concerned, 50% of the runoff generated on any particular property is considered sustainable. No investigations have been undertaken to date to determine whether the 50% rule has been successful in protecting downstream users from excessive surface water capture. It is likely that this will remain the default benchmark for sustainable yield for the foreseeable future outside of prescribed areas. Although intended for application at the property scale, the value of half total runoff provides a benchmark for comparison with existing dam development levels at any scale.

Table 10 compares catchment level development statistics for the Rocky River with those from similar studies done in other areas of the state. Although it has very modest total storage volume and dam density values, the low runoff from the catchment means that Rocky River has the highest proportion of runoff captured of the four studies shown. Despite this, it is still within the 50% criteria at whole-of-catchment scale.

Table 10 Comparison of farm dam statistics within South Australia

Catchment	Area (km^2)	Dam volume (ML)	Dam density (ML/km^2)	Dam vol./runoff (%)
Rocky River	1350	2600	1.9	29
Willochra	1200	1400	1.2	19
Finniss	200	5800	29	22
Onkaparinga	650	8500	13	15

Data taken from Risby et al. (2004), Savadamuthu (2003) and Teoh (2000). All values are approximate.

Despite being within the 50% rule benchmark, catchment-scale assessment can hide hotspots of dam development that may exceed the criteria. To determine levels of stress at smaller scales, it is necessary to divide the catchment and examine sub-catchment contributions to total dam storage.

Figure 25 provides an indication of the distribution of farm dam densities across the catchment in order to assess sub-catchment development levels. Sub-catchments shown in red in Figure 25 have a total capture volume exceeding median annual runoff. From a farm dam perspective these areas should be considered over-developed. Any future dam development should ideally be avoided in these areas, at least until more detailed information can be obtained.

Other areas that exceed NRM Plan policy guidelines are shown in orange (75–100% annual runoff capture). Dam development in these areas should proceed with caution and ideally be avoided until further information is available. Alternatively, a hydrological assessment could be requested of potential proponents to ensure that no impact will result from any planned dam on downstream users.

In general, areas in the low rainfall northcentral and, in particular, northeastern regions appear to be considerably over-developed. Table 11 provides a summary of the relevant statistics used in generating Figure 25 for further information. Catchment codes can be related directly to the figure.

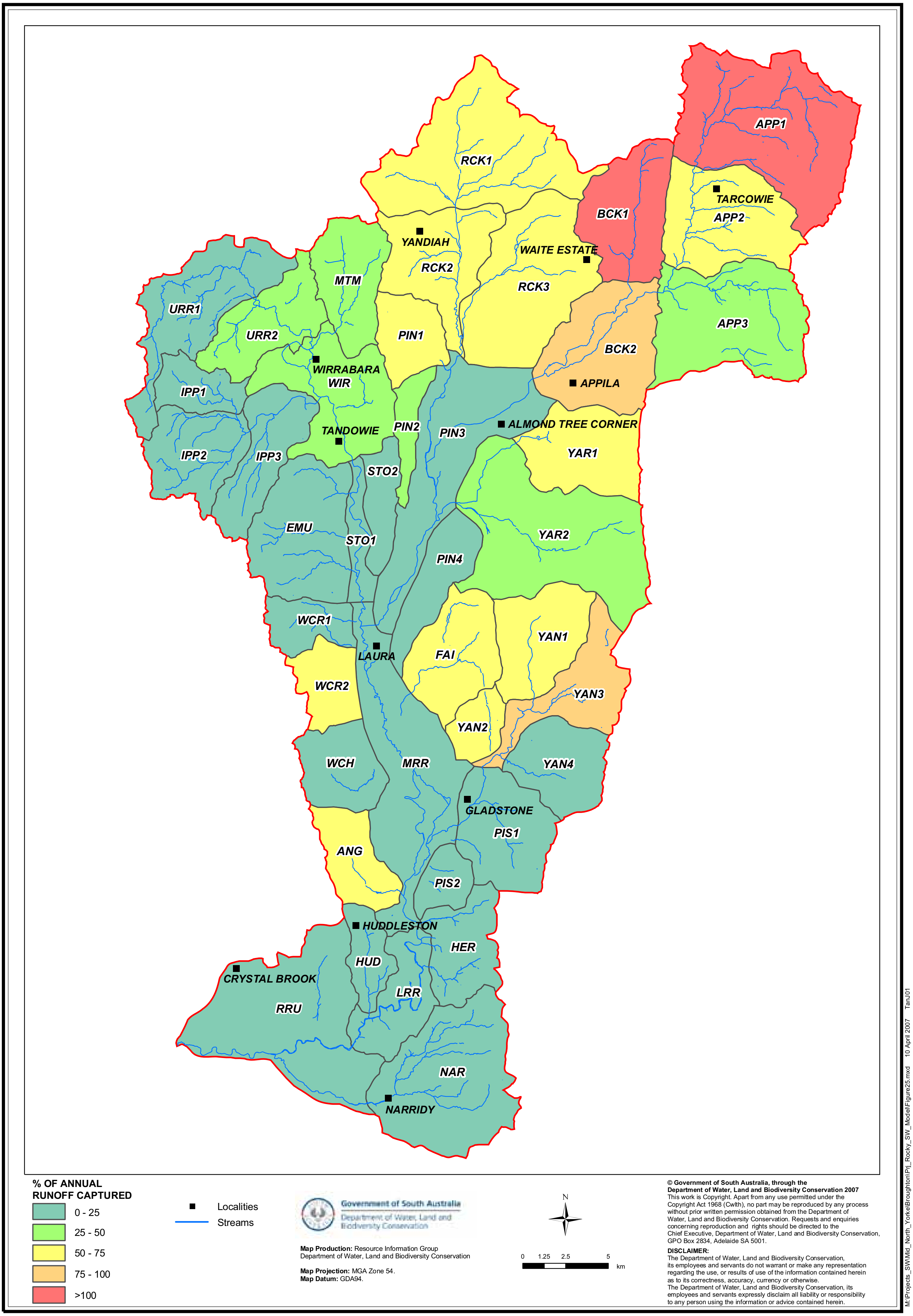


Figure 25 Farm dam development levels by sub-catchment in the Rocky River Catchment

Table 11 Selected farm dam and hydrological statistics for the Rocky River Catchment

Code	Area (km^2)	Total dam volume (ML)	Dam density (ML/km^2)	Average rainfall (mm/y)	Catchment Runoff (ML)	Catchment runoff (mm)	% capture of runoff
ANG	19.17	33.58	1.75	400	66.32	3.46	0.51
APP1	73.11	146.52	2	355	95.11	1.30	1.54
APP2	41.23	58.81	1.43	380	96.15	2.33	0.61
APP3	53.23	91.5	1.72	400	184.15	3.46	0.5
BCK1	33.82	105.92	3.13	380	78.86	2.33	1.34
BCK2	42.8	87.57	2.05	380	99.8	2.33	0.88
EMU	41.93	129.49	3.09	545	940.65	22.43	0.14
FAI	30.21	100.74	3.33	440	201.23	6.66	0.5
HER	23.24	19.38	0.83	446	168.75	7.26	0.11
HUD	12.09	0	0	425	64.09	5.30	0
IPP1	13.5	26.68	1.98	582	417.57	30.93	0.06
IPP2	27.01	21.36	0.79	621	1125.8	41.68	0.02
IPP3	25.9	52.82	2.04	568	712.89	27.52	0.07
LRR	22.15	1.66	0.08	433	132.93	6.00	0.01
MRR	61.35	14.71	0.24	438	396.76	6.47	0.04
MTM	26.01	72.67	2.79	440	173.25	6.66	0.42
NAR	57.6	36.05	0.63	439	378.03	6.56	0.1
PIN1	17.16	68.29	3.98	430	98.36	5.73	0.69
PIN2	9.01	30.24	3.36	450	69.16	7.68	0.44
PIN3	56.31	15.55	0.28	436	353.55	6.28	0.04
PIN4	20.13	28.41	1.41	452	158.88	7.89	0.18
PIS1	32.64	28.48	0.87	432	192.92	5.91	0.15
PIS2	10	9.8	0.98	436	62.76	6.28	0.16
RCK1	65.51	114.18	1.74	391	191.05	2.92	0.6

Code	Area (km^2)	Total dam volume (ML)	Dam density (ML/km^2)	Average rainfall (mm/y)	Catchment Runoff (ML)	Catchment runoff (mm)	% capture of runoff
RCK2	34.6	73.97	2.14	411	145.61	4.21	0.51
RCK3	54.96	105.87	1.93	393	166.63	3.03	0.64
RRU	69.06	2.86	0.04	409	280.72	4.06	0.01
STO1	9.41	5.5	0.58	500	133.98	14.24	0.04
STO2	12.77	36.14	2.83	481	146.2	11.45	0.25
URR1	40.55	118.19	2.91	497	558.46	13.77	0.21
URR2	26.98	125.45	4.65	488	335.42	12.43	0.37
WCH	21.25	29.02	1.37	457	179.54	8.45	0.16
WCR1	13.83	65.83	4.76	529	266.43	19.26	0.25
WCR2	16.04	73.53	4.58	449	121.47	7.57	0.61
WIR	39.8	134.45	3.38	482	461.1	11.59	0.29
YAN1	29.08	99	3.4	433	174.49	6.00	0.57
YAN2	10.54	28.89	2.74	420	51.58	4.89	0.56
YAN3	27.69	164.12	5.93	435	171.24	6.18	0.96
YAN4	24.98	16.93	0.68	440	166.35	6.66	0.1
YAR1	31.32	68.83	2.2	400	108.35	3.46	0.64
YAR2	72.69	129.4	1.78	423	373.29	5.14	0.35

6.3 GROUNDWATER DEVELOPMENT

Figure 26 shows the location of all 858 current wells within the catchment, of which 793 are still possibly actively used (SA Geodata 2005). The proportional uses listed in SA Geodata appears in Table 12.

