DWLBC REPORT

Ecological Condition Assessment: Streams of the Mambray Coast

2005/36

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

Ecological Condition Assessment: Streams of the Mambray Coast

David Deane, Laura Phipps and Paul Magarey

Knowledge and Information
Department of Water, Land and Biodiversity Conservation

October 2005

Report DWLBC 2005/36

Australian Government

Government of South Australia
Northern and Yorke Natural Resources Management Board

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

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

Disclaimer

The Department of Water, Land and Biodiversity Conservation and its employees do not warrant or make any representation regarding the use, or results of the use, of the information contained herein as regards to its correctness, accuracy, reliability, currency or otherwise. The Department of Water, Land and Biodiversity Conservation and its employees expressly disclaims all liability or responsibility to any person using the information or advice. Information contained in this document is correct at the time of writing.

ISBN 0-9758235-5-8

Preferred way to cite this publication

Deane, D, Phipps, L & Magarey, PD 2005, *Ecological condition assessment: Streams of the Mambray Coast*, Report DWLBC 2005/36, 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

Thanks are conveyed to members of the community who provided a wealth of much needed information. Particular thanks are also extended to Simon Westergaard, from Native Fish SA, for assistance in fish sampling.

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

Northern and Yorke Natural Resource Management Board

Michael Head, Trudie Stanley, Anita Crisp, Kerry Ward, Phyllis Robinson, Lindy Pearson, David Sloper, Saideh Kent.

Landholders and Community Members

Graham and Iris Herde, Gordon Leue, Kevin Pole, Neville Davis, Peter Dennis, Harvie and Joan Spencer, Cyril and Nancy Mudge, Darcy Evans (Nukunu representative).

Native Fish SA

Simon Westergaard (fish sampling), Mike Hammer.

State Agencies

Stuart Beinke (National Parks, DEH); Kym Hoffrichter, Jeff Robinson, Monique Blason (SA Water); Paul McEvoy, Sally Maxwell (Australian Water Quality Centre — macro-invertebrate analysis, App. E); Peter Goonan and Tracy Corbin (EPA); Sharon Connor, Carice Holland and Ann Young (PIRSA Publishing Services — Geological mapping, Figs 2, 3); Bruce Murdoch, David Cresswell, Mark Walter, Scott Evans, Anne Walters and Glen Scholz (DWLBC).

Photography: Unless noted otherwise, all photographs within this report were taken by the authors during field surveys in February, June and September 2005.

This work was funded by the National Action Plan for Salinity and Water Quality.

CONTENTS

FOREWORD .... **iii**

ACKNOWLEDGEMENTS .... **v**

EXECUTIVE SUMMARY **1**

1. INTRODUCTION **5**

2. AIM **7**

3. METHODOLOGY **9**

3.1 CONSULTATION PHASE 9
3.2 FIELD SURVEYS 9
3.2.1 Survey methods 9
3.3 DESKTOP ANALYSIS 10
3.3.1 Literature review 10
3.3.2 Spatial analysis 10
3.3.3 Hydrology 10

4. RESULTS **13**

4.1 CATCHMENT DESCRIPTION 13
4.1.1 History 15
4.1.2 Historical water resource development 15
4.2 LAND USE 16
4.2.1 Land-use classification 16
4.2.2 National parks and reserves system 17
4.3 GEOLOGY 18
4.4 GEOMORPHOLOGY 21
4.4.1 Sediment transport processes 21
4.4.2 Impacts on stream geomorphology 22
4.5 CATCHMENT HYDROLOGY 23
4.5.1 Surface water hydrology 23
4.5.2 Surface water development 36
4.5.3 Groundwater hydrology 38
4.5.4 Groundwater development 39
4.6 AQUATIC ECOSYSTEMS 41
4.6.1 Location of permanent aquatic habitat 41
4.6.2 Biological components 43

5. DISCUSSION **51**
5.1 ECOLOGICAL CHARACTER 51
5.1.1 Flow-related ecology 52
5.1.2 The importance and significance of groundwater 54
5.1.3 Biotic and abiotic structuring factors 55
5.2 SUMMARY OF ECOLOGICAL DRIVERS 59
5.3 THREATS TO ECOLOGICAL INTEGRITY 60
5.3.1 Loss of aquatic habitat 60
5.3.2 Reduced habitat amenity 61
5.3.3 Biological pressures 62
5.3.4 Lack of monitoring and research effort 62
6. CONCLUSIONS **63**
APPENDICES **67**
A. DETAILED FIELD FINDINGS 67
B. MACRO-INVERTEBRATE REPORT 92
UNITS OF MEASUREMENT **97**
GLOSSARY **99**
REFERENCES **103**

LIST OF FIGURES

Figure 1. Mambray Coast location 14
Figure 2. Geology plan, Mambray Coast region 20
Figure 3. Geological cross-section, Mount Remarkable National Park 21
Figure 4. Surface drainage features and major catchments of the Mambray Coast 24
Figure 5. Latitudinal influence on rainfall, Mambray Coast 27
Figure 6. Topographical variations in annual rainfall: central Mambray Coast 27
Figure 7. Quorn Olive Grove BoM Station 019030 annual rainfall 28
Figure 8. Rainfall isohyets, Mambray Coast 29
Figure 9. Monthly rainfall at BoM Station 019030 (Quorn Olive Grove) 30
Figure 10. Monthly rainfall residual mass for BoM Station 019030 (Quorn) — months showing decreasing trend 31
Figure 11. Monthly rainfall residual mass for BoM Station 019030 (Quorn) — months showing increasing trend 31
Figure 12. Modelled mean monthly rainfall and evaporation — central ranges of the Mambray Coast 32
Figure 13. Modelled monthly effective rainfall, 1970–2004, central ranges of the Mambray Coast 33
Figure 14. Regional decadal rainfall and 10-year moving average, Mambray Coast 34
Figure 15. Seasonality and duration of flow events 1979–91, Saltia Creek gauging station 36
Figure 16. Groundwater development, Mambray Coast 40
Figure 17. Location of permanent pool habitat, Mambray Coast 42
Figure 18. Relative abundance of animals in total sample by order grouping (or above) 46
Figure 19. Relative abundance of total sample by family grouping (or above) 47
Figure 20. Small pool within Telowie Gorge 67
Figure 21. Small step weir in Port Germein Gorge 71
Figure 22. Baroota Reservoir looking north towards Baroota Creek Catchment 72
Figure 23. Waterfall Creek pool showing good habitat — reed bed, overhanging sedges, boulders and woody debris 74
Figure 24. Permanent pool on Waterfall Creek looking upstream — ungrazed site 75
Figure 25. Waterfall Creek looking downstream — grazed reach 75
Figure 26. Gluepot Spring, upper Baroota Creek Catchment 78
Figure 27. Baroota Creek on Tony Said's property 79
Figure 28. Baroota Creek on Tony Said's property 79
Figure 29. Mambray Creek spring-fed pool, looking upstream 83
Figure 30. Alligator Creek pool 84
Figure 31. Nectar Brook survey site looking downstream 88
Figure 32. Nectar Brook survey site 89
Figure 33. Upstream of permanent pool, Nectar Brook, looking upstream 89

LIST OF TABLES

Table 1. Sites selected for on-ground surveys. 9
Table 2. Land use by summary category. 17
Table 3. Major catchment areas of the Mambray Coast. 23
Table 4. Summary data from field surveys, Mambray Coast. 44
Table 5. SA Museum waterbird records from the Mambray Coast. 48
Table 6. Ecological drivers and their influence on catchment ecology. 59

EXECUTIVE SUMMARY

This report provides a preliminary assessment of the condition of aquatic ecosystems associated with the small streams of the Mambray Coast, located in the Mid-North of South Australia. The study was undertaken by the Department of Water, Land and Biodiversity Conservation (DWLBC) for the Northern and Yorke Natural Resource Management Board (NYNRMB). The purposes of the study were to:

- map the location of permanent aquatic habitat in the catchment which represents a significant ecological asset within ephemeral stream ecosystems
- describe the ecological character and condition of the streams
- determine any threats to the ecological integrity of these systems, particularly those due to extraction of water for human use.

This project employed a combination of literature reviews, community consultations and desktop methods to investigate the hydrology and levels of water resources development. Due to their ecological significance, sites of permanent surface water were a focus of investigations. Once the locations of these were identified and mapped, representative sites were selected and field surveys, including a qualitative ecological and threat assessment, were undertaken. This report summarises the findings of the project and includes a conceptual framework for interpreting the observed condition in terms of flow-related ecology.

Around 1350 km^2 in total area, the Mambray Coast is centred 250 km north of Adelaide and comprises a number of small, unconnected catchments, rather than a single drainage system. These catchments all rise in the southern Flinders Ranges and drain to the west, terminating in eastern Spencer Gulf between Port Pirie and Port Augusta. Major land uses in the region are broadacre cropping and/or grazing, conservation reserves and irrigated horticulture.

The climate of the region is broadly Mediterranean, consisting of hot, dry summers and cool to mild winters. Winter–spring rainfall dominates with average annual rainfall decreasing with distance to the north. Elevation is more influential on rainfall however, and in the central eastern Mambray Coast where the highest relief is found average annual rainfall can exceed 650 mm. The majority of the region is semi-arid and regional average annual rainfall is of the order of 400 mm.

Individual catchments have only small areas within the high rainfall zones, and Baroota Creek is the largest at 138 km^2. The combination of the small catchment areas and semi-arid climate results in ephemeral plains watercourses that flow only following significant rainfall in the ranges. A zone of faulting and jointing occurs where the ranges meet the plains and this, in combination with extensive gravel beds near to the foothills, leads to high stream losses with downwelling water recharging the watertable aquifer. As a result of these factors, plains watercourses are poorly defined, and only the largest events are capable of reaching the coast, with the last such occurrence being in 1992.

Streams in the ranges are also largely ephemeral and many flow only in response to rain, but in some of the larger catchments groundwater spring discharges support permanent surface water habitat. The extent of wetted habitat depends on the season. In summer when evaporation is highest, springs maintain only shallow isolated pools. During late autumn through until early spring, as evapotranspiration rates decrease, resulting increases in discharge generate baseflows that can extend for several kilometres along watercourses. In addition to greatly increasing the extent and diversity of wetted habitat, these flows also connect refugia pools isolated during summer.

The reliance on groundwater springs to maintain the surface water habitat define these intermittent stream reaches as groundwater-dependent ecosystems. Refugia were present in the catchments of Nectar Brook, Mambray Creek, Baroota Creek, Port Germein Creek and Telowie Creek. The most extensive permanent habitat was associated with the Baroota Creek Catchment, and in all catchments except Telowie Creek the seasonal baseflows were observed.

Field surveys suggest that only moderate biodiversity values are currently represented within refugia pools. The aquatic community comprised robust species tolerant of moderate salinity and exhibiting generalist feeding and habitat preferences. Only limited predatory species were present, and the majority of macro-invertebrates were grazers of periphyton or detritivores. Historical records indicate that no native fish populations have ever been located within the permanent pools of the ranges, and this was supported during field surveys for this project. Only one fish species was present, the introduced pest *Gambusia*. This was only found in Baroota Creek Catchment where it appears to have an influence on the macro-invertebrate community through selective predation. This species has the potential to also be impacting on some anuran (frog and toad) species.

Due to the nature of this study, the full range of variability present in the system cannot be determined. The current condition is thought to be representative of these stream ecosystems only during periods of climatic drought. To place this in context, it is necessary to consider the likely influence of the two very different flow signals to which stream ecosystems are subjected. Having varying frequencies, durations, chemical compositions and ranges in volume, these can be expected to exert different influences on the structure of the aquatic community accordingly:

- Groundwater springs from fractured rock aquifers in the ranges provide permanent water, but the extent of this habitat follows seasonal cycles. Streams contract to small refugia pools over summer but during periods of baseflow provide seasonally predictable and reliable flows of modest volume and moderate quality.
- Surface water runoff generates surface flows of low salinity that are not as predictable or reliable as groundwater discharges. These can occur during any season, although they are more common and likely to be of greater duration when they occur during winter or spring.

In addition to the chemical differences between surface water runoff and groundwater discharges, the flow patterns themselves will exert different pressures. Being seasonally predictable, but of only moderate quality and quantity, groundwater discharges likely dictate the baseline aquatic biodiversity that can be supported within the catchment. The condition and biological composition of the pools surveyed for this study are thought to be representative of a community where this flow pattern dominates.

With relative volumes driven by variations in climate, surface flows may affect the levels of biodiversity present in streams by providing conditions that can support less-tolerant animals. During extended wet climatic periods, increased rates of groundwater discharge and higher surface runoff volumes will provide a greater number of refugia pools of lower salinity. This should allow more sensitive organisms to become a regular component of the aquatic community. The longer such conditions continue, the more likely that sensitive animals could be expected to re-populate the catchment. Aquatic biodiversity could therefore be expected to increase as the period of wet climatic conditions persist. Assessment of these patterns is hampered by the lack of long-term data, which can only be addressed by implementation of appropriate monitoring and research.

Community consultations indicate that pools and springs formerly considered permanent have been drying for the first time since European settlement. Given that only limited water resource development exists in the ranges, this is considered to be due to climatic patterns. Rainfall analyses suggest that the observed drying may be due to a combination of factors that together produce low rates of groundwater recharge and surface runoff.

Although clearance of riparian understorey, stock access to watercourses and introduced species all clearly impact on ecological condition, the major risk to the permanent aquatic ecosystems of the region is considered to be climatic. The main management challenge for the future is likely to be protecting permanent refugia pools and the supporting groundwater resources from development pressure.

The current understanding of biological structure and function of permanent pools through seasonal cycles is conceptually reasonably well developed. Despite this, biological sampling approaches such as the AUSRIVAS macro-invertebrate model are currently not sensitive enough to reliably detect trends in ecosystem condition. To improve existing models to enable this will require significant and long-term investment in scientific programs. A targeted long-term monitoring program, linked to sites where flow volumes and salinity are continually recorded and initially including a detailed aquatic biodiversity assessment, would be a good first step in improving knowledge throughout the region in this regard.

Regional NRM authorities would arguably collect more useful information in the short to medium term by concentrating on surrogate measures of ecosystem condition. This approach could focus on some more easily measured and interpreted drivers of ecosystem condition such as water quality parameters, the proportion of watercourses excluded from stock access, and the structure and condition of riparian vegetation, including river red gum populations which is an iconic species within the community.

1. INTRODUCTION

The Mambray Coast surface water catchment (Fig. 1) incorporates the catchments of numerous small streams draining the western slopes of the southern Flinders Ranges in the Mid-North of South Australia. As it comprises a collection of hydrologically isolated catchments the term 'Mambray Coast' is adopted when referring to the catchment as a whole in order to distinguish between this and the individual catchments.

The stream channels extend to varying degrees onto a narrow coastal plain between Port Pirie and Port Augusta, ultimately draining to upper Spencer Gulf. Although the streams are ephemeral and rarely reach the gulf, a number of waterholes and springs of varying permanence occur within the ranges.

Permanent surface water is an ecological and commercial asset in the dry South Australian landscape. Sites where permanent water is known to exist have been highly significant for human activity in the region, both pre- and post-European settlement. They also provide resources, habitat and drought refuges for native and introduced flora and fauna. Ensuring that such assets are able to co-exist with human activities is the responsibility of natural resource managers at all levels, from the individual through to all levels of government.

This work was motivated by a lack of documented knowledge as to the location, condition and threats to these ecosystems within the focus region. It forms part of a region-wide project initiated by NYNRMB. The aims are to develop an understanding of where these systems are, how they function and what their current condition is, particularly with regard to their environmental water requirements.

2. AIM

To provide information for resource managers and the community on aquatic ecological assets associated with small streams of the Mambray Coast. In particular, specific aims were to:

- locate and map the sites where permanent surface water occurs in the catchment
- collate information through community consultations, field surveys and reviews of relevant literature on the functioning of these ecosystems and describe their broad ecological character and condition
- determine any threats to the integrity of these ecosystems, particularly with regard to whether their environmental water requirements are being met.

3. METHODOLOGY

The work for this assessment was undertaken in three phases — consultations, field surveys, and desktop analyses.

3.1 CONSULTATION PHASE

Members of the NYNRMB Water Implementation Group and contracted NRM officers plus representatives from other state agencies were contacted to provide a list of references, landholders and community members who may have information to contribute to the project. Those members of the community identified were invited to contribute information either by telephone interview or through completion of a survey form.

A public meeting was held at Port Germein to launch the project and enable two-way information to flow between the local community and project staff. The meeting was well attended and provided an opportunity for further important contacts to be identified.

3.2 FIELD SURVEYS

Identified sites of ecological significance were visited on at least one occasion and site locations were recorded using a hand-held Global Positioning System (GPS) unit. Sites were assessed during late Autumn 2005 using standard field survey techniques including stream cross-sections, physical and chemical water quality parameters, and flora and fauna surveys (including pest and weed species). Sites for on-ground surveys are provided in Figure 17 and listed in Table 1.

Table 1. Sites selected for on-ground surveys.

Catchment name	Site No.	Description
Nectar Brook	1	Upstream of Nectar Brook homestead
Mambray Creek	2	Upstream of Mambray Creek camping ground
Baroota Creek	3	Waterfall Creek in Nukuna Land
	4	Baroota Reservoir and d/s of reservoir
Telowie Gorge	5	Telowie Gorge permanent pool

3.2.1 SURVEY METHODS

Broad on-ground surveys were conducted for each selected site with the aim of describing the components of important aquatic habitat and refuge areas, including:

- date and time of survey
- site photographs
- GPS coordinates
- physical features (i.e. the physical environment in which the site exists)
- hydrological features.

- geomorphology
- habitat types
- stream cover
- vegetation cover
- land use
- water quality (salinity, temperature, pH, transparency)
- fish sampling
- waterbird surveys.

In addition, macro-invertebrate samples were obtained at two sites for analysis using the AUSRIVAS model. Waterbird surveys were conducted using the Birds Australia '2-hectare Search' Atlassing methodology where a 100 x 200 m area is searched for 20 minutes (see http://www.birdsaustralia.com.au/atlas/).

3.3 DESKTOP ANALYSIS

This phase involved a review of literature, spatial analysis and reporting.

3.3.1 LITERATURE REVIEW

Literature and records reviewed included: South Australian Museum records; the South Australian Aquatic Biota database; State Environmental Database of South Australia (maintained by Department for Environment and Heritage); relevant hydrological and hydrogeological reports; historical documents; peer-reviewed ecological literature, biological surveys and various other documents.

All documents and databases were reviewed for information relating to the function, historical or current condition and potential threatening processes for the stream ecosystems identified.

3.3.2 SPATIAL ANALYSIS

Mapping of ecological assets and broad geomorphic zonation of streams were undertaken using information acquired during field surveys and using existing GIS information such as stream coverages and contours, and analysis of 1:80 000 colour aerial photography captured in 2002.

Surface water catchments of major streams were delineated using GIS ArcMAP and manual inspection of contours.

3.3.3 HYDROLOGY

Rainfall data were acquired from the Australian Bureau of Meteorology (BoM) in two forms — actual daily recorded data for individual meteorological stations, and spatially interpolated daily rainfall data from the SILO website (http://www.nrm.qld.gov.au/silo/datadrill). The latter dataset is available for locations based on a grid of three minute increments in latitude and longitude throughout Australia, and was used for analyses of spatial variations in rainfall patterns. Discussions on how the data were processed appear in the relevant sections of the text. For further information on the method used to interpolate the SILO data visit the BoM weblink listed above.

Limited water level data from the former departmental surface water gauging station on Saltia Creek (AW5080503) were analysed for seasonal patterns. Unfortunately the station was only operational during 1979–91 and was never rated. This analysis is therefore limited to flow seasonality and duration.

4. RESULTS

4.1 CATCHMENT DESCRIPTION

The Mambray Coast (Fig. 1) is centred around 250 km north of Adelaide. The catchment area of ~1350 km^2 includes the townships of Warnertown, Napperby, Nelshaby, Port Germein, Port Pirie and Port Augusta.

The eastern boundary of the Mambray Coast is formed by the southern Flinders Ranges, and these slopes dominate the topography. The coastal plains of eastern Spencer Gulf form the other main landscape feature. These are generally narrow, varying in width from only 1–2 km just south of Nectar Brook, to over 15 km near to Port Augusta. The slope of the plain is around 1–2% for most of the region, but roughly twice this at the narrowest point.

Major tributaries of the Mambray Coast are Napperby Creek, Nelshaby Creek, Little Broad Creek, Big Broad Creek, Telowie Creek, Red Creek, Nectar Brook, Cudnia Creek, Winninowie Creek, Tattiwa Creek, Horrocks Creek, Spear Creek, Blackfellows Creek, Woolundunga Creek, Catninga Creek and Saltia Creek (Fig. 4).

The area contains several tidal estuaries and salt marsh flats south of Port Augusta in Port Paterson, Chinaman Creek, Mambray Creek, Yalata Harbor, Port Pirie Creek (Napperby Creek), Magazine Creek, Shag Creek, Red Creek, Baroota Creek and Telowie Creek. Surface freshwater flows to these estuaries have been very rare in recent decades, with the most recent flow occurring in 1992. Prior to completion of the Baroota Reservoir in 1921, streamflow from this creek was effectively perennial, but since the dam wall was constructed flows have been almost unknown. Relatively fresh groundwater inflows to the near-shore marine environment may still have some ecological significance, for example as a source of nutrients.

There is a strong emphasis on conservation in the region and the Mambray Coast features several areas protected under the South Australian *National Parks and Wildlife Act 1972*. These include areas of high relief within the Flinders Ranges such as Mount Remarkable National Park and Telowie Gorge Conservation Park, and coastal salt marshes such as in Winninowie Conservation Park.

The region supports a number of agricultural activities including production of sheep, cattle, pigs and wool, and broadscale cropping. Over the last 20 or so years, a sizeable irrigation area has grown downstream of Baroota Reservoir, and recent years have seen expansion in the number, diversity and size of these developments. This has seen the establishment of potato crops, vineyards and olive groves. The level of development raised community concerns for the sustainability of water resources and dependent ecosystems, resulting in a moratorium on water resource development prescription of the area. The area should be prescribed during 2006, with a water allocation plan prepared that should ensure sustainability of the resource.

Outside of the Baroota Reservoir and irrigation area, there is limited information available on the water resources of the Mambray Coast. Information on aquatic biology of streams is also limited, although in the Flinders Ranges as a whole quite a body of work has been

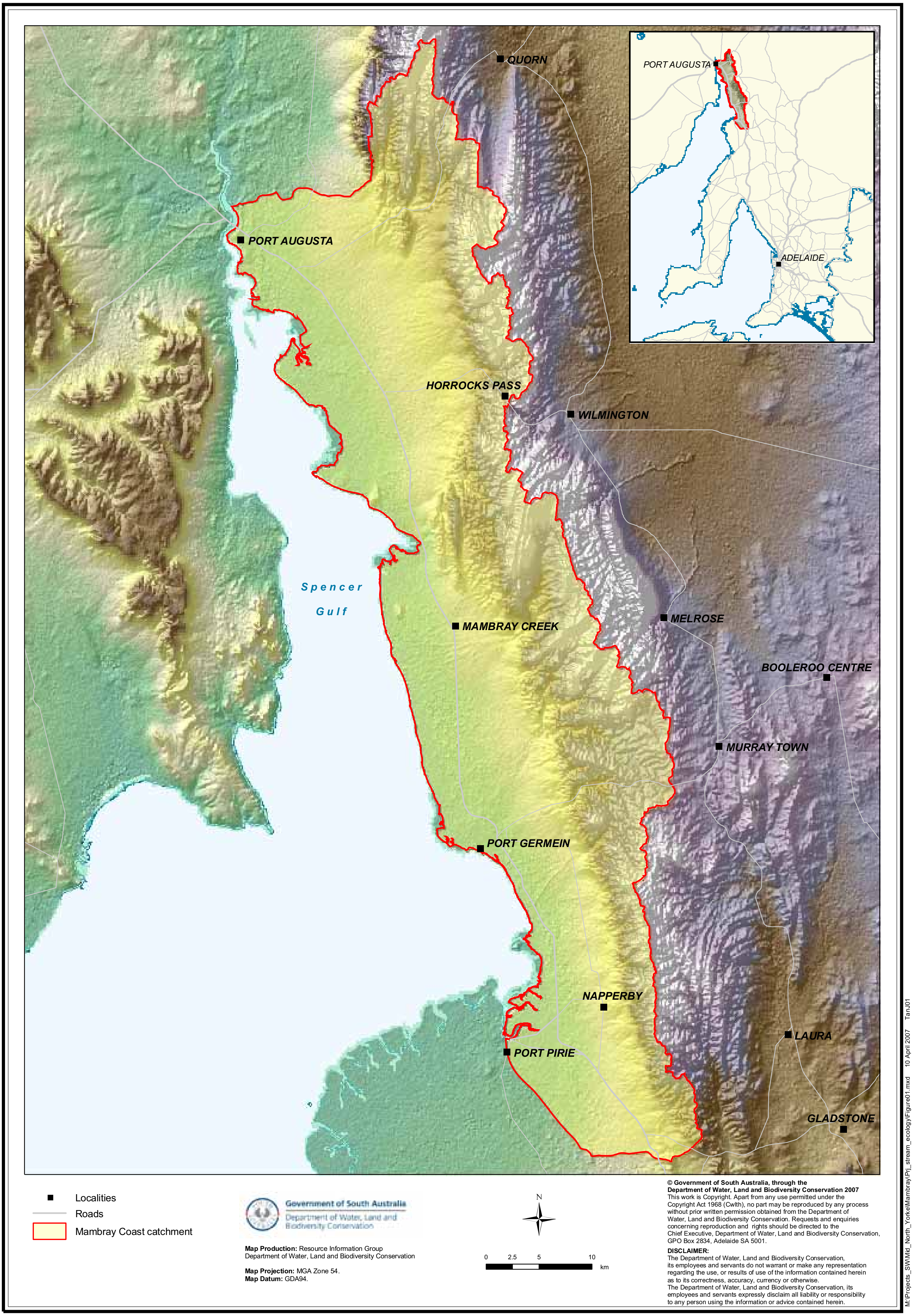


Figure 1. Mambray Coast location

undertaken on macro-invertebrates, frogs and native fish. Work completed within the focus region has mostly been undertaken in Mambray Creek within the Mount Remarkable National Park. Most notable among this work is the macro-invertebrate surveys undertaken as part of the joint state–federal government Measuring River Health Initiative (MRHI), from which was developed the AUSRIVAS model. Current aquatic biological monitoring is restricted to one site at Mambray Creek, which is surveyed twice yearly for macro-invertebrates as part of the Environment Protection Authority (EPA) Ambient Water Quality Monitoring Program.

4.1.1 HISTORY

Edward John Eyre was the first post-European land-based visitor to the region, conducting numerous expeditions to the north of Adelaide in the 1800s (Parkes 1961). Writing to Governor Gawler in a letter dated 2 July 1839, Eyre gave an account of his journey along the western slopes of the southern Flinders Ranges, stating[1] '..*we found numerous creeks taking their rise among the hills, dry generally in the flat country, but with springs and small waterholes among the hills; these all fall westerly towards the gulf, through a country more or less open, and divided by belts of scrub and pine bush*…'

The early ingress of European settlers was driven by the extension of pastoral country which, although lagging behind areas to the east of the ranges, was the first commercial land use and was well established by the late 1860s (Parkes 1961).

Early post-European settlement history of the coastal areas was also influenced by the maritime importance of Port Augusta, which was a major South Australian sea port between 1860 and 1890. Laden ships leaving Port Augusta would sail directly to Europe and had to be fully resupplied before embarking (G. Herde, landholder, pers. comm., 2005). Naturally occurring coastal freshwater springs were used to supply drinking water for the ships, and areas of the Mambray Coast plain region were devoted to market gardens, largely operated by Chinese migrants. These gardeners used water from the springs within the ranges. This situation continued until the late 1800s, when prolonged droughts were experienced (Parkes 1961). The Chinese market gardeners subsequently left in the late 1800s.

From ~1877, farmers began clearing mallee scrub and cropping the region. The scrub consisted mainly of mallee, peppermint, sandalwood, black oak, acacia and umbrella bush, with blue bush plains. Timber milling was an early industry, with saw pits and mills located along the coast cutting river red gum and native pine. Several mills were established at various locations including Mambray Creek and near the old Baroota Head Station (Parkes 1961).

4.1.2 HISTORICAL WATER RESOURCE DEVELOPMENT

Port Germein had permanent freshwater from Baroota Creek, which ran all year round prior to construction of the Baroota Reservoir, completed in 1921 (Parkes 1961). Plains farmers were able to flood irrigate their paddocks from the creek, and water levels were at ~3 m in wells across the region (N. Davis & K Pole, landholders, pers. comm., 2005).

[1]Quotation obtained from Parkes (1961)

Good supplies of groundwater in the Baroota area supported the expansion of irrigated crops, including lucerne during the summer months. Market gardening was introduced along the foothills for produce growing including grapes, tomatoes, peas and potatoes (Parkes 1961).

Like much of South Australia prior to construction of the Morgan to Whyalla pipeline, people relied upon isolated local water supplies that were installed by the government of the day. Such a scheme was constructed during the 1800s, where a pipeline linking permanent springs of the western Flinders Ranges in the north of the catchment supplied local landholders and also Port Augusta. In 1900, pipes were laid from Baroota Springs to Port Pirie to top up Port Pirie’s supply during water shortages.

In 1940, construction of the Morgan to Whyalla pipeline commenced, and this was completed in 1944 (Parkes 1961). A pumping station was established at Baroota Creek to pump to Whyalla.

4.2 LAND USE

4.2.1 LAND-USE CLASSIFICATION

Land-use data for the catchment area was obtained from the Bureau of Rural Sciences (BRS). The data were compiled using remote sensing, cadastre and ancillary data for 1999 and 2003. It was field verified, and final land-use maps produced. The data sets are available in spatial format and can be interpreted using GIS ArcMap.

For the purposes of this report, land-use information was grouped into the following seven broad categories.

Crop–grazing rotation — Land under cropping at the time of mapping that may be in a rotation system; includes cereals, hay and silage, oil seed and legumes.

Irrigation — Irrigated vines and other crops including irrigated pasture production and irrigated sown grasses.

Livestock grazing — Includes pasture and forage production; grazing by domestic stock on native vegetation with limited or no attempt to modify the pasture.

Conservation — Includes national parks, conservation parks and protected natural features.

Residential–industrial–infrastructure — Includes manufacturing and industrial, residential, services, utilities, transport and communications, mining, and waste treatment and disposal.

Reservoir or water storage

Forestry — softwood plantation areas.

Major land use in the Mambray Coast is shown in Table 2, and includes cropping and grazing rotation (10% of the total area), grazing (70%) and conservation (11%). Note that these proportions were as recorded at the time of the BRS survey, and therefore could vary considerably over the course of a year. Irrigation is predominantly for viticulture, olives and potato crops downstream of Baroota Reservoir.

Table 2. Land use by summary category.

Land-use category	Approximate area (ha)	% of total
Livestock grazing	120 000	70
Conservation	16 500	11
Crop–grazing rotation	16 000	10
Residential–industrial	10 000	6
Irrigation horticulture	525	0.3
Forestry	325	0.2
Reservoir or water storage	130	0.1

Source: BRS

4.2.2 NATIONAL PARKS AND RESERVES SYSTEM

The Mambray Coast has a very strong representation of areas protected under the National Parks and Wildlife Act, including the catchments of some of the streams featuring permanent aquatic habitat.

Mount Remarkable National Park (area 10 536 ha; proclaimed 1952)

In 1948, Mambray Creek Reserve and Alligator Gorge were opened for tourism (Parkes 1961). This national park comprises two adjacent but spatially separate areas. The smaller of the two is Mount Remarkable Range, which consists of Mount Remarkable and the ridge running northwards from it. The range is composed of steeply dipping, 800 million year old Rhynie Sandstone, forming a massive hogback ridge. The surface of the heavily jointed rock has been broken by weathering into countless angular fragments that form extensive scree slopes. The larger area lies to the west across the Spring Creek valley, and comprises the Alligator Syncline, a fold structure orientated north–south and dipping gently to the south where it is truncated by a fault, creating an elongated basin with upturned edges. The basin rock is 600 million year old ABC Range Quartzite.

The more extensive northern part of the basin is known as Alligator Gorge, and is drained by the south-flowing Alligator Creek. The southern basin is drained by Mambray Creek. The two creeks join and run southwest as Mambray Creek, which flows onto the plains and ultimately to Spencer Gulf. The long western rim known as ‘The Battery’ is north–south-orientated.

To date, 490 native plants, 52 native reptiles, 12 native mammals and 117 native birds have been recorded in the park (NPWS 2001). The park also features at least two permanent springs, one of which is included in the EPA Ambient Water Quality Monitoring Program for macro-invertebrates.

Telowie Gorge Conservation Park (area 1946 ha; proclaimed 1970)

This park is south of Mount Remarkable, and is on the western slopes of the southern Flinders Ranges facing Spencer Gulf near Port Pirie. Telowie Gorge itself is deeply incised into Rhynie Sandstone which forms the main range. Of particular note is the southernmost occurrence of the Yellow-footed Rock Wallaby (*Petrogale xanthopus*), which inhabits the rocky cliffs.

From an aquatic ecosystem perspective there is a series of small rocky waterholes located in the gorge country. Many of these are temporary, formed by rainfall that has collected in suitable rockholes following storms and occasional streamflow events. More permanent groundwater springs also occur in the park.

Near the park entrance is a small spring, which until recently was thought to have supported a small pool. Field visits as part of this survey did not locate any surface water at the spring, although boggy areas and stands of reed beds were observed in the creek downstream of the park entrance.

Winninowie Conservation Park (area 7847ha, proclaimed 1990)

This park was proclaimed ‘to conserve excellent examples of several coastal and marine ecosystems’ (NPWS 2000, p.2). No permanent freshwater occurs in the park, and surface water occurs only following episodic runoff and local streamflow. Groundwater of moderate to good quality is present in a deep confined aquifer (NPWS 2000).

Wild Rivers

The Wild Rivers project is a Commonwealth Government initiative administered by Environment Australia that aims to identify all watercourses in Australia that are in a relatively undisturbed or ‘wild’ state. Alligator Creek, Mambray Creek, Mount Remarkable Creek, Napperby Gorge and Nelshaby Gorge, the westerly flowing Napperby, and Nelshaby Creek drainage systems are all listed under the program. Assessment of these rivers has identified that their biological, hydrological and geomorphological processes have not been significantly altered since European settlement. The project addresses the conservation of wild rivers by:

- discussing the impacts of a range of activities on wild river values
- outlining some principles for wild river management
- providing a code for wild river management.

The project itself does not have any legislative power. The Mount Remarkable National Park Management Plan 2001 (NPWS 2001) has addressed the wild rivers rating and includes management objectives and actions consistent with the Wild Rivers Management Principles and Code.

4.3 GEOLOGY

The Mambray Coast has a variety of geological formations including Neoproterozoic and Cambrian rocks, and Cainozoic sediments of the Pirie Basin. Geologically, the region occupies an elongate depression between two major geological provinces — the Adelaide Geosyncline (southern Flinders Ranges) to the east, and the Stuart Shelf (Simmons Plateau) to the west.

The area between these two provinces is known as the Torrens Hinge Zone — a zone of flexuring and faulting that marks the transition from almost undeformed thinner Adelaidean and Cambrian sequences of the Stuart Shelf into the deformed and uplifted rocks of the Adelaide Geosyncline (Thomson 1969a as cited in Preiss 1987, p.15).

The following is a description of the geology of the Mambray Coast region, which incorporates the coastal plain west of the southern Flinders Range, and east into the ranges to the surface water divide of the Alligator Creek and Spring Creek Catchments. The area described is bounded to the north roughly in line with Horrocks Pass and to the south in line with Port Pirie.

Hard rock components of the Mambray Coast Region

A geology plan of the Mambray Coast region is provided in Figure 2. The hard rock formations east of the Mambray Coast plain comprise Neoproterozoic rocks deposited in the Adelaide Geosyncline and subsequently folded and uplifted during the early Palaeozoic Era 400–500 million years ago (collectively known as the Delamerian Orogeny; Preiss 1987). Most of the prominent features in the ranges are comprised of the hard, resistant ABC Range Quartzite, which is underlain by the softer Brachina and Nuccaleena Formations of the Wilpena Group. The ABC Range Quartzite is particularly prominent in the Mount Remarkable National Park, making up the Alligator Gorge Basin, Black Hill Range and Battery Range which overlooks Spencer Gulf (NPWS 2001).

The southeastern section of the park incorporates Mount Remarkable which itself is formed of Rhynie Sandstone (Burra Group). Watercourses draining the Mount Remarkable Range, including Spring Creek and Mount Remarkable Creek, do not flow into Spencer Gulf but flow within the Willochra Creek Catchment, which has its outfall at Lake Torrens.

Coastal sediments

The sediments of the Mambray Coast form part of the larger Pirie Basin that extends from Wallaroo in the south to ~15 km north of Port Augusta (Alley & Lindsay 1995, p.176), a distance of ~200 km. The Pirie Basin contains Quaternary and Tertiary sediments including early Tertiary Kanaka Beds, unconformably overlain by Late Oligocene to Early Miocene unnamed marine sand and Miocene Melton Limestone, and Gibbon Beds comprising a sand–clay succession (Alley & Lindsay 1995, p.175).

Tertiary sediments in the Pirie Basin were initially thought to be continuous with those of the Torrens Basin, but Tertiary sediments of the latter are non-marine, with deposition commencing in the Early Eocene, whereas those of the Pirie Basin contain marine facies, with deposition commencing in the Late Eocene (Alley & Lindsay 1995, p.175).

Basement underlying the Tertiary sediments consists of siltstone and quartzite of the Adelaide Geosyncline, which also forms the ranges to the east. The Mambray Coast plain lies directly over the Torrens Hinge Zone.

Quaternary sediments consist mainly of clay, silt and gravel derived by outwash from the Flinders Ranges (Clarke 1989). Marine transgressions and regressions into northern Spencer Gulf during the Quaternary resulted in alternations of marine and alluvial sediments in the subsurface of the gulf, but marine sediments do not crop out in the vicinity of the study site (NPWS 2000).

Figure 3 is a generalised cross-section of the Mount Remarkable National Park region, showing Quaternary sediments of variable composition underlain by Tertiary sand and Adelaidean basement (adapted from Clarke 1989).