Table 12 Status of all bores located within the Rocky River Catchment

Primary purpose	Number	Comments
Unknown	508	Some of these bores may be historical, but current information on status and use was not available
Stock and domestic	224	Domestic bores typically have a secondary purpose of stock use
Irrigation	47	
Environmental	1	Recharge at Wirrabara Forest
Town water supply	1	Wirrabara Forest
Drainage	4	
Recreational	1	
No longer used	65	May be abandoned, collapsed or backfilled
TOTAL	**858**	

Source: SA Geodata

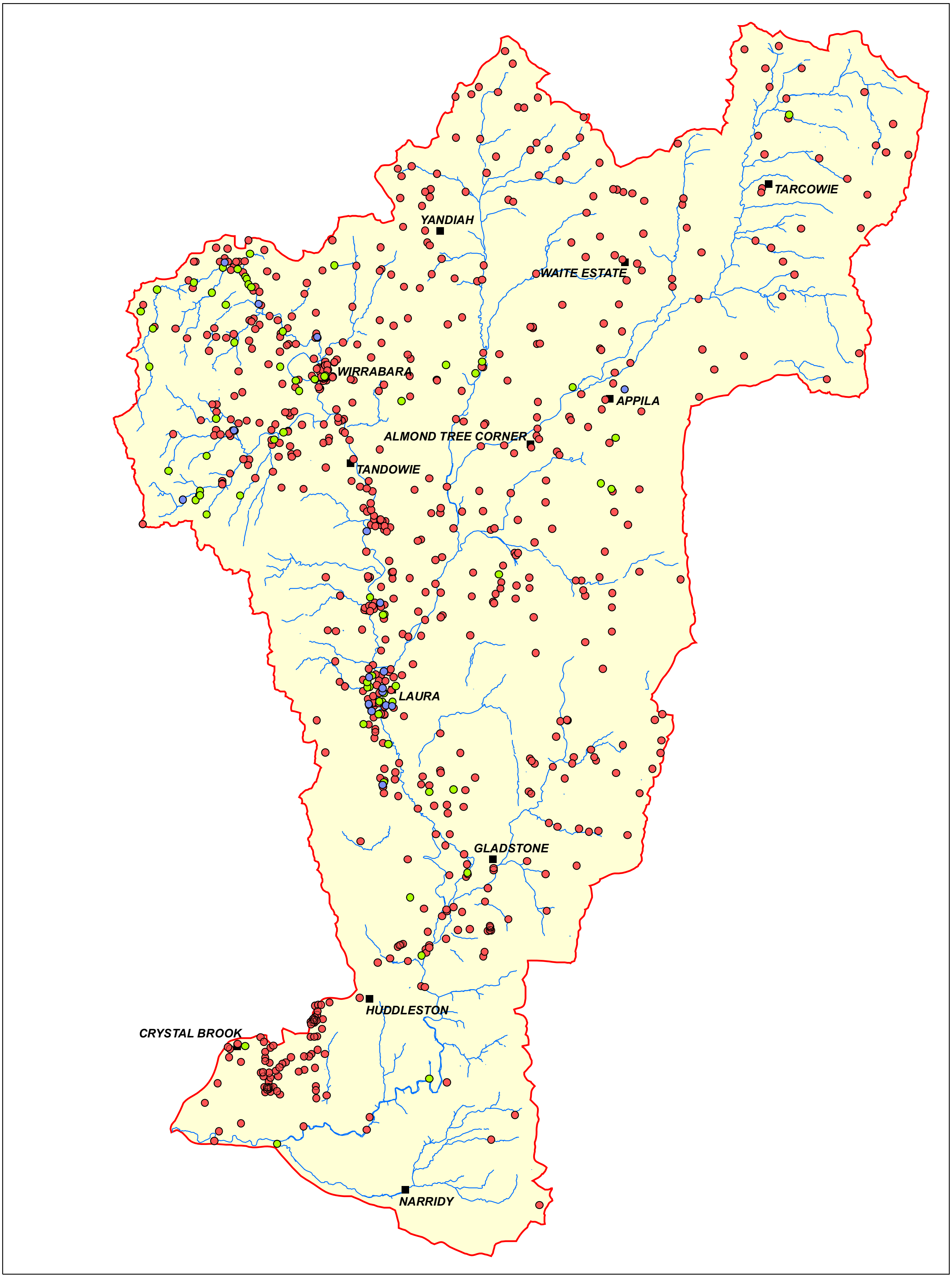
The majority of wells are located in an area from the central west near Laura through to the northwestern part of the catchment, roughly following the course of the Rocky River. Irrigation wells are found mostly in the vicinity of the townships of Laura and Wirrabara and along the upstream reaches of Rocky River north of Wirrabara.

The most widespread purpose for the use of groundwater in the region is for stock and domestic use, although the demand for irrigation is greater in terms of total volume. There is anecdotal evidence that use of the groundwater resource for irrigation has been increasing over recent years (see also Magarey & Deane 2004), and the drilling history for the region lends some support to this (Table 13). In the period since 1990, 19 out of 70 new wells drilled listed their main purpose as irrigation supply, but only two have been drilled since 2000. Of the new irrigation wells, eight are located within the immediate area of Laura. The location of all wells in the catchment with a purpose designated as irrigation is shown in Figure 26.

Table 13 Drilling activity in the Rocky River Catchment since 1990

Period	Stock	Domestic	Irrigation	Other	Total	Comment #1	Comment #2
1990–95	8	3	8	10	29	7 backfilled, 3 unknown	1 irrigation well backfilled
1995–2000	13	3	9	9	34	1 environmental well, 8 unknown	1 irrigation well abandoned
2000–05	2	2	2	1	7	1 stock well abandoned	
Since 1990	**23**	**8**	**19**	**20**	**70**		

Source: SA Geodata



Localities
Streams

WELL TYPE
- Irrigation drilled post 1990
- Other irrigation or low EC
- All other wells

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

Map Production: Resource Information Group
Department of Water, Land and Biodiversity Conservation

Map Projection: MGA Zone 54.
Map Datum: GDA94.

N

0 1.25 2.5 5 km

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Figure 26 Current groundwater wells, Rocky River Catchment

6.3.1 BENCHMARKING GROUNDWATER DEVELOPMENT

It is difficult to develop general policy relating to groundwater use because the nature of such resources is that they vary considerably in their recharge mechanisms and capacity. The nearest and most obviously similar area where sustainable groundwater yields have been established is the Clare Valley.

In Section 5 of this report, water balance data associated with development of the Clare Valley Water Allocation Plan (CVWAP) were applied to the Rocky River Catchment. Application of the criteria determining allowable extraction volumes in Clare also makes for a useful comparison to assess current water-use practice.

The CVWAP criteria when seeking an allocation to use groundwater present the following requirements:

- A maximum of 1 ML/y will be allocated per hectare of land owned.
- No more than 24 ML/y may be extracted from any one well.
- Wells cannot be established within a zone of influence of other wells (determined by formula) or aquatic ecological asset (mapped in the plan).

The zone of influence protects against the possibility that concentrated extractions will exceed the local capacity of the underground water resource, even if the total volume is within sustainable limits. The zone of influence is calculated as a circular area centred around the licensed well, as follows (CVWRPC 2000):

$$\frac{\text{rate of irrigation applied for (ML/ha) x area of land to be irrigated (ha)}}{\text{0.3 ML/ha (estimated underground water recharge)}}$$

or

$$\frac{\text{volume applied for (ML)}}{\text{0.3 ML/ha (estimated underground water recharge)}}$$

For a hypothetical scenario of an irrigation demand of 10 ML/ha being applied to a 10 ha crop area, the value of the circular zone of influence area would be ~330 ha. Assuming that water was available for allocation, the licence would not be granted if the zone of influence, a 1 km radius circle centred on the well, overlapped the zone from another well, or that of an ecological asset.

If these criteria were to be adapted to Rocky River, it would firstly be necessary to consider the lower rainfall. Love et al. (2002) used a value for regional average rainfall in Clare of 600 mm/y. Rocky River regional rainfall is ~450 mm/y. This would necessitate a larger zone of influence, or reduced allocation per hectare, to account for the relatively limited capacity of the resource to cope with concentrated extractive pressure.