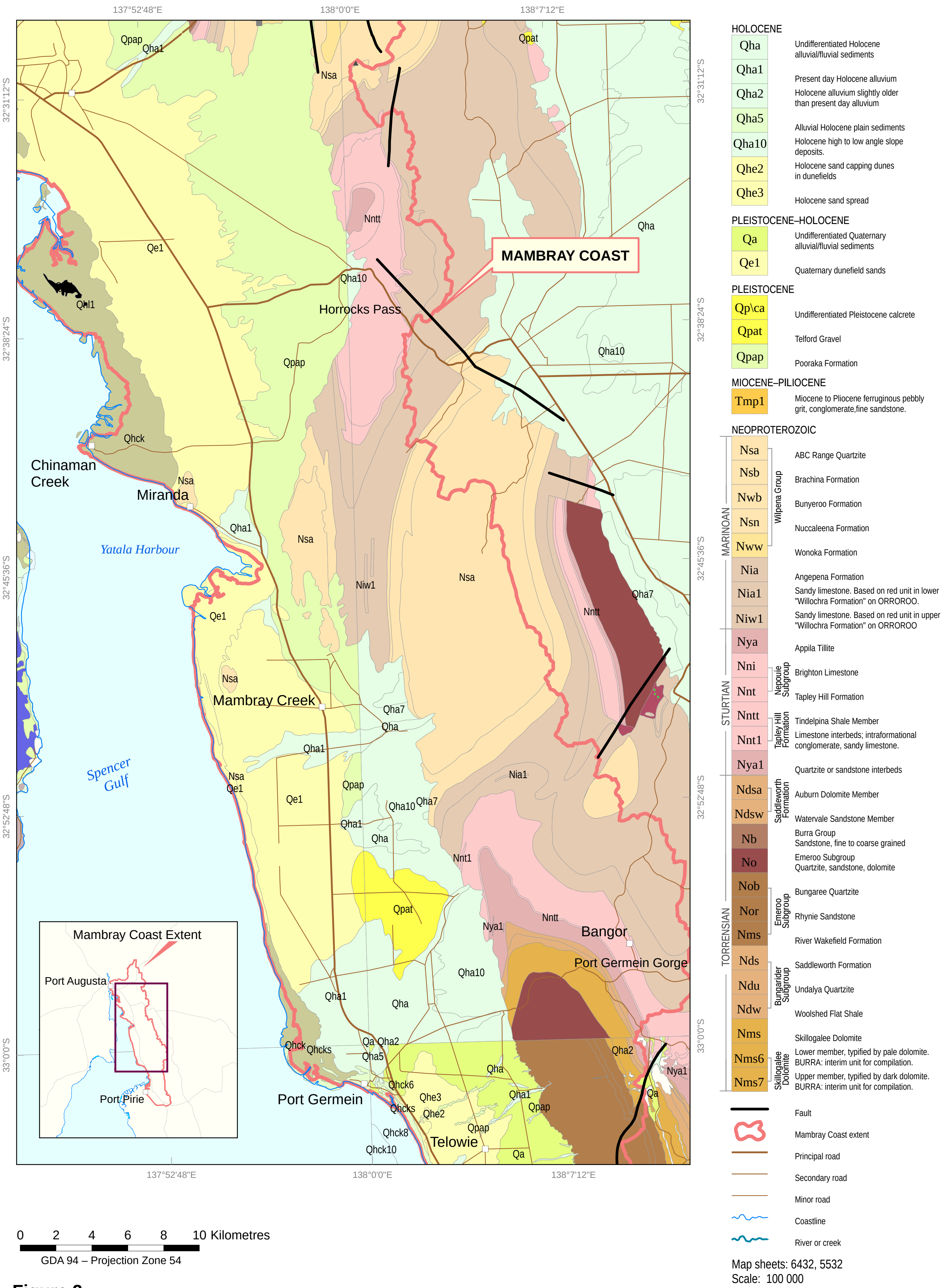


Figure 2

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

100 000 GEOLOGY – SOUTH AUSTRALIA
MAMBRAY COAST

PIRSA: 202896_001

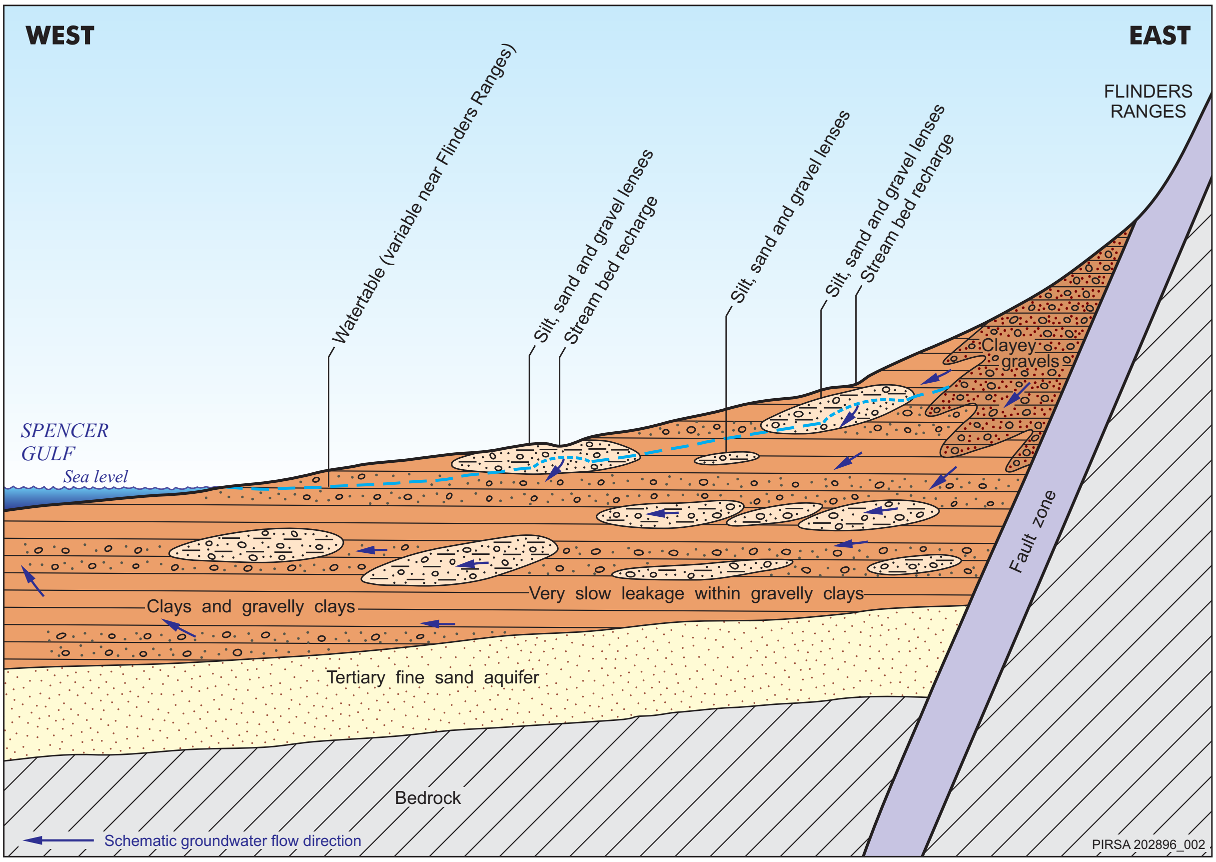


Figure 3. Geological cross-section, Mount Remarkable National Park.

Of significance for the watercourses once reaching the plains is the Quaternary sand dunefield (see Fig. 2), which occurs along the coast from ~6 km north of Port Germein to the top of the gulf. Defined channels are not generally found within this formation due to the high permeability of the substrate, with water infiltrating into the sand rather than creating a defined channel. Larger watercourses including Mambray and Baroota Creeks have formed channels within Holocene alluvium, which is part of the current bedload.

4.4 GEOMORPHOLOGY

Fluvial geomorphology is the study of the riverine physical environment and processes that produce the range of landforms observed. Geomorphological processes of erosion, transportation and deposition help to create and maintain the diverse variety of aquatic and riparian habitat, and have a close link to stream ecology.

4.4.1 SEDIMENT TRANSPORT PROCESSES

The movement of sediment through a river system is a natural and essential feature of its functional integrity. For example, sediment transport to estuaries is important for maintaining the estuarine environment. If sediment is not transported it builds up in one location, which can lead to loss of in-stream habitats and structural diversity, raising of the stream bed, and can favour some emergent macrophytes such as *Phragmites* or *Typha* (Gordon et al. 2004).

Sedimentation can also lead to encroachment of terrestrial vegetation into the channel, altering the hydraulic response of the stream and leading to bed or bank erosion.

The size and amount of sediment transported during a flow event depends on the stream energy, which increases with the size of the event. Changes to catchment vegetation or watercourse planform can also alter stream energy. Flows of different volume and duration are linked to different geomorphic processes and the threshold flows to trigger these processes are often referred to as flow bands.

For example, flows capable of scouring sediment from riffles are important in maintaining this habitat. Fine suspended sediments and organic detritus will progressively settle out of the water column and accumulate during no-flow or low flow periods. This has the effect of reducing substrate diversity, providing an advantage to some organisms over others and hence influencing the biological diversity represented. Periods of sufficiently high flow velocity provide an important ecological function by removing this build-up.

4.4.2 IMPACTS ON STREAM GEOMORPHOLOGY

Geomorphology of the watercourses in the ranges and plains areas of the Mambray Coast has changed since European settlement. These changes have been in response to clearing of vegetation (in some areas creating increased runoff volume and velocity) and also direct interventions such as the construction of dams, weirs and fords.

Channel adjustments in response to these changes include deepening and widening of watercourse channels, raising of bed levels due to sedimentation, and alterations to the channel course. In general, streams of the Mambray Coast are only slightly impacted, with only small amounts of active erosion detected on some plains watercourses observed.

An old weir on Nectar Brook upstream of the reservoir was part of the government water supply infrastructure. Construction of the weir has resulted in the accumulation of sediments upstream of the structure. Failure of the weir could release the sediments, infilling the permanent pools and channel downstream, and smothering aquatic habitats. An old step weir also exists in Port Germein Gorge, but is causing minimal impact to watercourse stability or flows.

Watercourses of the Mambray Coast have streamflow volumes that vary greatly between years. As a result, geomorphological processes are episodic, with little erosion or sedimentation in most years and major reworking occurring during infrequent flood events.

While significant deposition and reworking of stream channels of the coastal plain will occur during these events, the impact on overall ecological condition will be minimal as these are essentially terrestrial habitats. The extent of possible reworking in ecologically important sites within the ranges where permanent water was observed is limited as:

- topography largely dictates channel planform
- bedrock controls are a feature of upland streams, and these protect against bed lowering
- only limited floodplain development has occurred in these upland areas and hence the potential for reworking of these sediments to impact on stream ecology is minor.

As a result of this and the low impacts of current land uses, the risk to aquatic habitat associated with geomorphic processes is not considered to be significant.

4.5 CATCHMENT HYDROLOGY

A central focus of this project was to determine whether existing water resource development was impacting on the environmental water requirements of aquatic ecosystems of the Mambray Coast. The aim of this chapter is to describe the resource and current level of development, with both surface and groundwater considered.

4.5.1 SURFACE WATER HYDROLOGY

4.5.1.1 General description

The Mambray Coast consists of numerous small and unconnected surface water catchments draining the western slopes of the southern Flinders Ranges (NLWRA 2000; Fig. 4). Virtually all surface runoff is generated in the steep, higher rainfall areas of the ranges. Due to the lower rainfall and flat topography, excess rainfall on the plains is most likely to permeate into sediments and recharge watertable aquifers rather than run off as streamflow.

Watercourses within the ranges can follow quite sinuous pathways through the gorges and valleys as dictated by the prevailing topography (Fig. 4). Despite this, the maximum stream length from headwaters to the gulf is short, typically being of the order of 5–10 km. Even larger streams such as Baroota and Mambray Creeks are less than 30 km in length. Catchment areas are also small, in most cases being less than 40 km^2 (Table 3). Baroota Creek and its tributaries have the largest catchment, with an area of 138 km^2.

Table 3. Major catchment areas of the Mambray Coast.

Catchment	**Area** (km^2)
Baroota Creek	138
Saltia Creek	106
Mambray Creek	84
Mt Gullet Creek	56
Mundallia Creek	41
Horrocks Creek	35
Telowie Creek	33
Back Creek	30
Nectar Brook	25

Larger watercourses typically form braided, relatively broad channels as they emerge onto the plains, often tending to narrow and become discontinuous channels with distance away from the ranges. Plains watercourses are of low sinuosity, trending directly west to Spencer Gulf, with the exception of Baroota Creek, which flows almost due south, discharging at Port Germein.

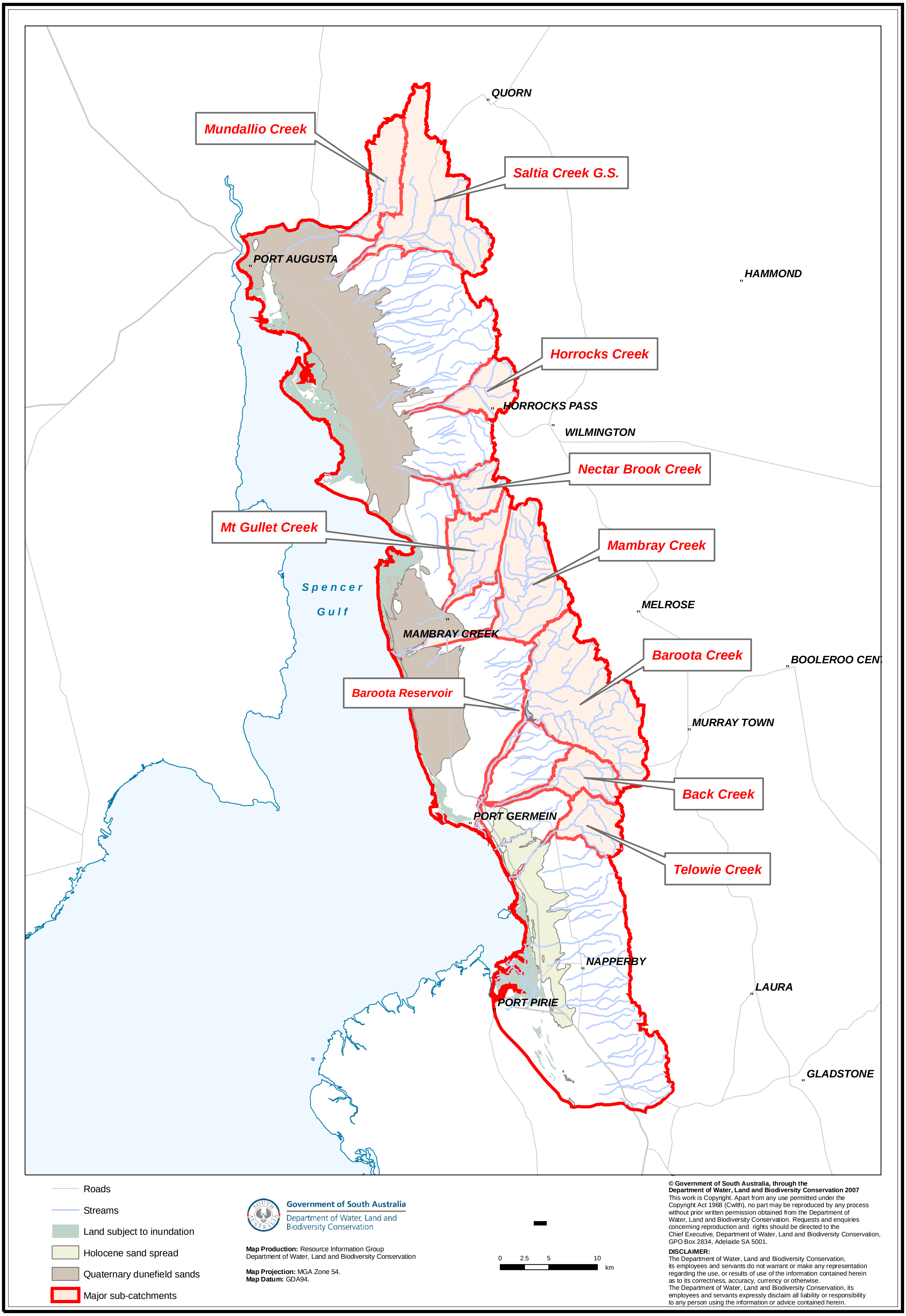


Figure 4. Surface drainage features and major catchments of the Mambray Coast

Erosion of the ranges over geological time has led to the development of a complex mosaic of depositional features across the coastal plains (Fig. 3). Variations in the volumes of streamflow over differing climatic periods have created the observed patterns, which consist of varying sediment sizes through clay, sand and gravel as streams built up their beds and changed course, eroding new channels (Clarke 1989).

Stream energy dissipates rapidly once reaching flat terrain, leading to the deposition of larger material closer to the foothills. Extensive gravel beds have been built up in many places along the foothills as a result of this. These bed materials result in high vertical flow rates, and streams flowing across gravel beds are strongly losing in nature. Additionally, a zone of faulting and jointing is located adjacent to the foothills, which also has the effect of increasing stream losses to groundwater (Clarke 1989). Where watercourses flow into the Quaternary dunefield sand, and Holocene sand (Figs 2, 4), defined channels do not form with water infiltrating into sediments.

As a result of these loss rates, streamflow events providing connectivity between the ranges and gulf are rare. Mambray Creek has reached the coast roughly one year in 10 since the 1980s (S. Beinke, Head Ranger, Mount Remarkable National Park, pers. comm., 2005). There is anecdotal evidence from long-term residents that these large-scale flow events were more common during decades earlier in the 20^{th} Century. The small runoff-generating catchment areas and steep topography will produce a ‘flashy’ response to rainfall, meaning that direct runoff will rise and fall rapidly. This, in combination with the low rainfall, permeable nature of the coastal plain sediments and the long distance across the coastal plain relative to total stream length, explains the rarity of flows reaching the gulf.

Harvie and Joan Spencer, long-term landholders on the Mambray Creek downstream of the national park, explained examples of the interaction between the streams and plains as follows — ‘when water flows in the creek for around a fortnight, much of the country around their property becomes swampy. Water is found just below the surface creating low-lying swamps adjacent to the watercourse. These swamps can remain for some time, indicating that a significant degree of recharge to watertable aquifers occurs as a result of streamflow on the coastal plains’.

4.5.1.2 Data quality and availability

Rainfall

More than 20 BoM stations recording daily rainfall are located in the Mambray Coast. Data from many of these stations are of short duration and the location of stations, particularly those with a long-term record, is focused on the low rainfall coastal plains. The lack of rainfall data from the runoff-generating steep topography restricts detailed spatial analysis.

To compensate for the lack of observed data, modelled rainfall data were obtained from the BoM SILO site (see Methodology) in order to conduct a spatial analysis of rainfall distribution.

Streamflow

Hydrological analysis of streamflow for watercourses in the region is hampered by a lack of data of an appropriate nature. Two sources of data are available — Saltia Creek Gauging Station and Baroota Reservoir.

Saltia Creek Gauging Station (AW508503) was a DWLBC site operational between 1979 and 1991, recording both water level and rainfall during that period. Unfortunately the site was located in a section of unconfined gravel bed, and no stage-discharge rating exists for the station due to the lack of bed stability at the site (B. Murdoch, DWLBC, pers. comm., 2005). A flow frequency and seasonality analysis was undertaken for events recorded during the 12 years of record at the site.

Baroota Reservoir (AW508500) has been monitoring reservoir water levels since 1941. The site does not provide information suitable for ready analysis of the frequency, duration or seasonality of individual flow events that are of ecological significance.

Under the National Land and Water Resources Audit 2000 (NLWRA 2000), a relationship between catchment yield and water level was developed. This was used for the purposes of estimating total resource size for the catchment and does not take into account operational extractions or transfers. Suitable flow data were not developed at the time of modelling to allow an evaluation of environmental water requirements. It may be possible to undertake a flow analysis using a modelling approach calibrated to reservoir level, but this is beyond the scope of this report.

4.5.1.3 Rainfall

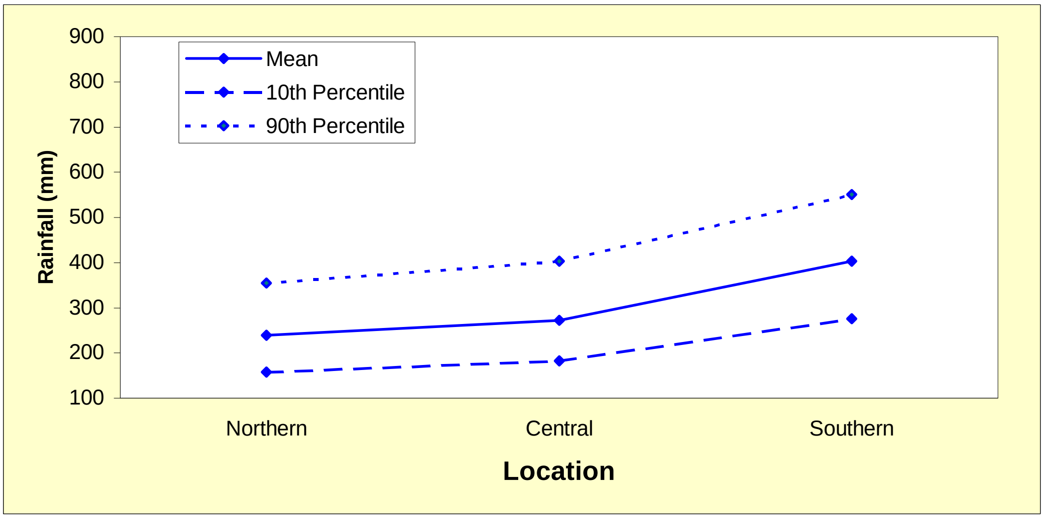
Spatial distribution

Rainfall is highly variable along the Mambray Coast, ranging from less than 260 mm to over 650 mm. Isohyets (lines of equal average annual rainfall) are shown in Figure 8 and provide an indication of the spatial distribution of rainfall. The average annual rainfall across the basin calculated using these isohyets is 380–400 mm. Rainfall on the ranges peaks in the south of the catchment at more than 600 mm. Average annual rainfall at the Mambray Creek (Alligator Gorge) BoM station from the last 30 years is 660 mm. On the plains, the annual rainfall varies from over 400 mm in the southern catchment near Port Pirie to ~250 mm close to Port Augusta in the north.

Hence both latitude and elevation are factors influencing catchment-scale rainfall distribution and this is illustrated in Figures 5 and 6. Shown are the median annual rainfall and the 10^{th} and 90^{th} percentiles, above which 90% and 10% of all records occur, respectively. The spread of the percentiles provides an indication of the difference in variability at each location.

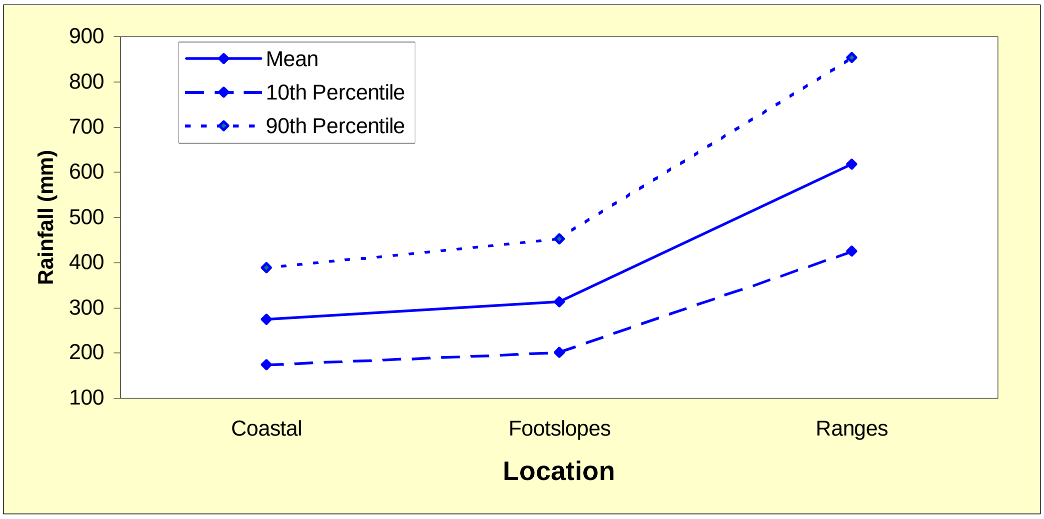
Variation in latitude of the coastal plain is shown for sites in the northern, central and southern Mambray Coast in Figure 5. At sea level, rainfall decreases with distance to the north, but variability remains almost constant.