Even if the lower recharge factor is ignored and the Clare criteria were applied, Figure 27 suggests that the concentration of irrigation wells in the vicinity of the township of Laura would exceed the criteria. The density of designated irrigation wells in the area is extremely high for the rainfall, with 16 wells located within 1500 m of the town centre. It is not known

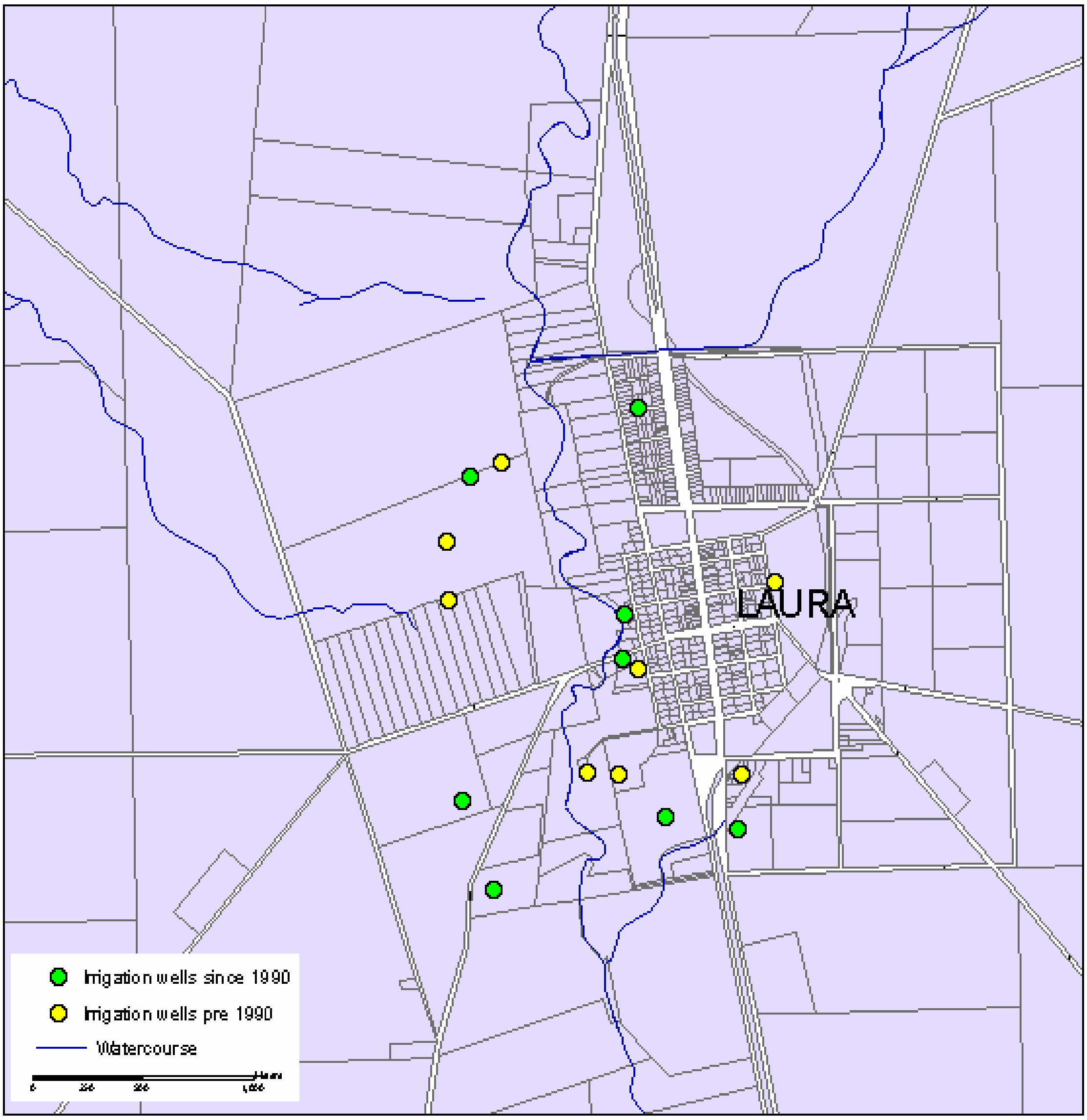


Figure 27 Proximity of irrigation wells to Laura township

how many of these wells are currently actively used for irrigation but many were observed as being active during recent field surveys. The concentration of these wells is arguably more of a concern than the total water extracted from them, as the influence of pumping from wells on the surrounding aquifer and other users is not accounted for.

Whilst it is understandable that good yielding areas will be targeted for groundwater development, the capacity of the resource must be considered when deciding if a development is feasible. The small size of land parcels in areas adjacent to townships warrants special consideration of this planning issue.

The Stone Hut region does not feature any irrigation wells, nor was any irrigation activity detected immediately to the north of the township. These criteria would apparently not have protected groundwater users in this area, who rely exclusively on groundwater for their water supply. Sustainable use for this area may rely more on regional watertable elevation and flows (see Section 5). Despite the lack of groundwater monitoring data that could support this conclusion, some indication of watertable levels can be gained from recently observed baseflow levels at gauging stations in the region.

Stream baseflows have been found to respond to the rainfall received in the preceding two or more years (D.J. Cresswell, DWLBC, pers. comm., 2005) and will also be greatest when watertables are at seasonally highest levels (Love et al. 2002). The period 2002–04 has returned below average annual rainfall (Section 4) and this has resulted in greatly reduced streamflow volumes due to the associated reduction in baseflows.

The lowered water levels and drying of wells then may well be simply a response to the recent dry years. Whilst extractive use of groundwater is probably not solely responsible for the observed declines, the potential for these activities to greatly increase impacts on water resources must be considered in future planning.

6.4 IRRIGATION

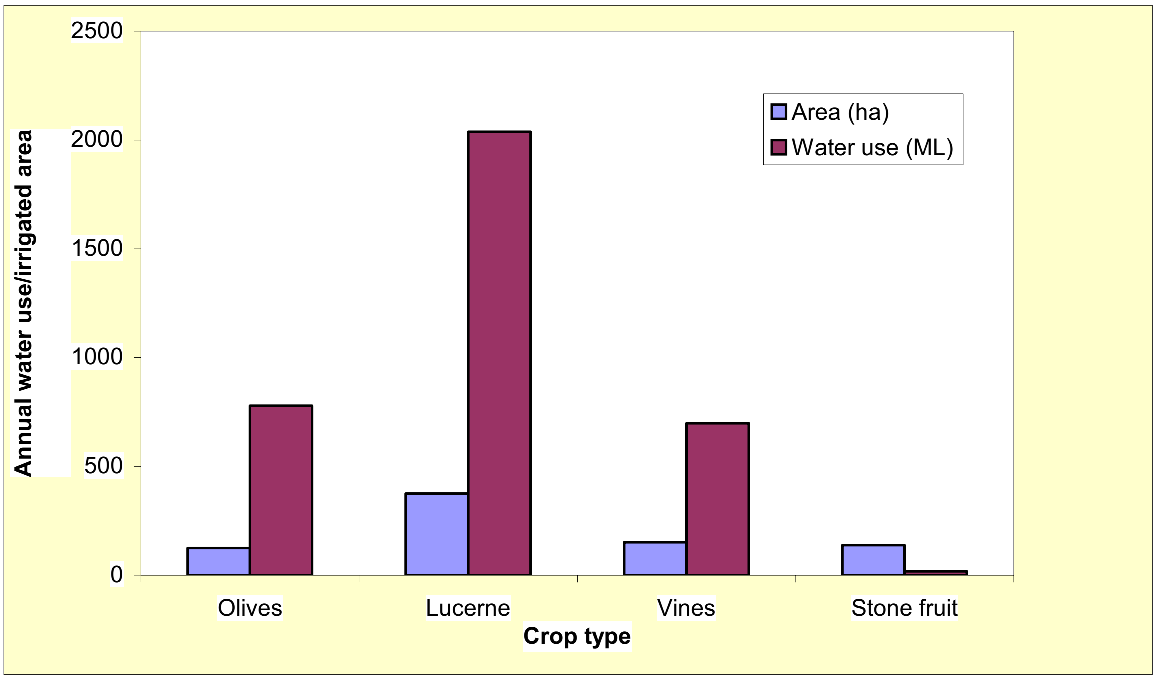
6.4.1 IRRIGATION USAGE

No evidence of any direct use of surface water for irrigation through farm dam capture or pumping of permanent pools was discovered during consultations or field surveys. Unlike the Willochra Catchment (see Risby et al. 2003), flood irrigation of riparian paddocks is not currently practiced, probably in part due to the fact that watercourses tend to be incised well below the level of the surrounding paddocks and diversion would not be a simple task.

All irrigation water-use must therefore come from groundwater supplies. The field surveys and consultations undertaken for this study suggest there is currently a decreased amount of irrigated lucerne but increased irrigation of vines, olives and stone fruit since the Bureau of Rural Sciences study (BRS 2001). Inspection of local government development records showed that a number of new land use change development applications have been received since 1999, but the total numbers involved are quite modest. The District Council of Mount Remarkable had processed five and Northern Areas Council four in the period. The most recent of these applications was in 2002, suggesting that pressure for new irrigation development had eased over recent years.