Figure 6 was created by analysing data from three modelled sites along a west to east transect roughly coincident with Alligator Gorge. Elevation has a more dramatic effect than latitude, and both median rainfall and the variability are greatest at the top of the ranges.



Source: BoM SILO data

Figure 5. Latitudinal influence on rainfall, Mambray Coast.

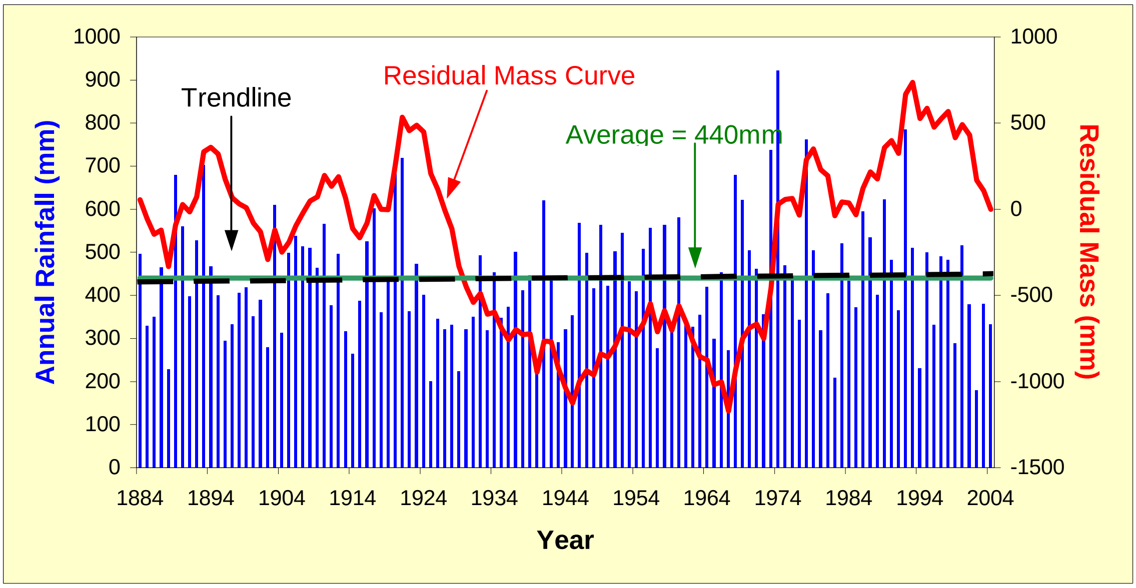


Source: BoM SILO data

Figure 6. Topographical variations in annual rainfall: central Mambray Coast.

Annual Rainfall

Figure 7 shows the longest actual continuous annual rainfall record from 1884–2004 for BoM Station 019030 (Quorn Olive Grove). The station is in the far northeastern corner of the Mambray Coast, one of the driest areas. A plot of the cumulative deviation from the mean rainfall, also known as the residual mass curve (RMC), is depicted in red. A flat period in the RMC indicates a period of average rainfall conditions, a positive slope indicates a period of greater than average rainfall, and negative slope indicates below average rainfall. The below average rainfall during the 1994–2004 period is indicated by the downward trend in the figure.



Source: BoM

Figure 7. Quorn Olive Grove BoM Station 019030 annual rainfall.

It is of interest to note the frequency of very wet years. This can be demonstrated by analysing the frequency of years where annual rainfall exceeded 550 mm (25% above the long-term average). The last time this occurred was 13 years ago, in 1992, whereas over the entire 120 year period this occurs on average every 5–6 years. Despite this, the current period is not the longest period without a similarly wet year, as an 18 year period between 1922 and 1940 where this occurred can also be seen in the record.

Monthly and seasonal rainfall patterns

Climate in the catchment is broadly Mediterranean in nature with relatively reliable, winter-dominant rainfall. Figure 9 shows the monthly rainfall statistics for BoM Station 019030 for the 1884–2004 period of record. Winter–spring rainfall dominates, with June the wettest month and March the driest.

A plot of the residual mass for the monthly rainfall can give an indication of changes to rainfall seasonality. Community members described perceived changes in rainfall distribution patterns over recent years, with shifts from rainfall predominantly occurring during the winter months, to a more even distribution throughout the year. Analysis of the monthly rainfall information undertaken for this report supports anecdotal evidence from landholders and other recent hydrological assessments that seasonal winter rainfall is commencing later in the year.

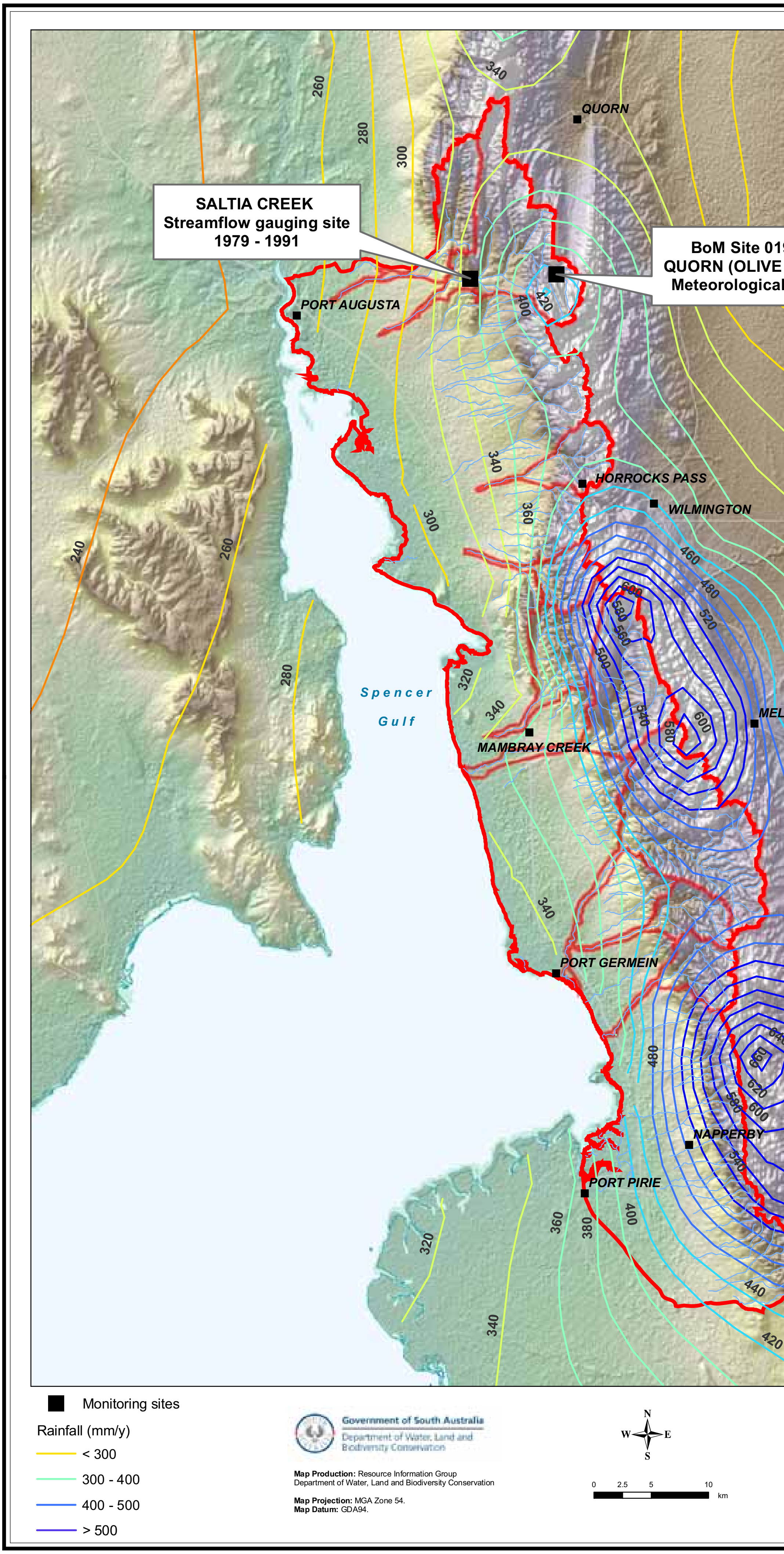
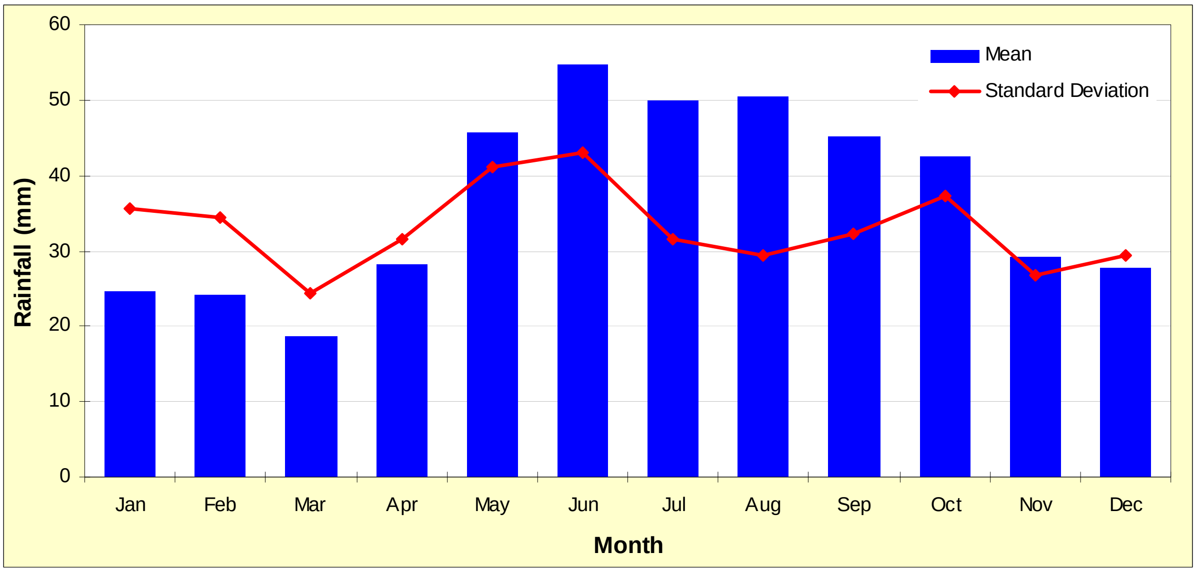


Figure 8. Rainfall isohyets, Mambray Coast



Source: BoM

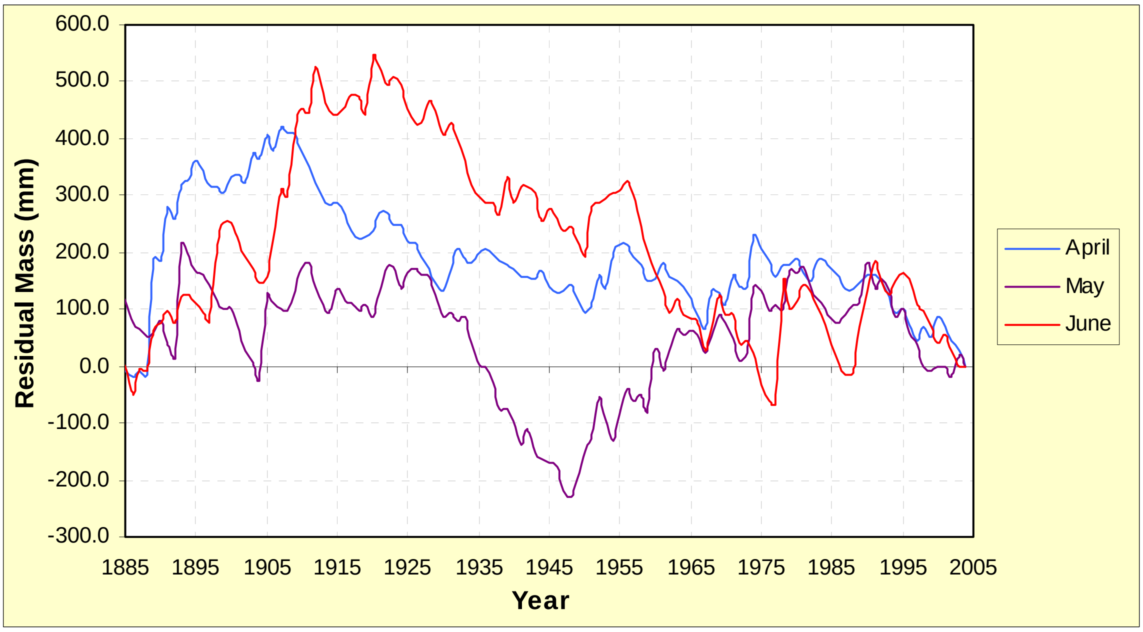
Figure 9. Monthly rainfall at BoM Station 019030 (Quorn Olive Grove).

Figures 10 and 11 show the monthly residual mass for the Quorn Olive Grove BoM Station (019030) for months where the trend in recent years is for decreasing and increasing totals, respectively. The months with an apparent decreasing trend, suggesting rainfall lower than the long-term monthly average, all appear to be early season months (April, May and June; Fig. 10).

June rainfall totals were generally below the long-term average between ~1920 and the mid-1970s. A period of high variability followed until around the early 1990s, and since this time it has again been consistently below average. April totals have generally been below average since around the mid- to late 1980s, with May rainfall showing a similar trend since ~1990.

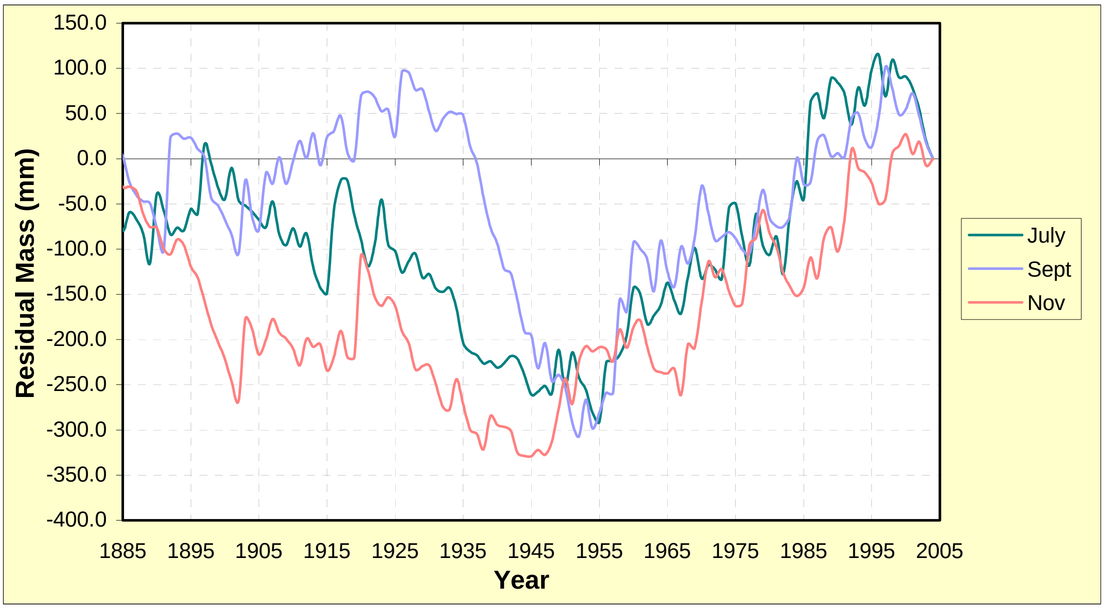
In contrast to the months showing a generally decreasing trend, Figure 11 shows a trend of above average rainfall for July, September and November since ~1950. As has been the case with annual totals, the last few years have seen below average falls during these months. August and October showed no clear trends over recent years and have not been included to improve clarity in the figure.

The seasonality of rainfall is an important consideration when determining what proportion of the rainfall received contributes to the useable water resource, and hence to the support of aquatic ecosystems. Slope, soil characteristics and degree of saturation, rainfall intensity and land cover are all factors in determining whether rainfall will run off, evaporate or infiltrate. Although summer storms will generally be of higher intensity, the most significant seasonal variation is in the prevailing soil moisture conditions. The effect of these variations can be inferred by analysis of the relative amounts of rainfall and potential evapotranspiration that occur on average over an annual cycle.



Source: BoM

Figure 10. Monthly rainfall residual mass for BoM Station 019030 (Quorn) — months showing decreasing trend.



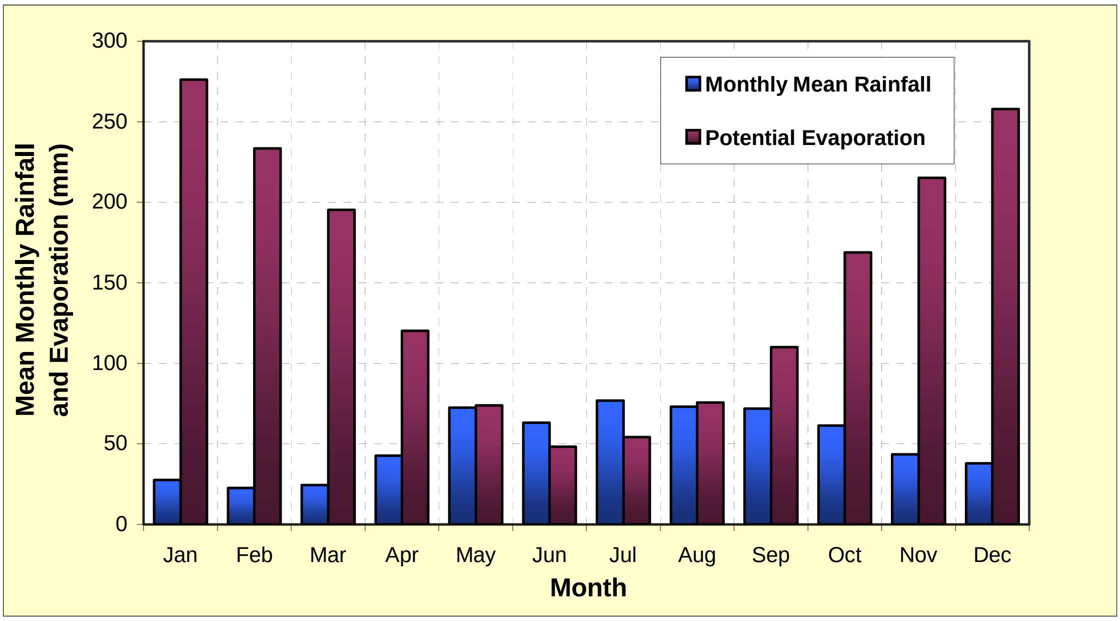
Source: BoM

Figure 11. Monthly rainfall residual mass for BoM Station 019030 (Quorn) — months showing increasing trend.

Whilst it is a simplification, the difference in these values when calculated on a monthly timestep provides a surrogate measure of the proportion of total precipitation falling during each month that can be expected to result in surface water runoff or groundwater recharge. The term 'effective rainfall' is used herein to refer to the difference between the total rainfall received and the potential evapotranspiration. Positive values then indicate that rainfall received exceeds the potential evapotranspiration, and a higher probability then exists that conditions during these months would foster runoff and recharge.

Figure 12 is a comparison between average monthly rainfall and potential evapotranspiration for the upland areas of the central Mambray Coast. In terms of the long-term average conditions, the only months where average rainfall exceeds evaporation are June and July. Consequently, rainfall during these months can be considered to be more likely to contribute to the useable resource.

Figure 12 and the concept of effective rainfall help to illustrate the consequences of the apparent shift towards later seasonal rainfall as suggested in Figures 10 and 11. Even if later months of the year begin to see increased average rainfalls, the higher evaporation rate of these months will in part negate any corresponding increase in runoff or recharge.