At the whole of catchment level, best estimates suggest that there is the potential for 3500 ML/y to be used if all irrigation activity identified occurred every year. While some irrigation operations were not evident, especially some of the lucerne listed as being irrigated in the BRS (2001) dataset, this represents a maximum use scenario. Estimates of water-use and irrigated hectares by crop type appear in Figure 28.

In terms of both water-use and number of users, irrigation appears to be focused around Laura and the density of irrigation activity is of some concern (see previous Section).



Source: Consultations data, BRS (2001)

Figure 28 Irrigation water-use and irrigated area by crop type, Rocky River Catchment

6.5 STOCK AND DOMESTIC USE

A total value for stock and domestic use is difficult to gain through consultation and a generalised stocking rate was used to model potential water-use. The total area available for grazing was estimated at 100 000 ha (BRS 2001). A regional average stocking rate in dry sheep equivalents (DSE) of 2.6 was applied based on consultation and published values (MNGWG/AIMS 2004; P. Harris, Goyder APPC Board, pers. comm., 2005; Hamblin 2001). It is recognised that through intensive farming practice it is possible to potentially stock up to three times this rate, but the figure was thought indicative at whole-of-catchment scale. Daily water-use of 6 L/DSE was considered to be a good average allowing for seasonal variation following landholder consultation and discussion (P. Harris, Goyder APPC Board, pers. comm., 2005).

The final value was the product of the available hectares, DSE and daily water-use multiplied by 365 days. Allowing a 30% value to cover evaporative and other losses through wasteful practice, plus domestic water-use, the total stock and domestic groundwater use was estimated at ~650 ML/y. This figure does not take into account surface water-use through farm dam capture, which may reduce the necessary volume required for stock supplies from groundwater resources.

6.6 WATER RESOURCES DEVELOPMENT KNOWLEDGE GAPS

In assessing the level of water resource development, it is crucial to be able to obtain information on the highest volume uses, in particular irrigation. Outside of the District Council of Mount Remarkable Horticultural Register, current information on irrigation activity is not collected, yet would provide a simple data source to collate total water-use pressure.

The creation and maintenance of an irrigation database by the NYNRM Board is suggested. Other high-volume water uses such as intensive stock feedlots should also be included. The database should have links to local government development approval processes in order for new developments to be incorporated. This would also provide the opportunity to identify areas where emerging development pressure was being exerted, and in this capacity would also fill a monitoring role.

Information included could be as simple as recording crop type, irrigated hectares, source of water and annual water-use, but ideally would record parcel and landholder contact information to allow for spatial analysis of irrigation pressure.

A database of this nature would also provide a targeted list of landholders with a major stake in water resource management issues. This would allow for the dissemination of information of potential interest, for example on emerging water-saving technologies or resource condition.

To provide a higher level of certainty on resource capacity than the current work, it will be necessary to implement a range of technical assessments, monitoring programs and subsequent evaluations of trends revealed once sufficient information is gathered. This process has already commenced but more is certainly required, especially with regard to groundwater monitoring. It is likely that a minimum of five years of data gathering will be required before significant improvements to the analysis presented herein will be possible.

Given the obvious stress that the resource appears to be under, it is considered essential that future water resource development be undertaken in a very precautionary manner. Ideally, no further development would be seen and water savings through improved efficiency should be encouraged.

7. CONCLUSIONS AND RECOMMENDATIONS

7.1 RISK ASSESSMENT

From a water resource management perspective, it is possible only to make educated guesses as to the sustainability of the current use levels in the longer term. Clearly this varies greatly from user to user, and for different locations within the catchment. It also depends on future climatic patterns, and although these are beyond management controls it will still be necessary to manage any resulting impacts.

Development in the catchment both in terms of farm dam density and irrigation usage is highly variable, with some areas being clearly over-exploited and others within existing sustainability benchmarks. These benchmarks are generalisations and cannot be reliably considered to guarantee long-term resource sustainability. It is essential that these are reviewed as improved estimates of resource capacity emerge.

Over-developed areas in particular are likely to require careful management in future to ensure that the situation is not worsened. Of equal importance is the need to ensure that areas currently under sustainable regimes are not pushed beyond this limit by uncontrolled development. The nature of the water resources present in the Rocky River Catchment should be recognised as being fragile and managed accordingly. In consultations for this report it was clear that many, if not most, users do use water sparingly, but a number of reports of wasteful use were also recounted.

Key factors to consider in sustainability discussions are the total pressure but also the distribution of this pressure, especially the density of high-volume extractive use such as for irrigation. The example of the CVWAP is one model upon which to assess future development proposals. The criteria used in the Clare region have been modified in Section 5.4 to account for the lower recharge rates observed in the Rocky River Catchment. These values could be employed as a starting point for discussions and may require adjustment to provide a workable basis for future allocations.

On the whole there is evidence to suggest that even in areas where no adverse effects have yet been observed that the resource is under unprecedented levels of stress. How this risk can be managed is a key question for water resource managers at all levels. The alternative to having criteria and guidelines is to consider regulation of the resource. If water resource development continues without consideration of resource capacity, NRM authorities may be left with little choice but to prescribe to protect the integrity of the resource for the future.

The following sections on surface and groundwater include policy suggestions and other recommendations for addressing these issues.

7.1.1 SURFACE WATER

The only identified use of surface water was through capture in farm dams. No streamflow diversions or pumping of permanent pools (as has been found in adjacent catchments — see Risby et al. 2003) was identified. The majority of dams in the Rocky River Catchment were found to be small (under 2.5 ML capacity). The sustainability of farm dam proportional capture is dependent on the scale of investigation.

At catchment scale it appears that total dam capture is within the 50% of median runoff sustainability criteria established under the State NRM Plan. At a closer scale of analysis, areas of high stress become apparent. Most notably some sub-catchments are capable of storing more than the total runoff volume in a median runoff year (shown as red in Fig. 25). Other areas are at 75–100% of capacity (shown as orange in Fig. 25), which is above recommended minimum sustainability criteria. In such areas, it is important that no further impact be placed on the sub-catchment. Ideally, no further dam development should be allowed in these areas, and any opportunities to fit low-flow bypasses pursued.

Recommendations for future surface water development are:

- All future dam development be limited to areas outside of the highly stressed sub-catchments designated red and orange in Figure 25.
- In all other sub-catchments, particularly those designated yellow, a precautionary approach should be adopted with no more than 50% of the median long-term estimated runoff being allowed as total dam storage on any one property.
- Any proposal to install farm dams of storage capacities greater than 5 ML should be based on the use of off-stream dams, and subject to an hydrological investigation to show that there will be no impacts on downstream users.
- On-stream dam development should be subject to the 50% criteria, limited to low order streams in sub-catchment areas marked as green in Figure 25, be of less than 2 ML capacity, and ideally should be fitted with a suitable low-flow bypass device.

7.1.2 GROUNDWATER

Based on chloride mass balance and water balance comparisons with the Clare Valley, the estimated annual groundwater recharge is at least 2500 ML. A hypothetical water balance using values derived for the Clare Valley (Love et al. 2002) suggests a sustainable yield might be in the region of 3600–6000 ML/y. This compares with an estimated current maximum use of ~4200 ML/y.

Irrigation activity identified is entirely groundwater sourced, not placing excessive additional stress on water resources and, from a purely volumetric perspective at catchment scale, is probably sustainable. Unfortunately the distribution of irrigators in the area around Laura is probably too dense to maintain adequate flow rates to supply the water needs for the current level of irrigation development in all but the years following extremely high rainfall. It is important to avoid further irrigation development in the vicinity of Laura township, as this would be highly likely to exacerbate the current problems for existing users. It is recommended that any further proposed groundwater extraction in this area be subject to the findings of an hydrological investigation that no impact on existing users, including water-dependent ecosystems, will result.

Outside of this region, limited higher volume resource uses may be possible, but the concentration of existing wells should be assessed as a general principle in all such development applications. Using the criteria required under the CVWAP, and adjusting these for the proportionally lower rainfall and recharge, indicative values could be:

- Annual maximum extraction of no more than 0.6 ML/ha of land owned.
- Limit all development to a maximum of 13 ML total annual extraction per well.
- Apply the same formula as is seen in the CVWAP for the proximity of irrigation wells and ecological assets to any proposed irrigation development. For ecological assets, it is recommended that the permanent pools coverage identified in the Broughton Catchment River Management Plan (Favier et al. 2004) could be used (see Fig. 6).

Given the lack of information on the groundwater resources of the catchment, any policy intended to ensure the sustainability of the resource must be considered as an initial estimate. Monitoring of the adequacy of the measures, and adjustment of the criteria subject to improved information, will also be necessary as required under an adaptive management regime.

7.1.3 WATER-DEPENDENT ECOSYSTEMS

As discussed in Section 3.5, knowledge relating to the biodiversity and the relationship between hydrology and ecology of aquatic ecosystems throughout the Mid-North is extremely limited. A research project of a minimum of 3–5 years duration will be required to develop sufficient understanding of the biota, their ecological responses and variations within these to develop an effective program for assessing the condition of water-dependent ecosystems. It is recommended that a project of this nature be viewed as a pilot monitoring program and be implemented as soon as practical.