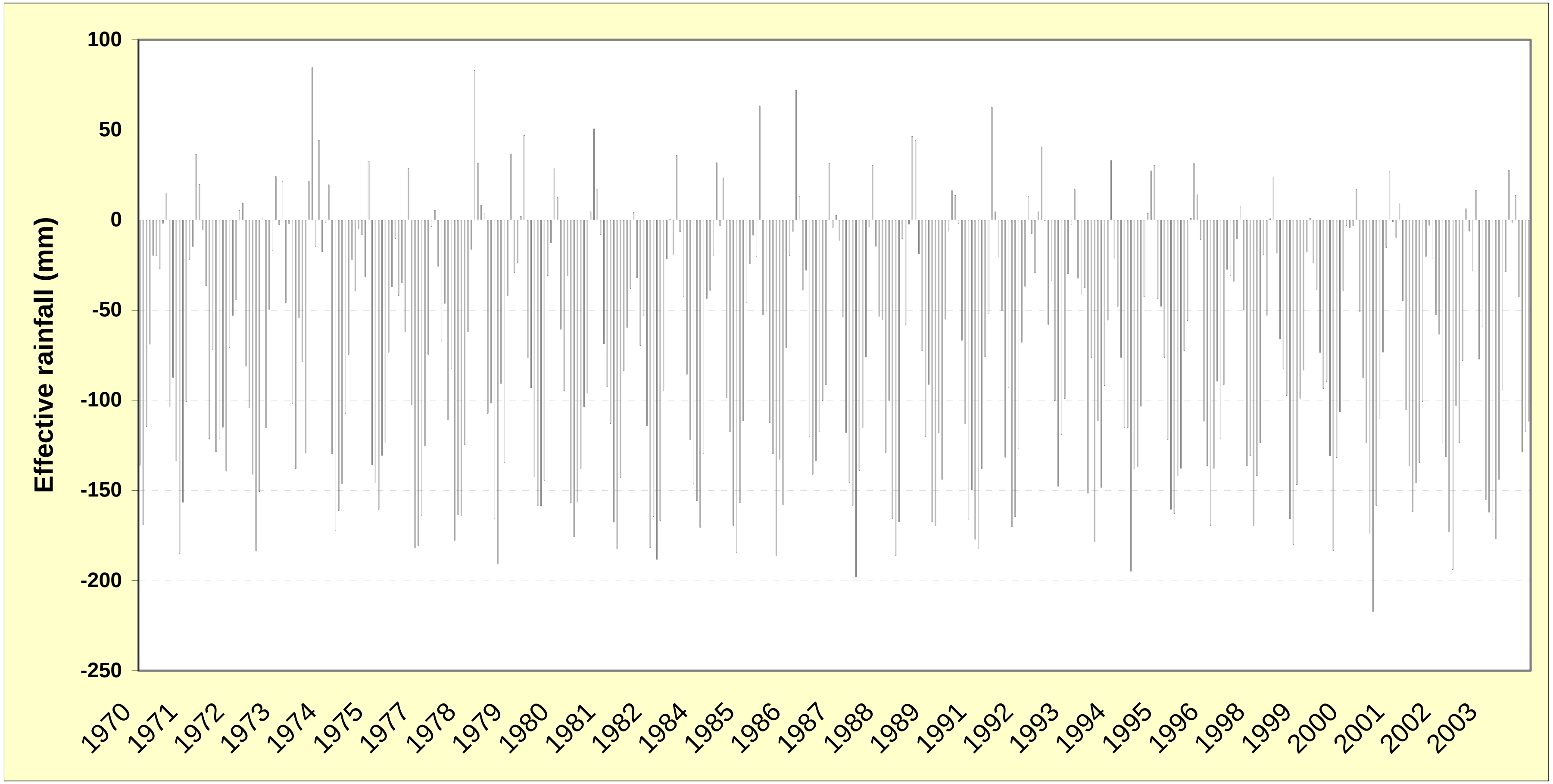


Source: BoM SILO data

Figure 12. Modelled mean monthly rainfall and evaporation — central ranges of the Mambray Coast.

Effective rainfall calculated for each month in the period 1970–2004 is shown in Figure 13. As discussed, values of greater than 0 mm indicate months during the period of record where rainfall exceeded potential evapotranspiration (defined as FAO56 Reference evapotranspiration obtained from BoM — see <http://www.nrm.qld.gov.au/silo/datadrill/> for an explanation of the methodology involved in deriving this value).

Months where rainfall exceeds potential evapotranspiration represent periods with the highest probability that conditions conducive to producing both surface runoff and groundwater recharge will develop. In general, the greater the volume of rainfall excess the higher this probability becomes, especially where this occurs during consecutive months. Figure 13 shows that since ~1997, both in terms of the number of months and volume of effective rainfall available, there has been relatively limited potential for these conditions to develop. It is unlikely that regular runoff and hence streamflow events have occurred during this time. It is also unlikely that any significant groundwater recharge has occurred during this period. In the absence of significant recharge, any natural groundwater surface discharge such as that supporting permanent pools, or human extractions through pumping, will be drawn from the groundwater store.



Source: BoM SILO data.

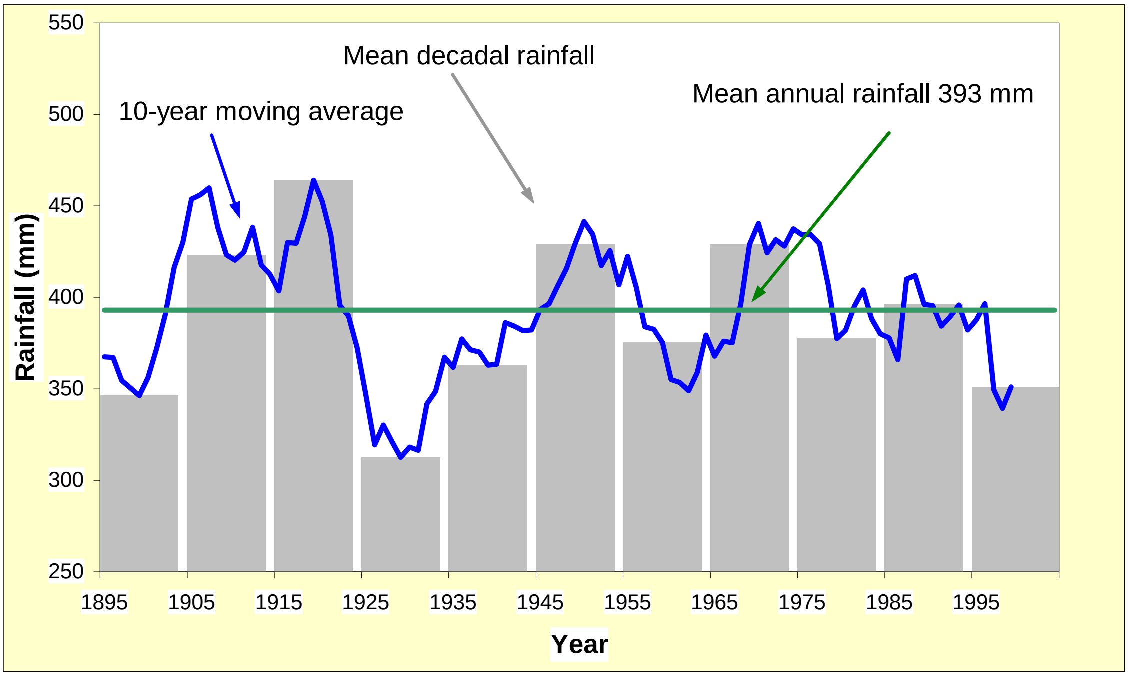
Figure 13. Modelled monthly effective rainfall, 1970–2004, central ranges of the Mambray Coast.

Decadal Rainfall

A feature of climatic patterns is the tendency for wet and dry years to cluster together, and analysis of this can be useful to help place the current condition of aquatic ecosystems in the context of these cycles.

Patterns in the rainfall record in recently published South Australian hydrological assessments have been observed to follow roughly decadal wet–dry cycles (e.g. Heneker 2003; Risby et al. 2003). Decadal averages for periods starting in mid-decades (e.g. 1905–14) have been shown to align well with peaks in a plot of the 10 year moving average (Heneker 2003). This analysis has been undertaken for a regionalised rainfall dataset for the Mambray Coast Catchment, and is displayed in Figure 14.

Although there is a cyclic variation that appears to exhibit a peak-to-peak duration varying from around 10–20 years, this is more clearly apparent during the early 20th century. The decrease in the definition of this pattern is due to a reduction in the magnitude of the variation between relatively wet and dry periods. This suggests that the magnitude of extreme periods, both wet and dry, decreased during the second half of the 20th century, and provides a clearer indication that annual rainfalls of, or below, the long-term average have predominated for the last three decades.



Source: BoM SILO data

Figure 14. Regional decadal rainfall and 10-year moving average, Mambray Coast.

Clearly the current dry period is not the driest on record, which occurred during 1925–34 with an annual average of only 312 mm. This compares with the period 1995–2004, which is the second driest decadal period and averaged 350 mm. The wettest period was 1915–24 with an average of 464 mm.

No inference can be drawn from this analysis with regard to climate change as the period of record is too short. It is clearly evident however, that the current period represents the longest continuous period of low to moderate annual rainfall on record. Owing to the small volume of effective rainfall, very wet periods are important in providing the conditions necessary for significant recharging of groundwater stores. Permanent surface water pools identified in the ranges are dependent on groundwater discharge to persist (see Section 5). Any reduction in groundwater storage that results in a decrease in the volume or pressure of discharges represents a threat to the permanence of these pools.

4.5.1.4 Streamflow

Streams of the Mambray Coast are all ephemeral, although permanent pools and seasonal baseflow can be found in a number of the relatively large streams, mostly in the area from Baroota Reservoir through to Nectar Brook. All of the permanent water appears to be a surface expression of groundwater.

Baseflow is relatively reliable compared to episodic surface runoff, producing extensive flowing reaches for periods of up to several months at a similar time each year. This is important from an ecological perspective as biota with a life cycle requirement for flowing water can link key elements of their life cycle to periods where flowing water is present. Limitations of these flows include their restricted ability to provide catchment-wide and lateral connectivity, and also their baseline salinity, which is higher than surface runoff, although no data are available to quantify this.

Streamflow from surface runoff is much less predictable and this will also influence the aquatic ecology. While there is insufficient data to undertake a detailed analysis of these characteristics, general patterns of surface streamflow can be determined from the streamflow record for Saltia Creek, which drains the northeastern Mambray Coast. Twelve years of record exist for the gauging station, which was operational during 1979–91. The location of the station within a highly permeable gravel bed meant that it recorded flows only after significant surface runoff events.

Figure 15 shows the number and average duration of flow events for Saltia Creek, by season. A total of 20 flow events were recorded during the 12 years that the station was operational. This may underestimate the long-term flow frequency at the site as the period of record coincides with a relatively dry phase.

With the exception of summer where only two events occurred, there is little difference between seasons in terms of the number of flows. However, the average duration of flows during winter and spring is considerably greater than the other seasons, being of the order of several weeks. Flows of this duration are sufficient for many macro-invertebrate species to complete the aquatic stages of their lifecycles. The reduced salinity, and increased extent and diversity of habitats produced by such flow events, will provide an environment suitable to an increased number of animals.

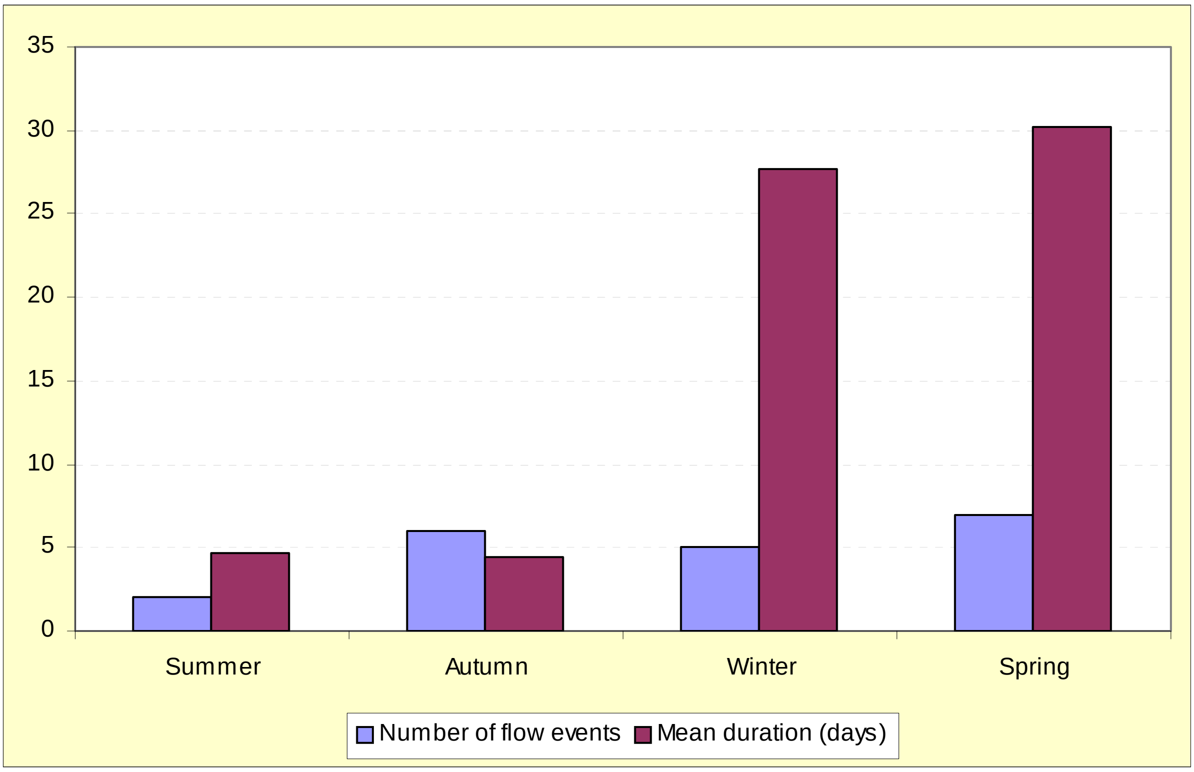


Figure 15. Seasonality and duration of flow events 1979–91, Saltia Creek gauging station.

4.5.2 SURFACE WATER DEVELOPMENT

Surface water development has a long history in the region, with a government pipeline linking a number of permanent springs for the purpose of supplying Port Augusta having been completed in the 1800s. Following completion of the first Morgan to Whyalla pipeline, bringing water supplies from the River Murray in 1941, the system was abandoned. Limited pumping from some of these spring-fed pools for domestic purposes still occurs, but appears to be sustainable. Two major currently utilised surface reservoirs are located in the catchment — the major reservoir at Baroota and a small storage at Nelshaby.

The major potential use of surface water is from Baroota Reservoir, but as this catchment and the downstream groundwater irrigation area is under a notice of intent to prescribe, the sustainability of this usage should be ensured. The creation of the reservoir in 1921 naturally had a profound influence on the hydrology of Baroota Creek downstream of the dam wall, resulting in the loss of formerly permanent pools near Port Germein. The potential for some of these impacts to be addressed through the introduction of an environmental release program from the reservoir in future is discussed in Section 6.3.3.1. Such releases should be among the considerations assessed during development of the water allocation plan for the prescribed area.

4.5.2.1 Farm Dam Development

The major potential threat to environmental water requirements in the ranges is an unsustainable level of farm dam development, in particular on-stream dam development on higher order streams. Excessive farm dam capture levels can impact on aquatic ecosystems by altering the natural hydrology. The impacts may include the complete removal of low level flows and delays in the onset of streamflows downstream of the dam. These impacts may lead to issues for all downstream users, including the environment. Unsustainable levels of farm dam capture have been observed in other areas of South Australia, including the Mount Lofty Ranges (e.g. McMurray 2004; Savadamuthu 2002).

The level of hydrological stress attributable to farm dams is dependent on the volume of total capture and location of the dam itself, both in terms of whether it is on or off stream and also where it is located within the catchment. Generally, the higher the stream order and therefore the larger the proportion of a catchment that is controlled by a dam, the higher the potential for impacts to occur. South Australian sustainable water-use policy sets a limit of no greater than 50% of the median annual runoff to be captured by farm dams.

An analysis of farm dam development levels was undertaken for this study using data from the DEH spatial dataset entitled 'Waterbodies', which has information on farm dam locations and approximate surface areas. Using this dataset and a surface area to volume relationship previously used in farm dam analyses in South Australia (McMurray 1996), total dam storage volumes were estimated using the following formula:

$$\text{Volume} = 0.000215 \times (\text{dam surface area})^{1.26}$$

The total number of farm dams in the Mambray Coast is ~300, and based on the above analysis these have a total storage volume of ~800 ML. The majority of these dams are located on the plains and many may in fact be used for the storage of groundwater.

A high level of development occurs within the Baroota Reservoir Catchment. Dams within this region number around 100, and have a total storage of 160 ML and average1.5 ML in size. This small size indicates that these are likely to be for stock and domestic purposes.

This volume can be compared with the median total yield of the catchment, which Purton and Davies (2005) reported to be ~3503 ML. Although the total volume of dam storage is trivial when compared to the total catchment yield, the proportional capture is not uniform. Most dams are concentrated in the lower southeastern area of the catchment.

In this area, the density of dams appears to be relatively high, and the potential that this might represent an unsustainable volume of storage was evaluated using Stony Creek sub-catchment as an indicator. Upper Stony Creek has a catchment area of 23 km^2, and assuming a uniform areal catchment yield, this corresponds to a median annual yield of ~592 ML. Dam storage volumes within this same sub-catchment are of the order of 72 ML, representing only 12% of the median catchment yield. As this sub-catchment had the highest dam densities observed, it appears that this is not currently a major source of hydrological stress. In below average years however, no streamflow will be seen downstream of even small on-stream farm dams, and it should be considered that the last average year was more than five years ago.

It is important that future dam development should take into account sustainability issues considering the resource as a whole, and the need to allow for environmental water requirements. Factors for consideration include ensuring that sufficient areas of the catchment remain free-to-flow without any farm dam capture. This can be achieved by siting dams off-stream and diverting a proportion of flow to fill them during seasonal high-flow periods. Where farm dams are sited on-stream, these can be fitted with low-flow bypass devices, which only allow for the capture of flow once it exceeds a predetermined threshold.

This then allows for ecologically significant lower flows, such as those common during early seasonal runoff and episodic summer storms, to pass unimpeded.

4.5.3 GROUNDWATER HYDROLOGY

This section is intended to provide a broad overview of the nature of the groundwater resources of the Mambray Coast plain and ranges to assist in understanding the importance of groundwater to the aquatic ecology. For a more detailed technical discussion of various aspects of the resource, including the lithology, the reader is referred to Martin et al. (1998). Clarke (1989) is also a useful reference, referring to the Baroota irrigation area in particular.

The nature and origin of the coastal sediments and underlying hard rock geology is provided in Section 4.3. This discussion also sets the scene for understanding the broad nature of the different groundwater resources. The coastal plain is underlain by a series of sedimentary aquifers collectively known as the Pirie–Torrens Basin. Within the ranges, which form part of the Adelaide Geosyncline, aquifers are exclusively in fractured rock.

4.5.3.1 Sedimentary aquifers of the coastal plain

The two coastal sedimentary basins are orientated north–south and are effectively continuous via a narrow corridor of Cainozoic sediments (Martin et al. 1998). The main feature distinguishing the Pirie Basin in the south of the coastal plain from the Torrens Basin to the north is the origin of the sediments, the Pirie being comprised of marine sediments and the Torrens non-marine (Martin et al. 1998). Although they are geologically distinct as a result of their origin and age, they have historically been considered to comprise a single groundwater basin (Martin et al. 1998).

Aquifers are found within both the shallow Quaternary and underlying Tertiary sediments and, whilst it is not known to be exploited currently, the underlying basement rock may have useable supplies (Clarke 1989). As discussed in Section 4.3, the Quaternary sediments comprise clay, silt and gravel sourced from the Flinders Ranges, and the underlying Tertiary sediments comprise fine sand, which overlie the basement rock and are up to 110 m below ground (Clarke 1989).

Lower salinity areas in the Quaternary aquifers are associated with the major creeks, particularly Baroota and Mambray Creeks (Clarke 1989). This pattern has been observed in shallower wells, but the trend in salinity is not observed in deeper wells. This provides an indication of the importance of streamflows for recharge to shallow aquifers, which is likely to be enhanced where gravel deposits occur within stream beds (Clarke 1989).

A zone of faulting and discontinuities occurs between the hard rock formations of the ranges and sedimentary deposits of the plains (Clarke 1989; Fig. 3). This presents a potential recharge path for water running off the ranges. It also provides a highly transmissive flow path for water to move between aquifers that are in hydraulic connection with this zone. Owing to the lower salinity of water in the deeper Tertiary sediments adjacent to the faulting, this zone is considered to be of importance for the downward movement of water to this aquifer (Martin et al. 1998).

Quaternary aquifers are confined or semi-confined, but in some areas the Tertiary aquifer has a higher potentiometric head than the Quaternary and, as a result, some artesian wells are known in the region of Port Pirie (Martin et al. 1998). No permanent springs or waterholes were found to be supported by the sedimentary aquifers, despite the artesian pressures, and the discharge point is presumed to be under Spencer Gulf.