APPENDICES

A. WATER-USE VOLUME METHODOLOGY

The estimation of current water-use involved collection of sources of data relating to land use and the processing of this information through GIS and simple numerical modelling techniques to estimate the water-use volumes represented.

Data on land use was collected by the Bureau of Rural Sciences in 1999 (BRS 2001). These data were used as a starting point, and current use was estimated based on analysis of local government development application (land use change) records, field inspection and direct consultation with landholders.

Water-use identified was limited to stock, domestic and irrigation use. No other major water-use such as town supplies or intensive animal feedlotting were identified in the region.

No evidence of surface water-use for irrigation was identified during the consultation or field inspection and this is assumed to be nil. Hence these calculations represent groundwater use.

Irrigated crops

Crop types identified in the catchment as currently being irrigated are lucerne, grape vines, olives, stone fruits, and sorghum (Table 14). The tropical tree genus *Paulonia* is also cultivated in at least one location.

Water-use surveys were mailed or handed out to around 20 irrigators in the catchment. Six surveys were returned, and these were used directly in calculations. Water-use from other irrigators was able to be determined through telephone interviews. Where no water-use data were obtained directly, an average water-use figure based on other irrigators of the same crop type was used.

A number of parcels listed as irrigated lucerne in the BRS data had no current evidence of irrigation. These properties are included in water-use totals using average values as presumably the potential exists for this irrigation to re-commence.

Table 14 Water-use and irrigated area by crop type

Crop type	Total area (ha)	Total use (ML)
Lucerne	376	2 032
Olives	125	779
Stone fruit	138	18
Grape vines	152	698
Sorghum	1	6.5

Stock and Domestic Use

These calculations were based on the use of BRS (1999) data to obtain a likely total grazing area (Table 15), a typical regional average of stock numbers using DSE, and an average daily water-use averaged over a year for each DSE.

Stock use was assumed to be the majority of water-use in this category, and domestic use was considered inconsequential and no attempt has been made to quantify this.

The majority of stock watering appears to be based on groundwater extraction, although surface water is used opportunistically. As surface water-use is already factored into the surface water modelling, all estimated stock and domestic water-use has been included as being groundwater sourced.

The major method of watering stock is from troughs rather than farm dams, and no allowance has been made for evaporative losses from troughs. These are assumed to be relatively small due to the small surface area of water available for evaporative transfer. Additionally, this was considered a way in which the opportunistic stock use of surface water from dams could be offset, as this was not possible to estimate.

Table 15 Land use types and associated areas for grazing calculations, Rocky River Catchment

Land use type	Total area (ha)	Assumed proportion[1]	Total area grazed (ha)
Crop and grazing rotation	61 676	30%	20 559
Grazing modified pastures	41 745	100%	41 745
Livestock grazing	6 192	100%	6 192
Total grazing area			68 496

[1]Factor used to account for areas under a rotation system, i.e. not continually grazed

A uniform stocking rate of 2.6 DSE was used for the catchment. DSE is a scaling system used to allow for comparison between different stock types to allow for productivity comparison. The rate used was based on landholder survey work undertaken by the Mid-North Grasslands Working Group and Agricultural Information and Monitoring Systems (MNGWG/AIMS 2004). It was also cross-checked with information from the Australian State of the Environment (Hamblin 2001) regional stocking rates.

A water requirement of 4 L/d/DSE was assumed. This rate, although lower than peak demand during dry months, or when grazing on low water content feed, was selected to make allowance for the reduced water requirement when feeding on green feed during wetter months.

Total water-use was the simple product of the total number of stock and the average water-use:

Total stock use = DSE/Ha x total grazed ha x average daily water-use x 365

This produced a total water-use figure of 260 ML/y.

260 ML = 2.6 x 68496 x 4 x 365

B. THE RECENT DRY SPELL

The apparent declining trend in regional rainfall volumes and reduced variability in recent times has significant implications for surface water resources availability and management, and warranted further assessment. Linear decreasing trends identified in regional annual rainfall time series data seem consistent since the 1950s, suggesting that they are a real consequence of the relative dryness of recent years rather than a statistical coincidence.

Frequency analysis of the average annual rainfall dataset indicates that 550 mm is the amount of rain expected to occur in 20% of years (Fig. 29). Since 1970, annual rainfall totals have equalled or exceeded 550 mm five times. If conditions reflected long-term rainfall patterns, regional annual rainfall totals should have equalled or exceeded 550 mm seven times in 35 years, superficially quite comparable to long-term expectations. However, since 1980 (25 years) annual rainfall has only equalled or exceeded 550 mm/y once, in 1992, the wettest year of the entire record (790 mm), while the statistically expected number of occurrences was five.

This tends to support the notion of a change in rainfall patterns after 1970, but simple comparisons of periodic rainfall averages can produce conflicting results and are highly dependent on the period chosen. For example, the average annual regional rainfall for the length of record was 460 mm. The average for the period of record up 1970 was 457 mm and 466 mm for the period after 1970, an apparent increase of 9 mm/y. The average up to 1980 was 463 mm but after 1980 it had dropped to 447 mm, an apparent decrease of 16 mm/y.

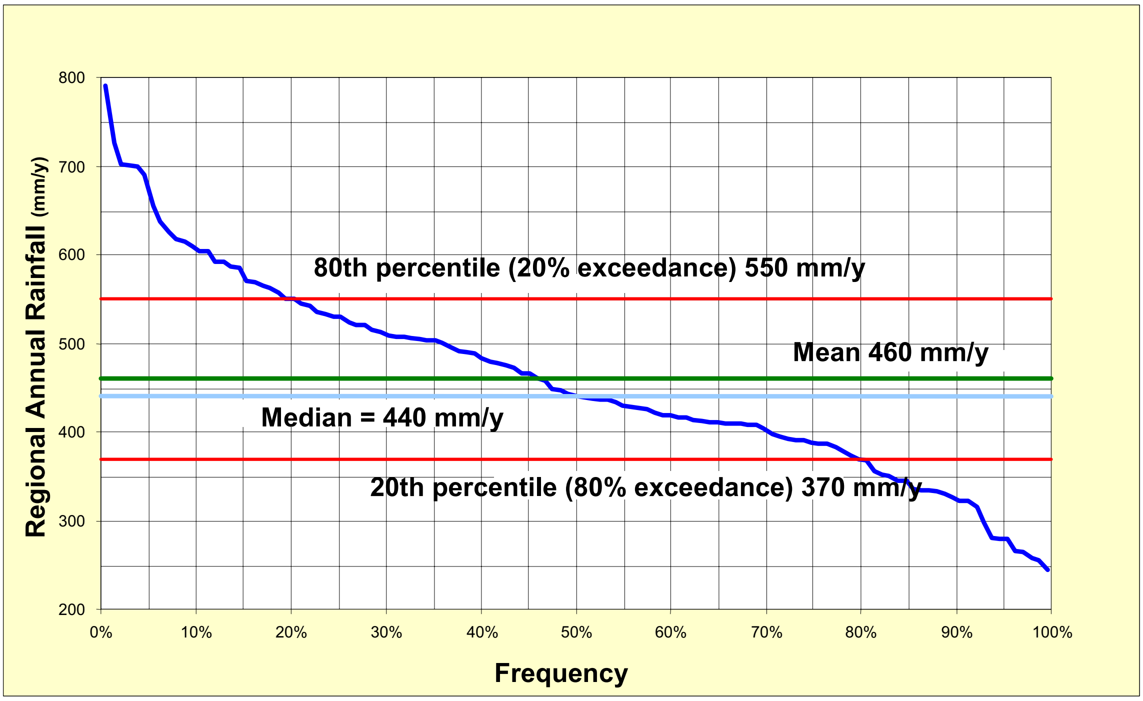


Figure 29 Frequency of regional annual rainfall totals, Rocky River Catchment

To investigate these characteristics of the data further, the periods before and after 1970, 1975 and 1980 were analysed for difference using the non-parametric Kolmogorov-Smirnov (KS) test.

The KS test (Fig. 30) is particularly useful in assessing the difference between two hydrometric time series like rainfall data since it actually compares the difference between two cumulative distributions of the datasets. This removes the effects that may arise from isolated extreme points or outliers, and that means the results are not dependent on how the raw point data are ignored or subdivided for analysis. The difference between the two periods is evaluated by the absolute difference between the two distributions and the significance of the difference is then calculated using a specific test statistic (Press et al. 1992).

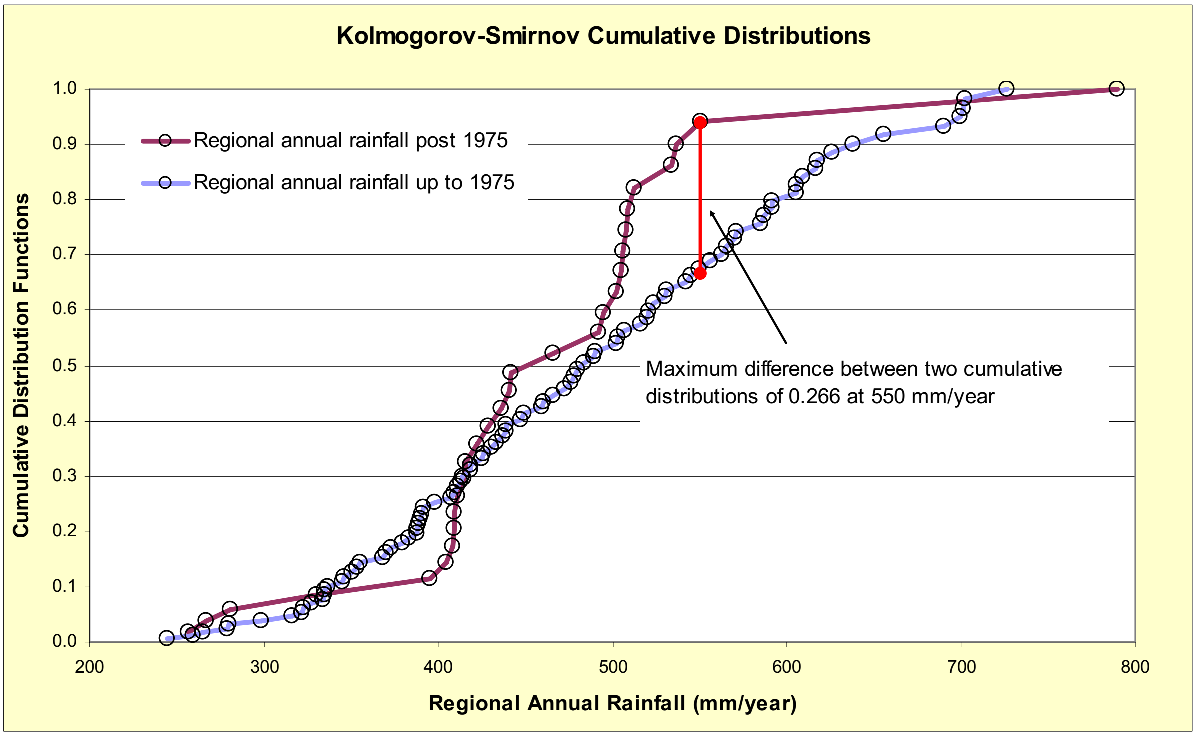


Figure 30 Kolmogorov-Smirnov test results, Rocky River Catchment

The difference between the two regional annual rainfall datasets up to and after 1970 was not significant (significance 59.1%), but the difference was significant for both periods after 1975 and 1980 at the 93% level ($p = 0.07$). Results from 1975 are plotted in Figure 31.

The period of record for the current analysis ceased at 2004. However, the recent drought suggests that conditions have continued to be dry since 2002, which was particularly dry with an average regional rainfall of 370 mm/y.

The reduction in rainfall variability is illustrated well in Figure 31, which shows the rainfall frequency distributions of the periods pre- and post-1975 plotted together (compare with Figure 30 but rotated 90°). The red post-1975 trace shows that years of above average rainfall were drier compared to the earlier record, by up to 100 mm/y, and some of the drier years show a modest increase in rainfall by up to 50 mm/y. With exception of the extreme year 1992, the result is a decrease in total annual rainfall since 1975. The extreme events at the far ends of the post-1975 rainfall distribution appear consistent with the long-term record.

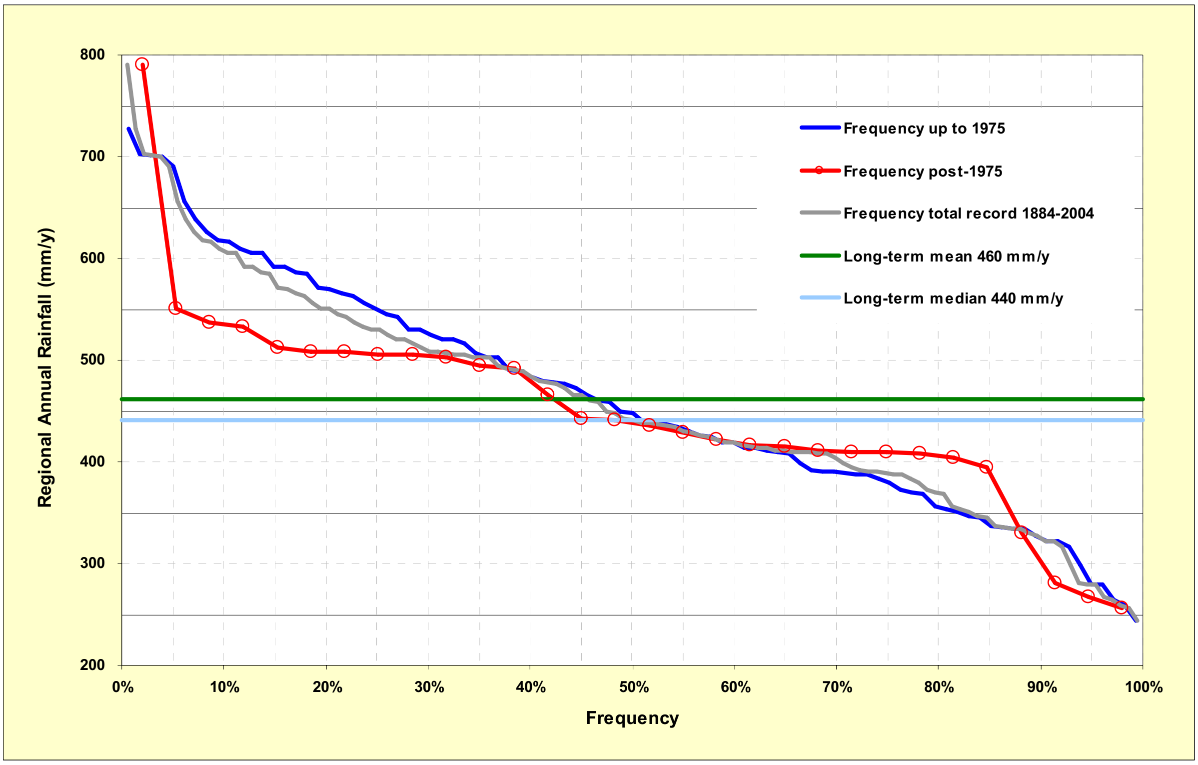


Figure 31 Rocky River regional annual rainfall frequency

The post-1975 trace shows that Rocky River rainfall has made a distinct shift toward the long-term average in recent years, representing a significant decrease in variability. Two commonly used measures of variability were employed to assess this further: the coefficient of variation or the standard deviation divided by the mean, and S80, the difference between the 80th and 20th frequency percentiles divided by the median or 50th percentile*.

Australian hydrometric time series, particularly streamflow and rainfall in arid areas, tend to be heavily influenced by large isolated outliers, a statistical expression of Australia's renowned 'droughts and flooding rains'. That is, a dry area which experiences a couple of very wet years will tend to have a mean annual rainfall higher than its median annual rainfall. This is because the mean is influenced by the magnitude of individual events with lesser regard to their frequency of occurrence, resulting in isolated large events gaining disproportionate influence in the average, whereas the median is also concerned with the frequency of an event's occurrence and its relative position within the data distribution.

The effect of the extreme rainfall in 1992 and the stability of statistics based on percentiles rather than the mean is evident in Table 16. Little change is seen in the coefficient of variation between the periods before and after 1975, suggesting little change in rainfall patterns. However, S80, a measure independent of the mean, shows a marked decrease in variability. If 1992 is removed from the record the coefficient of variation responds strongly toward less variability while S80 remains stable.

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*If all annual rainfall data were arranged from smallest to largest, the 80th percentile rainfall would be the rainfall below which 80% of the data occurred. The 50th percentile corresponds to 50% of the data or half way.

Table 16 Statistics for Rocky River regional annual rainfall, pre- and post-1975.

Statistic	1884–2004	Up to 1975	1975 onwards
Coefficient of variation	24%	25%	22%
S80	0.41	0.48	0.23
Mean	460	463	449
Median	441	448	438
Standard deviation	111	115	101
Skew	0.41	0.31	0.83
1992 removed			
Coefficient of variation	24%		18%
S80	0.41		0.23
Mean	457		438
Median	440		436
Standard deviation	108		79
Skew	0.29		-0.83

Concluding remarks

Regression lines fitted to regional annual rainfall over the last 50 years show decreasing trends. This is due to drier conditions in recent times. Very dry conditions in 2002 were followed by below average rainfall to 2004 and, while the data were not included in this work, the inclusion of year 2005 would be unlikely to improve the assessment.

The period 1975–2004 is significantly drier than the preceding record. Longer term decadal scale rainfall patterns indicate a shift toward lower variability and fewer very wet years. Wetter years that can be expected to occur between half and 5% of the time show decreases in rainfall of up to 100 mm/y, while the drier 15–25% of years show more modest increases in annual rainfall of up to 50 mm/y.

Only one year, 1992, the wettest year on record has exceeded the 80^{th} percentile since 1980, compared to an expected five. The magnitude of this isolated event and the slight increase in rainfall during historically dry years provide the only positive features in an otherwise drying landscape.