Despite the lack of permanent surface water on the coastal plain, shallow sedimentary aquifers are ecologically significant in terms of supporting groundwater-dependent vegetation such as river red gums.

Marine outflows from Quaternary, Tertiary and bedrock aquifers are also likely to have an ecological influence on marine ecosystems in Spencer Gulf, but evaluation of this was beyond the scope of the present study.

4.5.3.2 Fractured rock aquifers

In contrast to plains sedimentary aquifers, the fractured rock aquifers of the ranges support a number of ecologically important permanent springs and waterholes. Fractured rock aquifers are characterised by a high degree of spatial variability (Cook 2003), making it difficult to undertake an assessment of the resource to determine recharge processes and flow systems. Fracture characteristics such as orientation, spacing and length are all influential, but are also unique to each system, making predictions on their behaviour very difficult.

Zones where a high degree of faulting or jointing occurs provide preferential flow paths through these systems, and have significance for the interaction of groundwater and surface water. They are commonly associated with surface expressions such as springs and soaks, but they are also likely to function as important areas of groundwater recharge during runoff and streamflow events. There is currently limited information available in relation to the fractured rock systems of the region and, owing to the cost of investigations, this seems unlikely to change. As discussed in the following section, groundwater development is limited within the ranges and it is not thought that there are currently any human activities that pose a threat to the groundwater-dependent permanent pool systems in this area.

4.5.4 GROUNDWATER DEVELOPMENT

The most widespread use of groundwater is for stock watering, which occurs throughout the catchment. In terms of total volumetric extractions however, irrigated horticulture in the Baroota area accounts for the majority of groundwater use. Some irrigation also occurs at Napperby and Nelshaby, but this is relatively minor compared to the activity at Baroota.

Figure 16 shows the current drillholes listed within SA Geodata (the state drillhole database) and, where available, their salinities. The database indicates that there are ~996 drillholes potentially being used for all purposes. This figure should be used with caution as information regarding the status of wells is typically not comprehensive. Over half of the wells were listed as ‘status unknown’ or had no status listing at all. Some proportion of these wells are likely to be no longer in use.

In Figure 16 it can be seen that the highest density of wells is on the plains, and very little development can be seen within the ranges, with the exception of the Baroota Reservoir sub-catchment. The majority of groundwater used on the plains is sourced from the Quaternary aquifers. These are generally of moderate to high salinity, although close to the foothills this may be <1000 mg/L (Martin et al. 1998). Well yields are variable but the majority of wells fall in the range 0.6–2 L/s (Martin et al. 1998). Wells within the Baroota Reservoir sub-catchment also exhibit moderate salinities within the range of 500–5000 mg/L.

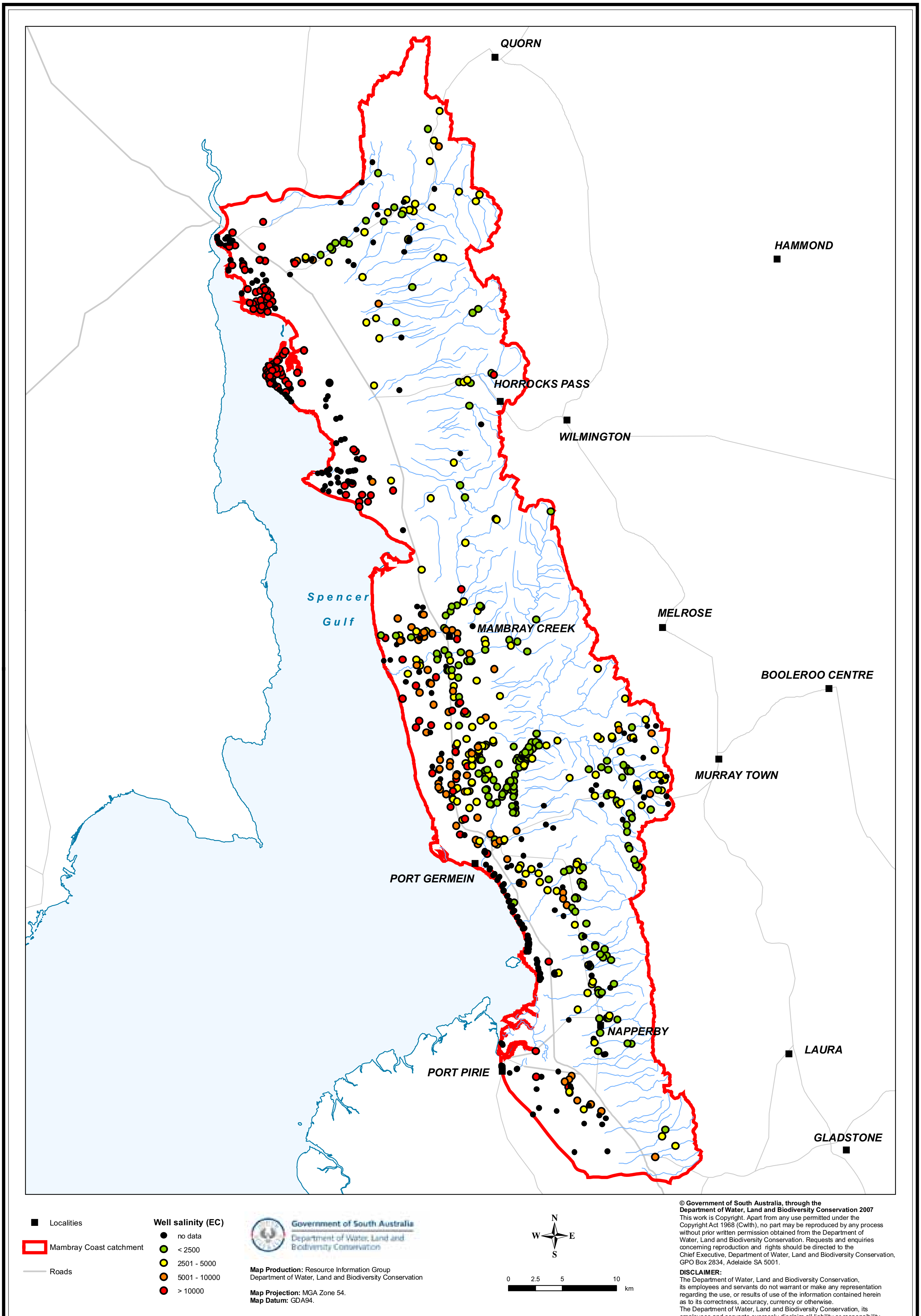


Figure 16. Groundwater development, Mambray Coast

The concentration of irrigation activity downstream of Baroota Reservoir is sustained via permanent recharge to the groundwater due to the hydraulic pressure of water held within the reservoir. This creates a resource of sufficient quality and quantity for use in irrigation. A high density of wells has been developed in the area below the reservoir, with drilling focused on the course of the creek itself.

The sedimentary aquifers are not thought to be directly coupled to the regional fractured rock groundwater flow systems of the ranges (S. Evans, DWLBC, pers. comm., 2005). This suggests that whilst the groundwater extraction in the Baroota irrigation area is supported by enhanced recharge due to subsurface losses from the reservoir, it appears not to currently present any significant risk to the springs and pools observed within the ranges. This also suggests that extraction for irrigation is not causing the decline in spring numbers and flow rates observed over recent years.

The major potential for any impact from groundwater extraction at Baroota, or elsewhere on the coastal plain, is to the condition of riparian river red gums along the creek, which appear to be under stress throughout the catchment. Water allocation planning for the Baroota Prescribed Area will need to account for this to ensure that drawdowns do not impact unnecessarily upon river red gum condition along the creek below the reservoir.

4.6 AQUATIC ECOSYSTEMS

The Mambray Coast comprises a collection of small, ephemeral stream ecosystems that all drain westerly into Spencer Gulf and share no common drainage. Streams of the coastal plain feature no permanent surface aquatic habitat, but a handful of small groundwater-dependent permanent pools occur in the upper catchment of a few streams draining the central Mambray Coast. Seasonal increases in groundwater spring discharge rates result in baseflows that may extend several kilometres along the watercourse, greatly increasing both the area and diversity of wetted habitat.

Due to the relatively high ecological value of permanent surface water, the location of these sites is of interest in understanding the potential for biological interactions between sites. This is important when considering the ecology at landscape or catchment scale. Catchments within the Mambray Coast where permanent pools were identified are discussed in the following section.

4.6.1 LOCATION OF PERMANENT AQUATIC HABITAT

Sites of permanent aquatic habitat were identified through the consultation process (Fig. 17). All of these were in the upper catchments of streams draining the central third of the Mambray Coast, between Nectar Brook in the north and Telowie Gorge in the south.

Sites within all identified catchments where permanent habitat was present were visited during February and/or June 2005. The permanent surface storage at Nelshaby Reservoir was assessed by Seaman (2002) and was not included in the field surveys. The reader is referred to that reference for a preliminary assessment of the aquatic ecology of the reservoir. Baroota Reservoir, as an artificial habitat, was beyond the scope of this study, but due to its potential importance as a migration pathway, especially for fish, one visit was made to conduct fish sampling.

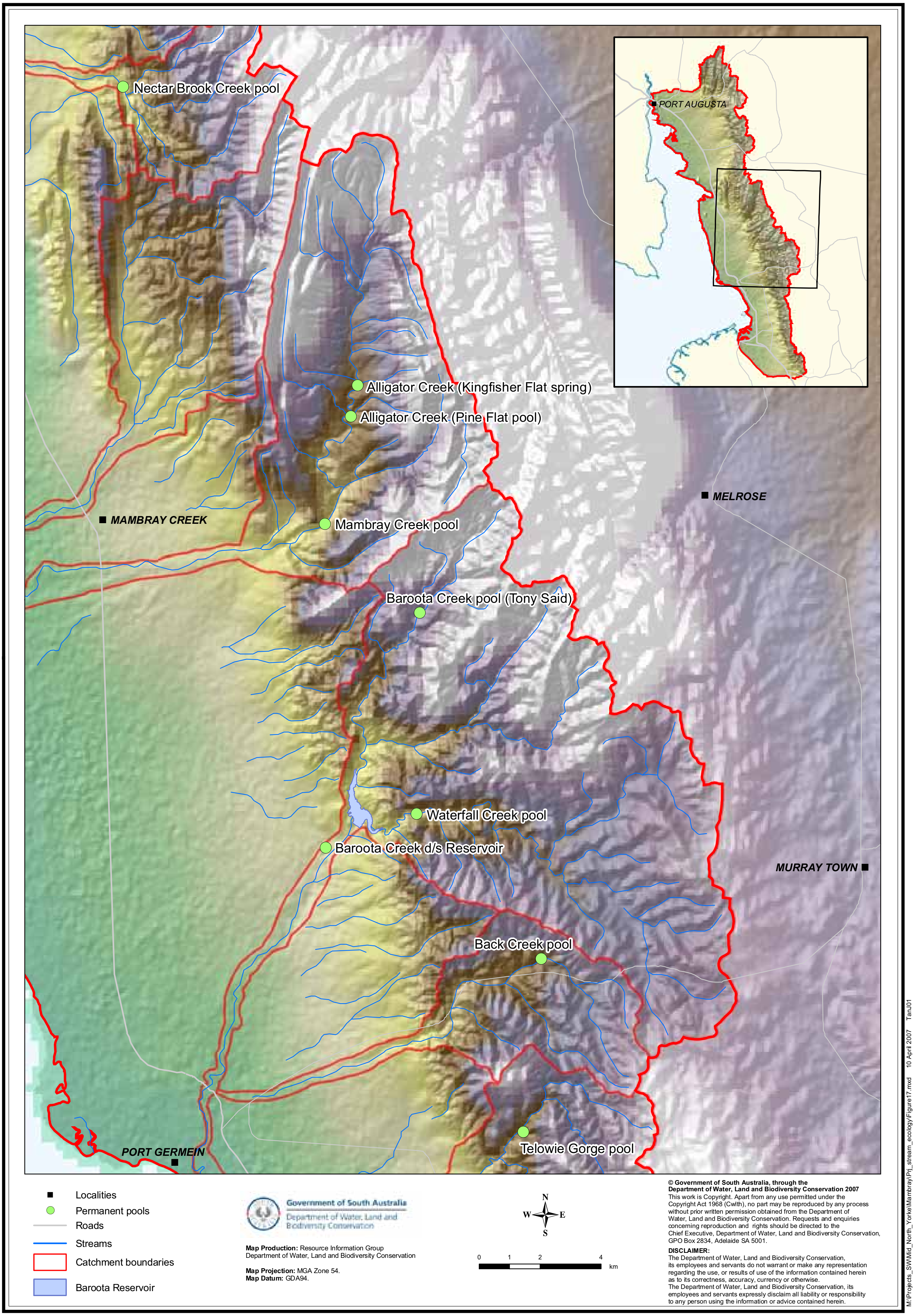


Figure 17. Location of permanent pool habitat, Mambray Coast

Physico-chemical parameters were measured at most sites, in addition to qualitative biological surveys. Two sites were chosen for assessment using the AUSRIVAS model, which rely on the ratio of aquatic macro-invertebrate populations present compared to that which would be expected based on habitat characteristics. This information was complemented by previous data collected by the EPA. Table 4 summarises all the above findings. In addition to the information recorded in the table, riparian vegetation associations were noted at the site and any submerged or emergent aquatic macrophyte species observed were recorded. Frog calls were also noted and waterbird surveys were conducted. The results of all findings are discussed in more detail and the field data sheets are reproduced in Appendix A.

Flows resulting from surface runoff at these sites, whilst ecologically important, are not of sufficient volume or duration to create persistent aquatic habitat. All permanent surface water habitat is therefore groundwater dependent. In-stream springs support permanent pools during the summer when these are reduced to small surface areas and generally shallow depths. From late autumn through to early spring, discharge rates exceed evapotranspiration rates to the point that extensive baseflow is created along the stream channel.

4.6.2 BIOLOGICAL COMPONENTS

This section describes the individual aquatic floral and faunal components of the Mambray Coast by biotic grouping. The ecology of the catchment as a whole is the subject of Section 5.

4.6.2.1 Fish

No native fish species are known to have been recorded from within the catchment, and only one species of fish, the pest species *Gambusia* (*Gambusia holbrookii*), was recorded during the June 2005 surveys. This was present in great abundance in the Baroota Reservoir sub-catchment and downstream in the overflow pool. The species was not found elsewhere on the Mambray Coast.

In addition to the fish surveys, records from the South Australian Museum were reviewed to determine those species that may have been present historically. These indicated that only two introduced species have been recorded within the catchment (*Gambusia* and redfin). There was a single record for redfin within the catchment, which was Baroota Creek, downstream of the reservoir. This fish is a predatory species and can have a significant detrimental impact on native fish. *Gambusia* was recorded from Waterfall Creek within the reservoir catchment and Baroota Creek downstream of the reservoir. Yellow eye mullet and small-mouthed hardyhead have been recorded from Fisherman's Creek near Port Pirie. This area is outside of the catchment but it is likely that these species are also present in the tidal estuaries of the Mambray Coast.

Surface water flows in the catchment rarely connect to the estuaries, and as a result cannot exert seasonal influence on coastal ecological processes such as fish recruitment. Episodic flood events will however be critical in maintaining estuarine habitat by delivering fresh sediment and nutrients to the estuarine environment. These irregular events may produce local boom cycles in near-shore marine ecology, such as major spawning events in fish and other marine biota. Ambient regional groundwater marine outflows may be important for the

Table 4. Summary data from field surveys, Mambray Coast.

Site name	Catchment	Description	Elevation (m AHD)	Dissolved oxygen (mg/L/%sat)	pH	EC (mS/cm)	Macro-invertebrates Sampled/ AUSRIVAS rating	Fish Sampled/ present
Waterfall Creek	Baroota Creek	Small pool within baseflow reach	195	8.14 / 75	9.27	4.5 (pool) 11.27 (backwater)	Yes/B	Yes/*Gambusia*
Baroota Reservoir	Baroota Creek	Artificial open water habitat	NR	NR	NR	NR	NR	Yes/No
Downstream Baroota Reservoir	Baroota Creek	Constructed channel pool maintained by reservoir outflow	70	NR	NR	NR	NR	Yes/*Gambusia*
Nectar Brook	Nectar Brook	Confined valley permanent pool	180	5.65 / 61	7.91	2.61	Yes/A	Yes/No
Mambray Creek	Mambray Creek	Partly confined valley, multiple channel pool	160	0.58 / 5.5	6.8	1.055	No/A*	Yes/No
Telowie Gorge	Telowie Creek	Bedrock scour pool	215	1.75 / 17	7.9	0.572	NR	Yes/No
Pt Germein Gorge	Back Creek	Small pool within confined valley	300	NR	NR	NR	No/B*	Yes/No

*Autumn edge AUSRIVAS data collected 1995–99 (source: EPA, collected under the Monitoring River Health Initiative); NR = parameter not measured maintenance of estuarine processes. Given the hyper-marine salinities observed in upper Spencer Gulf, it is likely that groundwater discharge may help to ameliorate these naturally high levels, as well as provide a source of nutrients.

Sampling undertaken for this study does not prove that no self-sustaining native fish populations are present, but these are clearly not widely distributed. Fish are sensitive to changes in their environment and can be good indicators of watercourse condition but, due to the limited diversity represented, fish do not appear suited for use in monitoring programs within the focus region.

4.6.2.2 Anurans

Frogs and toads were not a specific target of sampling, but occasional calls were heard at most sites and these were all identified as being of the Common Froglet (*Crinia signifera*), which was also observed at two sites. Large tadpoles observed in Telowie Gorge during June 2005 are thought to most likely be those of the Eastern Banjo Frog (*Limnodynastes dumerili*) due to the size, time of year, habitat and known distribution. This level of diversity is not considered representative of the region however, as the time of day and season that field surveys were undertaken was not optimal for detecting anuran activity. In addition to the above two species, the EPA Frog Census has recorded the following frogs in the region since 1998:

- Brown Tree Frog *Litoria ewingii*
- Spotted Grass Frog *Limnodynastes tasmaniensis*
- Bibrons Toadlet *Pseudophryne bibronii*
- Painted Frog *Neobarrachus pictus*
- Streambank Froglet *Crinia riparia*

In 1962, zoologists from the University of Melbourne discovered the frog species *Crinia riparia* at Mambray Creek and Alligator Gorge — and it has been found to occur throughout the Flinders Ranges. This species is endemic to the Flinders and Gammon Ranges, and is the only species of frog unique to South Australia. The species is thought to breed in spring, laying eggs under rocks adjacent to flowing streams (Hutchinson & Tyler 1996). Tadpoles are adapted to flowing environments and feed on encrusting algae (Piller, cited in Boulton & Williams 1996, p.105). It is likely that the species would be present throughout the catchments where seasonal baseflows create flowing water habitat.

For further information on the frogs and toads of South Australia refer to the Frog Census website <http://www.epa.sa.gov.au/frogcensus/>.

4.6.2.3 Macro-invertebrates

Macro-invertebrate diversity in the Flinders Ranges is considered to be high, with over 400 species known. Some of the more common animals found include chironomid midge larvae, caenid mayfly nymphs, oligochaetes and biting midge larvae (EPA & AWQC 2003). These groups also featured prominently within samples collected for this study and analysed by the AWQC (see App. B). Less common species previously recorded from Mambray Creek include the stoneflies *Riekoperla naso* and *Dinotoperla Evansi,* which are endemic to the state (Boulton & Williams 1996), and the leptocerid caddisfly *Lectrides varians* (EPA & AWQC 2003).

Two sites, Nectar Brook and Waterfall Creek (Baroota Creek Catchment), were selected for macro-invertebrate sampling and analysis using the AUSRIVAS protocols. The sites were sampled during June 2005 and assessed using the 'Autumn Edge' AUSRIVAS model by the AWQC. The model returned a Band A (indicating reference condition) for the Nectar Brook site, and a Band B (indicating a slightly impaired condition) for the Waterfall Creek site.

The Nectar Brook site had both a higher diversity and abundance of animals with 1127 animals representing 34 taxa collected, compared to only 264 animals from 27 taxa at Waterfall Creek. Figure 18 shows the percentage relative abundance of animals grouped together by order or higher taxonomic level. The most abundant taxa from both sites were from the order Diptera, or true flies, comprising 63% of the animals from Waterfall Creek and 85% of the Nectar Brook sample. Animals from the order Ephemeroptera (mayflies) were the next most abundant grouping, comprising 23% of the total Waterfall Creek sample but only 4% at Nectar Brook.

Nematode species constituted ~8% of the Waterfall Creek sample, but were absent from Nectar Brook. Conversely, *Austrochiltonia australis,* a common amphipod species belonging to the family Ceinidae, was abundant at Nectar Brook but absent from Waterfall Creek.

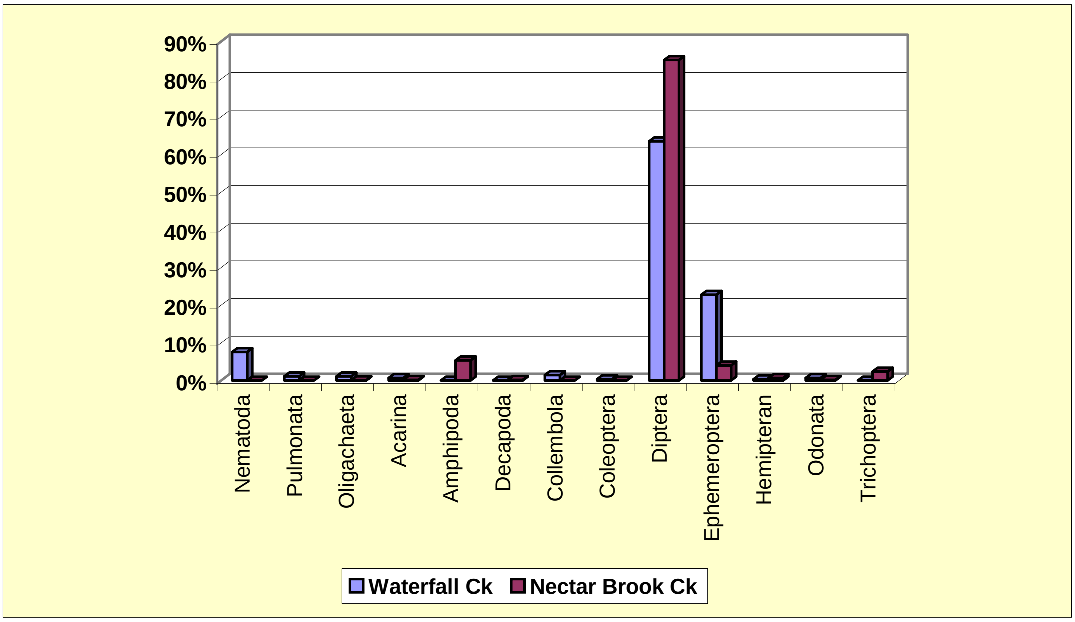


Figure 18. Relative abundance of animals in total sample by order grouping (or above).

Figure 19 shows the macro-invertebrate data grouped by family (or higher where this level of taxonomic resolution was not possible). The Nectar Brook sample was predominantly comprised of animals from the Dipteran family Ceratopogonidae (biting midges). This represented over 80% of the abundance at the site. Waterfall Creek was dominated by the Chironomidae (non-biting midges), with 60% abundance.

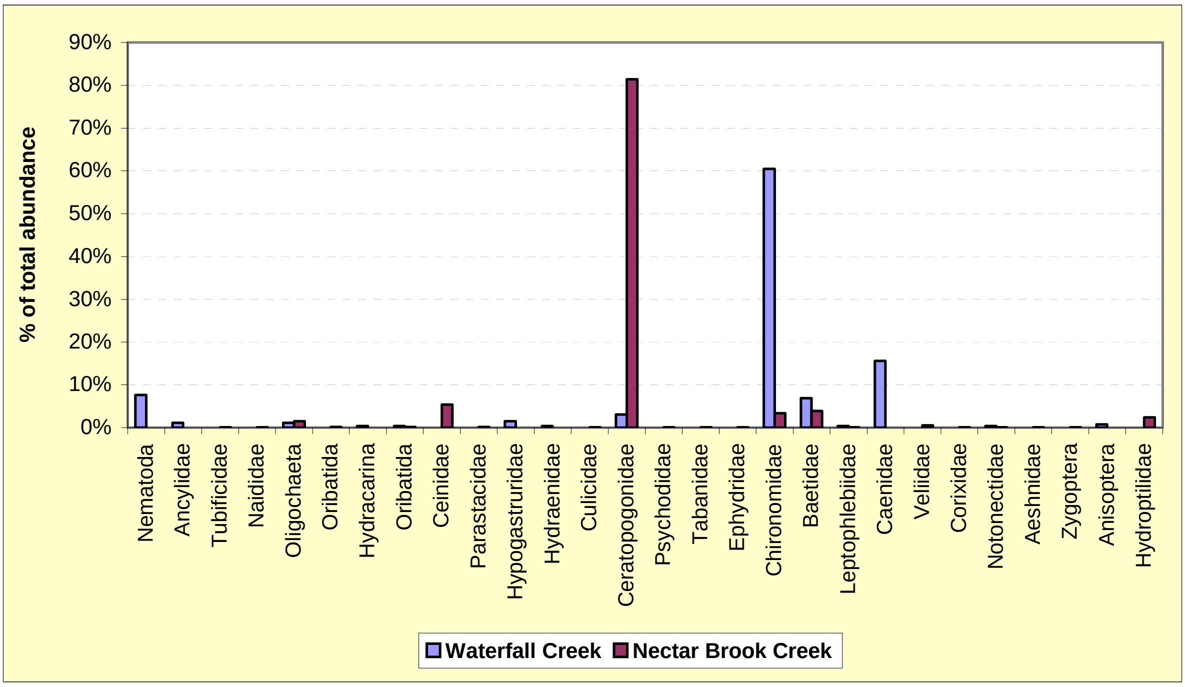


Figure 19. Relative abundance of total sample by family grouping (or above).

The SIGNAL (Stream Invertebrate Grade Number Average Level) index was developed to provide an indication of the sensitivity of macro-invertebrate families to water quality parameters such as salinity and alkalinity (Chessman 2003). SIGNAL scores for the majority of animals collected at both sites are in the range 1–4 (out of a possible 10 for the most sensitive of animals) implying that the macro-invertebrate community is comprised of species tolerant of water of high salinities.

4.6.2.4 Waterbirds

The SA Museum database has records of over 100 species of birds from the Mambray Coast and 17 species have a known requirement for aquatic habitat (Table 5). The typically woodland landscape in which the permanent pools were located was more suited to passerines (perching songbirds) than true waterbirds. Many of the species in Table 5 are associated with larger water bodies or coastal habitat. Estuarine and coastal salt marsh areas of the catchment represent good waterbird habitat for species such as stilts and cormorants, but these areas were not surveyed as part of this study. Freshwater inputs during flow events may well increase the productivity of these habitats, supporting increased populations of waterbirds.

Only Australian Wood Ducks were sighted during field surveys, and these were only found within Baroota Reservoir sub-catchment. This cannot be considered indicative of the full range of waterbirds that visit the permanent pools of the ranges as surveys were opportunistic and were limited to a 20 minute period. Seasonal uses of the region, for example during migrations, cannot be ruled out.

The small size of the naturally occurring permanent aquatic habitat within the ranges means these are unlikely to support large numbers of waterbirds. Hence, provision of waterbird habitat is not considered a major ecological value supported by these ecosystems.

Table 5. SA Museum waterbird records from the Mambray Coast.

Scientific name	Common name
Anas gibberiffrons/gracilis	Grey Teal
Anas superciliosa	Pacific Black Duck
Ardea pacifica	White-necked Heron
Calidris ruficollis	Red-necked Stint
Charadrius ruficapillus	Red-capped Plover
Chenonetta jubata	Australian Wood Duck
Cladorhynchus leucocephalus	Banded Stilt
Egretta novaehollandiae	White-faced Heron
Elseyornis melanops	Black-fronted Dotterel
Gallinula ventralis	Black-tailed Native-hen
Phalacrocorax melanoleucos	Little Pied Cormorant
Phalacrocorax varius	Pied Cormorant
Poliocephalus poliocephalus	Hoary-headed Grebe
Porphyrio porphyrio	Purple Swamphen
Tachybaptus novaehollandiae	Australasian Grebe
Vanellus miles novaehollandiae	Masked Lapwing
Vanellus tricolor	Banded Lapwing

Source: SA Museum

4.6.2.5 Aquatic and riparian plants

Riparian species: vegetation of the upper catchment adjacent to low order streams were often comprised only of terrestrial species such as *Callitris* or *Acacia*, and evidently streamflow is of insufficient volume or duration to exert an influence on these associations. In larger catchments such as Baroota Reservoir, flow-dependent species most notably river red gums were present. River red gums were also common on larger streams on the coastal plain, but in many cases appeared to be under stress.

Outside of conservation reserves, the riparian zone lacked any understorey, or where present this consisted entirely of sedges, notably *Juncus* spp. Brown and Kraehenbuehl (2000) listed a number of shrub species that would have been present in the adjacent Broughton River Catchment. Many of these were present in the riparian areas of the conservation protected sites, suggesting that they have been cleared from the grazed areas of the ranges. Species include Golden wattle (*Acacia pycnantha*), Sweet bursaria (*Bursaria spinosa*), Weeping emu bush (*Eremophila longifolia*) and Native myrtle (*Myoporum montanum*). With the possible exception of Native myrtle, these are not recognised riparian species. Under natural conditions the species listed above would probably have been present throughout the ranges and would provide equivalent ecological functions to riparian species.

Emergents — Sedges: were often found to be the only riparian species but diversity was limited, with *Juncus krausii* the most abundant. *Cyperus gymnocaulos* was also common. Other species observed included *Baumea juncea*, *Cyperus vaginatus*, and *Isolepsis* sp.

Emergents — Reeds: *Typha* sp. was the most commonly observed reed, but was present in only small stands around pool edges in the upper catchments. Downstream of Baroota Reservoir, extensive stands of *Typha* and *Phragmites* were present in the overflow channel and the downstream pool.

Submerged species: The dominant submerged plants were unbranched filamentous green macro-algae such as *Spirogyra* sp and whorled or branched species, in particular the Stoneworts *Chara* sp and *Nitella* sp. The vascular plants Watercress (*Rorippa* spp.) and Water buttons (*Cotula coronopifolia*) were also present in some locations (see App. A).

5. DISCUSSION

5.1 ECOLOGICAL CHARACTER

The watercourses of the plains along the Mambray Coast comprise ephemeral channels that flow only following extensive rainfall on the ranges. Watercourses found within the headwaters of the ranges are also predominantly ephemeral, but a number of small, spring-fed permanent pools connected by reliable seasonal baseflow also occur. These permanent surface water features are an ecological asset to the system as a whole and are reliant upon the surface expression of groundwater to persist.

Within the setting of ephemeral and intermittent streams, aquatic organisms without a desiccation-resistant life-history phase are able to persist in the system only by retreating to refugia pools as flow ceases. Refugia pools in intermittent streams have previously been found to have the highest biodiversity measured for all aquatic habitat types immediately following the cessation of flow (Boulton & Lake 1992; Acuña et al. 2005). When suitable flow conditions present, surviving organisms are able to re-colonise the catchment, maintaining a higher level of biodiversity at the landscape scale.

Owing to this re-colonisation potential, the connectivity between refugia pools is often a key consideration in studies of ephemeral streams. Most catchments of the Mambray Coast only feature one or a few pools at most, so re-distribution of organisms between pools during flow events is not considered a key aspect of the ecology. The possible exception to this is Baroota Creek sub-catchment, where the relatively high number of refugia and their distribution across the landscape may enable significant migration of fauna during flow events, possibly via the reservoir itself.

Irrespective of this, catchments with permanent refugia can be expected to support organisms that cannot persist in temporary waters. Hence it is important from an ecological perspective to distinguish between those catchments that are purely ephemeral, and those where permanent water is found. Such catchments within the Mambray Coast can be found in the previous section, in particular Figure 17. Prior studies have highlighted the location and ecological importance of permanent refugia pools on high order streams within all major river systems of the Mid-North (Favier et al. 2000, 2004; Risby et al. 2003; VanLaarhoven et al. 2004).

As a result of their relatively high biodiversity values, refugia pools were a focus of field surveys, but the ecological value of pools was comparatively low relative to other similar features in the Mid-North. The community composition was dominated by generalist organisms that are tolerant of moderate water quality, with simple detritus-based food webs. This should not be seen to imply that the systems were degraded. Many sites are within catchments under conservation protection and were not under threat from human activities. Although there are clear differences between conservation areas and those under a grazing regime, no sites were considered to be heavily impacted.

The current condition is thought to be representative of a system responding to extended drought conditions. In order to place the findings of the field surveys and information review in context, it is important to consider the overall nature of the stream ecosystems and the manner in which they function. The remainder of this chapter discusses the significant structural and ecological driving factors that influence the composition and condition of these systems, concluding with a discussion of perceived threats.

5.1.1 FLOW-RELATED ECOLOGY

A major driving factor for the ecology of flowing waters is the pattern and seasonality of flow, including periods of no flow. Streamflow is recognised as a key organisational factor in the ecology of lotic (or flowing) aquatic ecosystems (e.g. Walker et al. 1995; Richter et al. 1996; Poff et al. 1997; Bunn & Arthington 2002). The range of observed streamflow conditions is referred to as the flow regime. Organisms have adapted and evolved in response to this, and it is typically described in terms of the magnitude, duration, frequency and rates of rise and fall averaged over some period (Richter et al. 1996; Poff et al. 1997). Flow variability within these average values, both seasonal and inter-annual, is also a critical feature of the flow regime that influences the patterns and processes of stream ecosystems.

Ephemeral watercourses are generally defined as being influent or losing streams, having their beds well above the level of the groundwater table (Mosley & McKerchar 1993; Dingman 2002; Gordon et al. 2004). As no groundwater can enter the watercourse, these streams only feature surface water flows for short periods during, and immediately following, rainfall. All plains watercourses within the study area can be considered to have ephemeral lower reaches after leaving the ranges in the majority of years. Although the watertable may rise to levels where temporary riparian swamps may form during wet years, the presence of surface water on the coastal plain is dependent on rainfall on the ranges generating periods of major streamflow.

Within the ranges, runoff is more common, and streamflow events in headwaters can occur at any time throughout the year. The limited available data from Saltia Creek suggests that while these events may occur during any season, they will not occur every year. Additionally, the duration of continuous flow periods is greater during winter and spring (see Section 4.5.1.2). In contrast, at least for the intermittent stream reaches surveyed, increases in spring discharge rates during autumn create seasonal baseflow[1] within the stream channel that may extend for several kilometres and persist for several weeks to a few months. The ecologically significant feature that distinguishes baseflow from surface runoff flows is its predictability, as baseflow occurs every year at a predictable time, driven by seasonal decreases in the evapotranspiration rates in the catchment.

Effectively, these flow patterns subject the stream biota to two flow signals:

- **surface runoff flow driven by climatic cycles** — is seasonally unpredictable, of good water quality, of varying duration, discharge volume and rate of change
- **seasonal baseflow driven by the volumes of groundwater in storage and annual climatic cycles** — is seasonally reliable, of moderate quality, of constant, low volume and has a relatively slow rate of change.

Periods of drought and flood events are the extremes of disturbance to which stream ecosystems are subjected and are considered to exert a major influence on community structure (Lake 2000). The two flow patterns described and their interaction defines the

[1] The term ‘baseflow’ refers to that proportion of surface flow derived from groundwater, and implies flowing water rather than still pools, although the latter still derive their permanence from groundwater.

disturbance regime for the ecosystems. Ecologists categorise different forms of disturbance (pulse, press or ramp) according to the manner in which the forces they exert on an ecosystem change in intensity over time (Lake 2000; Downes et al. 2002). Seasonal drought is considered to represent a press type disturbance, where the impact occurs over an extended period and is of constant intensity (Lake 2000; Humphries & Baldwin 2003). Supra-seasonal droughts are considered to comprise a ramp disturbance, where the forces concerned continue to increase the longer the drought continues (Lake 2000; Humphries & Baldwin 2003).

The type of disturbance has been found to produce a different response on the observed patterns of biodiversity recovery (Lake 2003). Recovery from seasonal droughts tends to follow predictable trajectories, whereas the recovery from longer term droughts is less definite (Lake 2003). This is an important conceptual point when evaluating the representativeness of the observed condition of a stream ecosystem subjected to a 'snapshot' assessment such as the current study. This is also a consideration for the interpretation of monitoring program data where conclusions are to be drawn regarding the condition of the ecosystem.

The effects of the disturbing force should be distinguished from the response of the biota to its effects. Responses of aquatic fauna are often found to exhibit a stepped response, where some critical threshold is crossed beyond which the animal cannot persist (Humphries & Baldwin 2003; Boulton 2003). A simple example of this would be the difference between the effects of a gradual reduction in water level, and the total loss of a pool. Gradual declines in depth may not produce any dramatic differences in the community present until it dries completely, resulting in the loss of all aquatic fauna. In this example the threshold concerned is the drying and loss of the habitat.

Compared to less predictable surface runoff, the seasonal reliability of flows resulting from groundwater baseflow means that these surface expressions will provide the baseline conditions for the survival and seasonal dispersal of organisms. Aquatic organisms are adapted to this, resulting in a community necessarily tolerant of moderate salinity, with generalist habitat requirements and feeding strategies. This can be seen in the composition of the macro-invertebrate and submerged plant communities present.

Superimposed on these patterns however, is the response of the stream ecosystems to the ramp disturbance of climatic drought. It is likely that during climatic periods where surface runoff occurs regularly, stream biodiversity will increase. As conditions suitable for biota with specialist habitat requirements (such as sand–gravel riffles free of fine sediment) or physiological tolerances become available, the more mobile of these taxa will re-populate the habitat. Conversely, during dry periods, conditions such as water quality will deteriorate and available habitat will decrease in diversity and area, resulting in only tolerant organisms being able to survive.

A lag effect has been observed in intermittent stream ecosystems recovering from drought. Boulton (2003) noted that drought-sensitive organisms including stoneflies and caddis flies were removed from intermittent streams due to the effects of drought conditions over a number of years. Once removed from the system, these were not able to recruit the following year despite a return to flows that exceeded baseflow conditions. That author used this example to highlight the need for long-term datasets in order to interpret stream condition effectively. Similarly, Closs and Lake (1994) observed that the re-colonisation of predatory animals lagged behind a general increase in biodiversity observed as the period of streamflow continued. This highlights the importance of interpreting data in terms of the climatic and flow history of the site, and clearly lack of data over even a single annual cycle is a limitation of the work undertaken for this assessment. The preceding discussion does however help to place the observations made during this study into the context of system behaviour over a full wet–dry climatic cycle.

5.1.2 THE IMPORTANCE AND SIGNIFICANCE OF GROUNDWATER

The presence of permanent surface water pools with seasonal connecting baseflows is a feature of ecological significance that should be recognised as being dependent upon groundwater surface expression. Hence, the intermittent reaches identified within these streams under current climatic conditions should be categorised as being groundwater-dependent ecosystems.

Hatton and Evans (1998) categorised groundwater-dependent ecosystems of this nature as river baseflow systems, although this perhaps suggests a larger scale system than found within the study area. As with all groundwater-dependent ecosystems, a key to understanding their environmental water requirements is to determine their degree of dependence upon groundwater. Hatton and Evans (1998) suggested five levels of dependency, ranging from entirely to opportunistically dependent. For the refugia pool systems discussed here, the level of groundwater dependence will vary in accordance with the availability of surface runoff, which in turn depends on climatic conditions. Hence, currently for much of the year, in the majority of years, these groundwater-dependent ecosystems will be entirely dependent upon groundwater as no significant alternative source of water is available.

A further category of groundwater-dependent ecosystems found within the Mambray Coast is phreatophytic (groundwater dependent) vegetation, and river red gums fall within this category. The dependence of red gums on groundwater is also dependent upon whether or not alternative sources of water are available. The decline in condition of many of the coastal plain red gums found adjacent to watercourses suggests that watertable decline and associated increases in groundwater salinity are causing physiological stress to these populations.

As they are dependent on groundwater, the permanent surface expressions are also indicative of the strong interaction between surface and groundwater in the ranges. Where this interaction occurs via sediments below the stream bed, it becomes increasingly significant to the ecology and is referred to as the hyporheic zone (Brunke & Gonser 1997; Boulton et al. 1998; Hose et al. 2005). By providing an hydraulic link between the surface and sub-surface habitat, hyporheic zones provide refuge from drought and flood disturbance for suitably adapted organisms (Brunke & Gonser 1997). The movement of water can occur in either direction, and each supports distinct ecologically important processes and considerations. Downwelling stream water provides dissolved oxygen and organic matter to biota within the hyporheic zone, whereas discharging groundwater exposes organisms to water of a different chemical composition to surface runoff, supplying stream organisms with dissolved nutrients, but also typically a higher concentration of salts than surface runoff.

Groundwater is typically higher in dissolved ions than surface water (Gordon et al. 2004), and the difference in chemistry between water sources exerts a significant influence on the aquatic ecology of Mambray Coast streams. Observed conductivities in surveyed streams exhibited a broad range of concentrations varying between 500–4500 EC (~340–3000 mg/L). The uppermost limit represents a moderate level of salinity, and well above that of surface water dominated streams. Two recently published categories of water quality in Australia (Neilsen et al. 2003; NLWRA 2002) classify freshwater as having an upper boundary of 5000 EC, hence some of the stream ecosystems could be considered to be borderline saline by definition.