These observations have significant implications for the availability of both surface and groundwater resources. Despite an isolated wet year in 1992, recent times have been very dry and continue to be so. It is likely that there has been insufficient water to replenish surface and groundwater stores to historical levels, particularly as it is thought that recharge processes rely on years where rainfall and runoff are well above average (Cresswell 1999).

It is reasonable to suggest that unless a prolonged period of well-above average rainfall is imminent in the Rocky River Catchment, the amount of water in the landscape will remain significantly less than historic levels. The implications for water resources management are that less water will be available to all users at sustainable levels.

C. DISAGGREGATION AND INFILLING OF RAINFALL RECORDS — METHODOLOGY

Rainfall data are collected at 0900 on a daily basis in the BoM stations. Rainfall collected during weekends and public holidays is recorded at 0900 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 (2000) throughout South Australia up until the end of 1998 for disaggregation of rainfall data is based on the method outlined by Porter and Ladson (1993). The same methods were applied in this study to disaggregate and infill daily data collected since that time.

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

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

where $\sum_{j=1}^{m} \mathrm{P}_{jS}$ 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 which fell on day **j** at **k** station over the total rainfall accumulated over **m** days at the same **k** station. That is,

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

An automated procedure has been developed to redistribute the accumulated data. The procedure limits the search to only 15 rainfall stations closest to the station of interest. Where no record could be found from these stations, redistribution was undertaken using a manual approach based on between the station of interest and the most correlated infilling station available. As a final resort where no reference station can be found, redistribution was carried out evenly over the period of accumulation.

For infilling 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 infilling the records using the long-term relative proportional relationship between the means as a correction factor.

D. RAINFALL RECORD HOMOGENEITY

Changes in instrument exposure at a measurement site often leads to differences between the actual rainfall and the recorded rainfall at that site. Comparison of long-term rainfall records from this site with the regional rainfall average assists in detection of this discrepancy and hence the non-homogenous nature of the data being considered.

A monthly double mass curve analysis was used to check the homogeneity of the rainfall records of each station analysed against a regional average. For a homogeneous dataset this should be a straight line. Sections of the line indicating alterations of slope greater than 5% are considered non-homogeneous and require adjustment of the raw data.

Homogeneity checks were performed for the long-term rainfall records of the following stations, which were all examined for potential use in modelling:

019011 Doughboy Creek	019052 Wirrabara	019053 Wirrabara Forest
021021 Gladstone	021016 Crystal Brook	019006 Booleroo Centre
019001 Appila	019062 Yongala	021013 Caltowie
021031 Laura	021027 Jamestown	019005 Orroroo

For each of these stations, a monthly double mass curve was plotted against the average of all other stations was constructed and an example of these is shown below (Fig. 32).

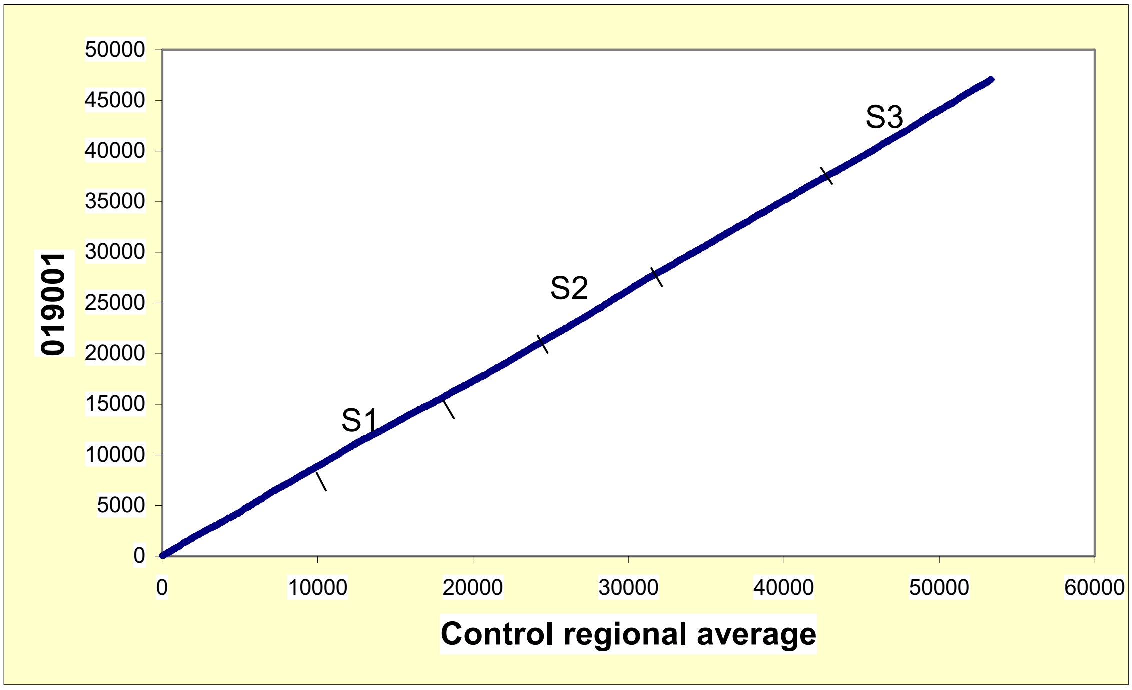

Figure 32 Monthly double mass curve for 019001 versus regional average

The double mass curve was plotted between the monthly rainfall at Station 019001 and the average monthly rainfall of 11 stations listed above. Slope changes were observed in the plot leading to three sections (S1, S2, S3) with varying slopes being identified. The details of these sections are listed in Table 17.

A change in slope of 5% or more is generally considered to be a non-homogenous data set. Sections that are non-homogenous are then adjusted by using the average slope of the sections on either side of the curve. In this case, all sections were considered to be non-homogenous (as the change in slope was >5%) and hence these were adjusted by the correction factors shown in Table 17.

Table 17 Slopes, % variation and correction factors, BoM Station 019001

Section	Duration	Slope	% Variation in slope	Correction factor
S1	10/1912 – 9/1931	0.710	9.43	1.094
S2	9/1948 – 9/1955	0.830	-5.96	0.940
S3	2/1992 – 12/2005	0.829	-5.9	0.941
Total slope	–	0.774	–	–

E. SURFACE WATER MODELLING

Model Construction: is the process of formulation of a series of mathematical equations that represent the relationships between the various processes involved in the hydrological cycle, rainfall, interception storage, evaporation, transpiration, infiltration, percolation, baseflow, etc.

Model Calibration: is an iterative process of solving the abovementioned set of mathematical equations. Some of the main steps involved in this process are:

- Input data to the model — one or more measured sets of hydrological parameters (e.g. daily rainfall data set).
- Iteratively vary the other unobserved hydrological and catchment characteristics parameter sets (e.g. pan factor for soil, interception storage, ground water discharge, etc.) to mathematically simulate one or more hydrological parameters that have been measured (e.g. simulation of catchment runoff).
- Compare the simulated values to the measured values and continue the iteration process until a ‘good correlation’ is obtained between the simulated and measured values.
- Use the set of parameters providing this ‘good correlation’ for modelling further 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.

Modelling Scenarios: is the process of running the calibrated model with measured long-term hydrological parameter data set(s) to obtain long-term estimates of the other hydrological parameter set(s) that were not measured (e.g. to generate long-term runoff from 100 years of measured rainfall data). This provides an historical insight of the hydrological condition of the catchment and also the probable impacts on the catchment hydrology of the various changes (natural and human-influenced) that had occurred in the past. Furthermore, this can be used as a good tool for prediction of impacts on catchment hydrology of possible future developments and changes.

This study utilised long-term daily rainfall data to simulate long-term runoff data for the Rocky River Catchment. A model was successfully developed but the usefulness of a model in running catchment-change scenarios depends on successfully calibrating the model against an observed streamflow record from a well-rated gauging station. This is essential to provide a high degree of certainty that the model is capable of simulating current conditions, which in turn provides confidence in the modelled scenarios. It was in the calibration of the model against streamflow data that the model development was limited in this study. As the data record improves it will be possible to calibrate the model to observed conditions allowing for different scenarios to be investigated quantitatively. Details of the development process and results are presented in the following section.

Methodology

WaterCress (Cresswell 2000, 2002), a computer-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 to convert rainfall into runoff, namely AWBM, SFB, HYDROLOG, and WC-1. WC-1 is a water-balance model that has been used to construct and calibrate models for various catchments in South Australia and hence was selected for use in this study. WaterCress allows the incorporation of different components in its water balance models:

1. Demand components, which include town and rural demands.
2. Catchment components, which include rural and urban catchments.
3. Storage components, which include reservoir, tank and off-stream dam.
4. Treatment components, which include sewage treatment works and wetlands.
5. Transfer components, which include weir and routing component.

Both the demand and catchment components are where runoff generation is modelled.

Model Construction

Construction requires the subdivision of the catchment into smaller areas thought to be representative of relatively similar hydrological characteristics (e.g. rainfall, topography, land use, etc). This allows the spatial variation in the response of a catchment to rainfall in terms of the runoff it produces to be more accurately represented.

A key aspect of the preparation and construction of the model is the processing of input rainfall data and spatial rainfall analysis of the catchment. The disaggregation, infilling and homogeneity checking and correction of the daily rainfall data used in this study is discussed in Section 7 and the relevant appendices. Briefly, 18 stations in the region were assessed for data quality, of which eight were considered suitable for full data analysis.

Of these stations, three were selected for use in modelling based on the data quality and suitability for providing a complete coverage of the spatial distribution of rainfall observed within the catchment.

The average rainfall within each sub-catchment was determined using isohyet coverages. The relative area under each isohyet within each sub-catchment was summed and divided by the total sub-catchment area to derive an average rainfall for that sub-catchment. Each sub-catchment within the study area was assigned to the rainfall record considered most indicative of the likely precipitation pattern.

Having assigned a rainfall record and calculated the sub-catchment average rainfall, the ratio of this value and the long-term mean from the rainfall station concerned was used as an adjustment factor for daily rainfall. The rainfall station and adjustment factor for each sub-catchment is shown in Appendix E.

The model itself is constructed as a series of ‘nodes’, each being one of the components mentioned above, and representing the behaviour of one aspect of the relevant sub-catchment. The nodes are then linked based on the drainage direction to form one catchment.

For the Rocky River Catchment, the model was set up as a series of rural catchment nodes and off-stream dam nodes. Each rural catchment node in the model represents a sub-catchment (refer to Fig. 3 for sub-catchment boundaries).

Each off-stream dam node in the model represents the accumulation of dams or diversions within that subdivision. The drainage paths link each rural catchment node to the corresponding dam node, which in turn is linked to the next downstream rural catchment node until each sub-catchment is represented, as displayed in Figure 16.

The input data for each rural catchment node were:

- Area of the subdivision.
- Corresponding measured daily rainfall and monthly evaporation data files.
- Runoff model (WC-1 in this case), which also requires the initial estimated values for the catchment parameter set for that particular model type (for WC-1 these are: median soil moisture content; interception storage; catchment distribution; groundwater discharge; soil moisture discharge; pan factor; fraction groundwater loss; storage reduction coefficient; groundwater loss and creek loss).

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

- Dam storage volume, which in this case was the cumulative storage capacity of all the dams in the subdivision.
- Corresponding measured daily rainfall and monthly evaporation data files.
- 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 was an 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 dam was located further upstream or when the dams were off-stream (see App. F).

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.

F. TANH FUNCTION

The Tanh function (Grayson et al. 1996) is a standard hyperbolic function and was used by Boughton (1966) as a simple rainfall-runoff relationship.

Calculation

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

where

Q runoff (mm)

P rainfall (mm)

L notional loss (mm)

F 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.

G. MODEL PARAMETERS — SUB-CATCHMENTS

Sub-catchment	Area (km^2)	Dam capacity (ML)	Dam surface area (m^2)	Divert fraction (% of catchment)	Dam density (ML/km^2)	BoM station	Sub-catch Ave RF	Rainfall factor
Anglevale	19.17	33.583	22 524.19	37	1.75	021031	400.0	0.870
Appila Creek	167.57	296.825	195 189.34	36	1.77	019001	375.4	0.963
Bauer Creek	76.61	193.488	128 776.93	42	2.53	019001	380.0	0.974
Emu Spring	41.93	129.494	82 791.73	43	3.09	019053	545.0	0.801
Fairview	30.21	100.738	65 077.86	56	3.33	021031	440.0	0.957
Huddleston	12.09	0	0.00	00	0.00	021031	425.0	0.924
Ippinitchie Creek	66.42	100.863	63 782.64	21	1.52	019053	592.4	0.871
Lower Rocky River	22.15	1.664	1 395.98	00	0.08	021031	433.0	0.941
Mid Rocky River	61.35	14.706	9 845.45	02	0.24	021031	438.0	0.952
Mt Herbert	23.48	19.381	12 785.07	09	0.83	021031	441.5	0.960
Mt Mick	26.01	72.67	47 895.62	85	2.79	019053	440.0	0.647
Pine Creek	102.60	142.492	94 848.3199	17	1.39	019001	439.4	1.127
Pisant Creek	42.40	38.277	26 465.6017	16	0.90	021031	435.3	0.946
Rocky River Creek	155.07	294.017	189 592.9209	36	1.90	019001	396.2	1.016
Stone Hut	22.18	41.638	28 818.4501	27	1.88	019053	489.1	0.719
Upper Rocky River	67.53	243.633	158 745.9149	49	3.61	019053	493.4	0.726
White Cliff Hill	21.25	29.023	18 577.3225	24	1.37	021031	457.0	0.993
White Cliff Range	29.88	139.361	77 054.0587	40	4.66	021031	486.0	1.057
Wirrabara	39.80	134.449	88 816.5318	43	3.38	019053	482.0	0.709
Yangya Creek	92.28	308.929	178 291.1733	37	3.35	021031	434.0	0.943
Yarrowie Creek	104.01	198.228	127 455.5469	32	1.91	019001	416.1	1.067

UNITS OF MEASUREMENT

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

Name of unit	Symbol	Definition in terms of other metric units	Quantity
day	d	24 h	time interval
gigalitre	GL	10^6 m^3	volume
gram	g	10^{-3} kg	mass
hectare	ha	10^4 m^2	area
hour	h	60 min	time interval
kilogram	kg	base unit	mass
kilolitre	kL	1 m^3	volume
kilometre	km	10^3 m	length
litre	L	10^{-3} m^3	volume
megalitre	ML	10^3 m^3	volume
metre	m	base unit	length
microgram	µg	10^{-6} g	mass
microlitre	µL	10^{-9} m^3	volume
milligram	mg	10^{-3} g	mass
millilitre	mL	10^{-6} m^3	volume
millimetre	mm	10^{-3} m	length
minute	min	60 s	time interval
second	s	base unit	time interval
tonne	t	1000 kg	mass
year	y	365 or 366 days	time interval

GLOSSARY

Adaptive management — A management approach, often used in natural resource management, where there is little information and/or a lot of complexity and there is a need to implement some management changes sooner rather than later. The approach is to use the best available information for the first actions, implement the changes, monitor the outcomes, investigate the assumptions and regularly evaluate and review the actions required. Consideration must be given to the temporal and spatial scale of monitoring and the evaluation processes appropriate to the ecosystem being managed.

Ambient — The background level of an environmental parameter (e.g. a background water quality such as salinity).

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

Aquifer test — A hydrological test performed on a well, aimed to increase the understanding of the aquifer properties, including any interference between wells, and to more accurately estimate the sustainable use of the water resource available for development from the well.

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

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

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

Biota — All of the organisms at a particular locality.

Bore — *See well.*

Buffer zone — A neutral area that separates and minimises interactions between zones whose management objectives are significantly different or in conflict (e.g. a vegetated riparian zone can act as a buffer to protect the water quality and streams from adjacent land uses).

^{14}C — Carbon-14 isotope; (percent modern Carbon; pmC).

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

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

CFC — Chlorofluorocarbon; parts per trillion volume *(*pptv)

Cone of depression — An inverted cone-shaped space within an aquifer caused by a rate of groundwater extraction that exceeds the rate of recharge. Continuing extraction of water can extend the area and may affect the viability of adjacent wells due to declining water levels or water quality.

Conjunctive use — The utilisation of more than one source of water to satisfy a single demand.

CVWAP — Clare Valley Water Allocation Plan.

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

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

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

δD — Hydrogen isotope composition ($^{o}/_{oo}$).

$\delta^{18}O$ — Oxygen isotope composition ($^{o}/_{oo}$).

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

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

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

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

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

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

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

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

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

EPA — Environment Protection Agency.

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

Eutrophication — Degradation of water quality due to enrichment by nutrients (primarily nitrogen and phosphorus), causing excessive plant growth and decay. *(See algal bloom).*

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

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

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

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

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

GL — *See gigalitre.*

Groundwater — *See underground water.*

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

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

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

Hydrometric — Literally relating to *water measurement*, from the Greek words *hydro* (water) and *metrikos* (measurement). See also DWLBC fact sheet FS1 <http://www.dwlbc.sa.gov.au/assets/files/fs0001_hydrometric_surface_water_monitoring.pdf>.

Hyporheic zone — The wetted zone among sediments below and alongside rivers. It is a refuge for some aquatic fauna.

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

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

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

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

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

ML — *See megalitre.*

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

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

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

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

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

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

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

ppm — Parts per million.

ppb — Parts per billion.

Precautionary principle — Where there are threats of serious or irreversible environmental damage, lack of full scientific certainty should not be used as a reason for postponing measures to prevent environmental degradation.

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

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

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

PWA — Prescribed Wells Area.

PWRA — Prescribed Water Resources Area.

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

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

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

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

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

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

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

Taxa — General term for a group identified by taxonomy — which is the science of describing, naming and classifying organisms.

Time series data — Any series of data collected over a sequence of time. Hydrometric data is typically time series, being collected over a sequence of minutes, days, months or years.

TDS —Total Dissolved Solids; milligrams per litre (mg/L).

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

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

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

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

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

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

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

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

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

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

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

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