While this is a natural feature of the system, salinity is a major structuring factor in aquatic biological systems (Gordon et al. 2004) and imposes a limitation on the diversity of the plants and animals that are able to survive. Salinities of >3300 EC for example have been found to produce significant reductions in emergence among macro-invertebrate species and adverse effects on freshwater fish (Kimberley et al. 2003). Whilst detailed plant inventories were not undertaken, it was apparent that the aquatic plant community was not highly diverse. Submerged vascular plants were virtually absent, with this niche filled by filamentous green algae and charophytes. While this is in part due to the limited area of permanent water, this is also attributable to the salinity of the groundwater. Kimberley et al. (2003) suggested that salinities >2000 mg/L are limiting to submerged vascular plants, whereas algae and charophytes are tolerant of salinities up to at least 10 000 mg/L.

Groundwater can also contain important nutrients beneficial to stream productivity. Spring-fed pools similar to those along the Mambray Coast occur throughout the Flinders Ranges. Following significant work on these systems, Boulton and Williams (1996) stated that the aquatic fauna of flowing streams of the southern Flinders Ranges are broadly similar to that found within the central and northern ranges (Boulton & Williams 1996). Within many Flinders Ranges streams, the availability of nitrogen has been suggested as the most important factor limiting productivity (Boulton, in Boulton & Williams 1996, p.104), and groundwater supporting many of the springs within the Flinders has previously been found to be naturally high in nitrogen (Boulton & Williams 1996). Concentrations of nitrogen within these streams were found by the same authors to decrease rapidly with distance from the spring source, as it is taken up by primary producers notably macro-algae.

In response, a longitudinal distribution pattern of green macro-algal species was commonly observed (Boulton & Williams 1996). As was found in Mambray Coast streams, macro-algae is an important component of in-stream flora in other parts of the Flinders Ranges. For example, it was reported as a key food source for aquatic fauna including tadpoles, which demonstrated a feeding preference for certain species (Boulton & Williams 1996). The potential for changes to the macro-algal diversity in small stream ecosystems to have been driven through riparian clearance and introduction of stock has not been evaluated, but has the potential to alter natural patterns of biodiversity.

5.1.3 BIOTIC AND ABIOTIC STRUCTURING FACTORS

More complex aquatic habitat generally supports higher levels of biodiversity (Minshall & Robinson 1998; Vinson & Hawkins 1998), presenting optimal conditions for a wider range of individual species preferences. A high degree of hydraulic and physical complexity provides for a greater range of functional approaches to feeding and increased opportunity to avoid predation. Habitat complexity is dependent upon abiotic factors such as substrate type and diversity, pool dimensions, flow velocity and light environment, and also upon factors relating to biological components such as the vegetation present, both aquatic and riparian (Gordon et al. 2004).

In terms of hydraulic habitat, refugia pools provide only a still-water environment, and not all aquatic organisms are adapted to this. Still-water habitat limits opportunities for filter feeding organisms that require the movement of water to provide an adequate flux of organic nutrients. Flowing water also tends to create turbulence that increases the concentration of dissolved oxygen in the water column. Several smaller pools visited had an extremely low oxygen tension which would exclude all aquatic organisms incapable of using atmospheric oxygen, for example through aquatic surface respiration.

The diversity of the stream substrate also plays a role in structuring the aquatic community (Downes et al. 1998; Minshall & Robinson 1998). The deposition and build-up of sediment on all stream beds during low flow periods imposes limitations on substrate heterogeneity. While this accumulation is a natural process during climatic drought conditions, such build up reduces the diversity of available habitat. Fine sediments can smother high value habitat, notably stony gravel and sand by blocking the interstitial pores of coarser sediments. This process, known as colmation, also has the effect of reducing material fluxes with the hyporheic zone, with resulting implications for the ecology and hydrology (Brunke & Gonser 1997). Other effects of sedimentation include cover and loss of rocky substrates, which reduces available attachment sites for epilithic (growing on rocky surfaces) organisms, and it has also been found to reduce the rate of leaf litter breakdown (Bunn 1988), which has implications for nutrient cycling within pools. Significant leaf litter was present in some pools, which may be indicative of a low rate of leaf decomposition.

Aquatic macrophytes can increase the range of habitats available, and both emergent and submerged species can play a role in this regard. Emergent reeds such as *Phragmites* and *Typha,* although not thought to contribute significant carbon directly to in-stream food webs, tend to provide additional habitat complexity benefiting a range of animals from macro-invertebrates to water birds. Only limited reedbeds were observed within the ranges, although these were extensive in the overflow channels for Baroota Reservoir. These species need permanent inundation and the limited surface water habitat is restricting the extent of reeds. Stock damage was also evident at Waterfall Creek, with both reeds and sedges subject to grazing pressure, further restricting their growth.

Submerged aquatic vegetation also provides additional habitat complexity. In addition to contributing to stream primary production though photosynthesis, submerged plants are an important habitat structural feature providing physical shelter and three-dimensional complexity. While they are not thought to contribute significant amounts of carbon to stream food webs, they provide an additional growth substrate for periphyton, which is recognised as a key food resource in aquatic ecosystems (Bunn et al. 1999). In the refugia pools surveyed, macro-algae fill the in-stream vegetation niche featuring both unbranched filamentous and more complex branching forms, notably charophytes.

As a taxonomic grouping, macro-algae, and charophytes in particular, have life histories well suited to ephemeral and intermittent water bodies. In addition to having a broad salinity tolerance, they are able to reproduce from vegetative fragments or via desiccation-resistant propagules known as oospores. Coupled with the high metabolic rate exhibited by the group, this allows charophytes to rapidly extend their range once connecting flows commence. At the Waterfall Creek site, individuals were observed over a kilometre from the refugia pool and appear to be present wherever aquatic habitat is available within weeks of inundation.

Charophyte oospores, and other desiccation-resistant algal propagules, are also redistributed by waterbirds through ingestion and external transport pathways (Figuerola & Green 2002; Van den Berg et al. 2001). This suggests that the species present would be widespread across the region. Although they are a major structural component of aquatic ecosystems, freshwater macro-algal taxonomy in Australia is currently unclear (Casanova 2005) and the biodiversity represented in South Australia is poorly known. This is considered to be an important gap in knowledge relating to the biodiversity of small stream ecosystems throughout the state.

The structure of riparian vegetation has implications for stream ecosystems in terms of providing both shade and terrestrial carbon inputs including leaves, bark and woody debris. Riparian vegetation of surveyed streams differed markedly between land uses. Most larger streams had a discontinuous river red gum canopy both within the ranges and along larger plains watercourses. The understorey however, varied considerably within the ranges, where a diverse range of shrubs and small trees were present in conservation areas, particularly in the upper catchments. Although these were generally not true riparian species, they were present in the stream-side zone and were functionally equivalent. In contrast, grazed and cropped areas had only simple understories, presumably the result of clearance. These comprised sedge species such as *Juncus* within the ranges, and terrestrial grasses on the plains. The clearance of the riparian zone leads to changes in stream ecosystem function relating to the influence this exerts on the stream food web due to increased amounts of direct sunlight and decreased input of terrestrial carbon.

An increased light environment in the stream favours photosynthetic organisms such as macro-algae and macrophytes, yet these have been shown to not contribute significantly to stream food webs (Bunn et al. 1999). Periphytic algae, especially diatoms, are thought to be a higher quality food source for aquatic animals and have been shown to be more closely linked to in-stream productivity in small streams (Bunn et al. 1999). These are more abundant in shaded and generally lower light environments (Bunn et al. 1999).

Higher light penetration also leads to elevated stream temperatures that will reduce the amount of dissolved oxygen present within the water column, but increases the metabolic rate of aquatic biota, further increasing oxygen demand and metabolic waste accumulation. In this aspect, the presence of charophytes in particular is likely to have a beneficial effect by helping to maintain dissolved oxygen concentrations, particularly in still-water environments. A recent study found that one species of *Chara* in a Mediterranean stream had a mean annual metabolic rate almost 50% higher than periphytic algae (Velasco et al. 2003).

The limited extent and diversity of permanent aquatic habitat can be seen in the structure of stream food webs, which appear to be simple relative to more extensive aquatic systems. This was evident in the macro-invertebrate samples (Section 4.6.2.3; App. B), which were representative of a generalist community with broad environmental tolerances. Most animals collected were grazers of periphyton or detritivores, and only a limited number of potentially predatory animals were collected. This community functional composition has previously been observed in intermittent streams in Victoria, where re-colonisation by predatory species was found to increase with the duration of the period of constant streamflow (Closs and Lake 1994).

Hence, the sampling time within the flow history must be considered when interpreting the results of macro-invertebrate sampling. For example, the lower abundance of animals found at Waterfall Creek may have been due to the much greater extent of flows and the higher flow rate as animals naturally dispersed along the watercourse. However, flow alone cannot explain the differences in the suite of species that were present. Although similar in functional composition, the two sites demonstrated large differences in relative abundance between family groups (Fig. 19). This may simply be evidence of the importance of stochastic processes in small refugia pools, where a single egg-laying female may have a large influence on the overall population structure (Smith et al. 2004). Another possible explanation for this is the water quality, as Nectar Brook was of a much lower salinity and the influence of salinity on community structure is discussed in the preceding section.

A further possibility is suggested by the simple food web structure of the pools and lack of higher predators. Irrespective of whether the system was naturally devoid of fish, tadpoles or predatory macro-invertebrates are likely to currently be the top predators. Hence, top down pressure on macro-invertebrate populations from the introduced fish *Gambusia*, which has previously been reported to reduce zooplankton and littoral invertebrate diversity (Timms 1992), may be influencing community structure. Evidence of this may be found in the B rating (indicating a slightly impaired condition; see App. B) from AUSRIVAS modelling at the Waterfall Creek site, which is attributed to a range of expected taxa missing from the sample, an example being Corixidae, or water boatmen. Water boatmen are a known preferred source of food for fish (Gooderham & Tsyrlin 2002; Wade et al. 2004). They are also capable fliers, which should enable wide and rapid distribution and re-population (Gooderham & Tsyrlin 2002). Corixidae are often the first to colonise newly available aquatic habitat (Wade et al. 2004). *Gambusia* are visual predators (Bence & Murdock 1986) that feed from all parts of the water column (Lloyd 1987). Hence, they may well account for the absence of water boatmen and possibly other missing taxa at the site such as amphipods.

The impact of *Gambusia* will be greater than might be expected in other habitats due to the shallow dimensions of the pools and lack of habitat complexity providing refuge from predation. Shallow, slow-moving water is preferred habitat for the species, and the high density of fish observed (which numbered in the hundreds at the Waterfall Creek site) is of concern. In high numbers, these fish are known to feed on the young and eggs of native fish and also to feed on the larvae of small anurans such as *Crinia* spp.(Blyth 1994). Among the reported impacts of *Gambusia* is declines in NSW frog populations (Phipps 2000). Tadpoles in Flinders Ranges pools exert preferential grazing pressure, thereby influencing the species of macro-algae present (Piller, in Boulton & Williams 1996, p.105). This is a further example of potential top-down influence on community structure, where predation of tadpoles by *Gambusia* may in turn alter the observed composition of macro-algae.

The failure to locate any native fish species does not necessarily mean that no populations survive in these streams, but if they do then they are clearly not widespread or abundant. Native fish populations in the Flinders Ranges are thought to originate from marine ancestors that subsequently evolved adaptations to the environment (Pierce et al. 2003). Under appropriate flow regimes, there is theoretically the potential that diadromous fish (those species having a life cycle with both freshwater and marine phases) could populate the freshwater stream habitat from estuarine reaches thereby migrating between drainage basins. It is unlikely that estuarine species with a migratory requirement for freshwater would be capable of inhabiting these permanent pools under recent hydrological conditions, as connecting flow events are too rare when compared to lifespan. A study on the adjacent Willochra Creek Catchment (Risby et al. 2003) also failed to locate any native fish in upper catchments, although both the native fish Lake Eyre Hardyhead and *Gambusia* were present in permanent waterholes on the Willochra Plain.

In the absence of historical data, it is not possible to say whether any native fish species previously present were lost to the region prior to European settlement, but the loss of native fish could certainly be explained by a number of factors, not the least being the isolated and small size of the refugia pools. Factors other than competition and predation by exotic fish species (redfin and *Gambusia*) include the loss or degradation of habitat and the isolation from any potential populations through the limited connectivity, both between watercourses and with the estuary.

5.2 SUMMARY OF ECOLOGICAL DRIVERS

From the above discussion, a number of factors can be identified as exerting a major influence on the ecology of streams in the Mambray Coast. These factors are listed in Table 6 along with a summary of the manner in which they exert an influence on ecological processes. Listing the key ecological drivers provides a reference point from which to consider potential threats to the ecological integrity of the Mambray Coast streams.

Table 6. Ecological drivers and their influence on catchment ecology.

Ecological driver	Processes supported
Groundwater surface expression	Maintains permanent pool habitat, allowing for the persistence of organisms without a desiccation-resistant resting phase to survive through no-flow periods.
	Baseflows provide a seasonal extension in the extent and diversity of wetted habitats, allowing re-colonisation of organisms from refugia pools.
	Seasonality of baseflow defines the basic patterns of flow-related connection between habitat refugia.
	Provides thermal and disturbance refuge (e.g. hyporheos).
Groundwater chemistry	Salinity exerts a fundamental influence on aquatic biota due to physiological tolerances.
	May be an important source of nutrients, especially nitrates to stream and estuarine to near-shore ecosystems.
Surface runoff and resulting streamflow	Provides water quality improvements (reduced salinity).
	Increases the extent and duration of connecting flows (necessary for surface flows to reach the coast).
	Drives geomorphically important flow events such as scouring of fine sediments and channel maintenance — influences the range and quality of available habitats.
	May significantly contribute to groundwater recharge where streams cross fault zones or highly permeable features such as gravel beds.
Climatic conditions	Periods of extended drought would be expected to produce lower biodiversity — the extent of impacts will increase the longer drought conditions continue (ramp disturbance) and available permanent surface habitat decreases as groundwater discharges fall with decreases in storage.
	Conversely, during wet climatic periods, the biodiversity would be expected to increase over time as more sensitive organisms are able to re-colonise, completing their life histories in response to the increased habitat complexity and improved water quality.
Pool refugia morphology and physical extent	Shallow nature and small dimensions limit the variety of available habitat — exert an influence on the species and complexity of the biological structure.
Riparian structure and land use	Stock access to waterways can increase turbidity and nutrient inputs, and reduce vegetative complexity (e.g. grazed understorey affects reed beds and riparian vegetation through grazing of understorey and canopy species seedlings.)
	Loss of riparian complexity such as understorey species leads to increased light penetration and reduced allochthonous carbon inputs such as leaf litter. This may alter community metabolic balance towards autotrophic status, influencing the resulting macro-invertebrate fauna.
Introduced species	*Gambusia* appear to exert top-down (predatory) control of biological components including macro-invertebrates and possibly anurans.

5.3 THREATS TO ECOLOGICAL INTEGRITY

The loss of permanent aquatic habitat would present the greatest impact on the ecological function of those catchments where it is present. Consultations clearly showed that the number and extent of springs has reduced over the last 2–3 years, and in some cases springs have dried for the first time on record. An indication of the severity of the decline was recounted by Mr Tony Said, a landholder and grazier within the upper Baroota Creek sub-catchment. Mr Said has noted that of eight permanent spring-fed watering points formerly found on his property, only two persisted through the 2004–05 summer.

As water resource development within the ranges was limited, the decline is attributed to very low groundwater recharge over the last few years. Historical reference to widespread drying of springs following a three year drought period in the 1920s was found in Parkes (1961; see Section 4.5). Groundwater baseflow has been shown to be dependent on the rainfall received over recent years, possibly up to three years previous (D. Cresswell, DWLBC, pers. comm., 2005). Declines in the number and flow rate of springs observed during the last two or so years correlates well with the low rainfall, and are in fact a response that should be expected.

The period over which these declines were observed suggests that the groundwater storage from which these discharges occur is vulnerable to fairly short drought periods. Due to the limited development present, climatic stress is seen as the major threat to the aquatic ecology. There is a limit to what can be achieved from a management perspective to address this and the emphasis should then be on ensuring that no additional pressures are exerted.

The following section considers the main perceived risks to the aquatic stream ecosystems present in the Mambray Coast and, where possible, discusses management of these risks. The main threats can be summarised as:

- Loss of aquatic habitat through reduced groundwater discharges and surface runoff.
- Reduced habitat amenity due to salinisation or land-use pressures.
- Biological pressures from introduced invasive species of flora and/or fauna.
- Lack of monitoring and research to develop a more complete understanding of ecosystem patterns and processes and hence the best management responses to increasing climatic stress.

5.3.1 LOSS OF AQUATIC HABITAT

Due to the higher habitat values, the loss of the permanent pool refugia in the Mambray Coast would likely be significant for aquatic biodiversity. This would also be likely to have an impact on terrestrial native animals dependent on these as watering points. The loss of formerly permanent springs and pools is already proving problematic to graziers, and further losses would compound this.

The problem from a management perspective is that there is little that can currently be achieved to reduce extractive pressures, as water resource development is limited. The land use within the ranges, in particular within the higher rainfall areas where recharge rates are likely to be the highest, is largely conservation. Even outside dedicated conservation areas, there is limited extractive use within the ranges to be of concern. Only the Baroota Reservoir sub-catchment features significant development, and this will be managed under the impending development of the water allocation plan.

If as predicted by most climate models the current drying of climatic conditions continues, it is to be expected that all water resources are likely to come under increased pressure for development. Within the ranges this is likely to include increased stock pressure on the remaining springs, additional farm dam development to trap as much surface runoff as possible, and also for additional stock wells to be drilled. It is in ensuring that future developments are undertaken in a sustainable manner where management responses to increasing development pressure will become important.

How long these permanent pools and springs can persist under current climatic patterns will depend on the storage capacity and characteristics of the local to intermediate groundwater flow systems of the ranges. These are currently unknown and, due to the likely associated cost, technical investigations to determine this seem unlikely. Areas of faulting and jointing are likely to be important for groundwater recharge and transport, but the nature of fractured rock aquifers makes it impossible to speculate as to exact flow directions and the sources of recharge for the springs supporting permanent habitat.

Possible policies that would address the need to limit further development could include:

- Any change of land use from grazing to higher volume water use activities should be discouraged from being located within the ranges.
- Any future stock wells should be located so as to avoid impacting on water levels in permanent pools. (The Clare Valley PWR Water Allocation Plan specifies buffer distances for the location of wells from permanent pools that could possibly be adapted for use in the Mambray Coast.)

5.3.2 REDUCED HABITAT AMENITY

As mentioned in Section 5.1, groundwater chemistry, in particular salinity exerts a strong influence on the biota capable of inhabiting refugia pools. Some pools are already borderline saline in nature and, as discharge rates decrease, the salinity of these pools can be expected to increase.

As with loss of aquatic habitat, this is largely a risk associated with climatic conditions. The potential for the situation to be exacerbated by groundwater pumping should be incorporated in future policy.

Management responses to increasing salinity are similar to that of protecting water quantity, in particular ensuring that groundwater wells and pumping rates do not affect the quality or quantity of water in refugia pools.

Land use also exerts an influence on the amenity of habitat, most particularly grazing. Stock access to waterways has the potential to cause increased turbidity and nutrient concentrations, and decrease bank stability. Additionally, changes to the composition or complete clearance of riparian vegetation can have effects discussed in Section 5.1. Appendix A includes a description of the differences observed between an adjacent grazed and ungrazed site in the Baroota Creek sub-catchment.

Ideally, stock would be precluded from all watercourses, and in the areas visited this would undoubtedly improve the ecological condition. There remains the practical issue of how this could be achieved in catchments that are both remote and feature extremely rough topography. Riparian fencing would be too costly to be practical, if possible at all, at many sites. Hence, only the retirement of certain areas from grazing altogether would be an option. Permanent water is not only ecologically important, it is commercially important and it seems unlikely that retirement of the grazing country around such areas will occur without financial incentives.

The low stocking rate and the streambed and bank morphology appears to be limiting damage to streams used as watering points compared to other areas in South Australia, at least at sites surveyed. Some alteration of the nature of the riparian habitat is occurring and there is also evidence of increased turbidity through bed sediment disturbance, nutrient loading and reduced shading impacts such as growth of algal mats. Insufficient understanding exists to enable a quantitative assessment of these impacts.

5.3.3 BIOLOGICAL PRESSURES

Introduced species are a major threat to the integrity of all aquatic and terrestrial ecosystems. Evidence from this study suggests that the introduced fish *Gambusia* is already impacting on aquatic diversity as measured by the AUSRIVAS model.

Future introduction of non-native species should be prevented, and translocation of *Gambusia* should also be avoided.

Where possible, pest plants should be controlled to prevent impacts on riparian zones, and streams within the ranges would also benefit from revegetation of native understorey species in grazed catchments.

5.3.4 LACK OF MONITORING AND RESEARCH EFFORT

Section 5.2 indicates the range of influences that act to structure the observed biodiversity in these systems throughout seasonal cycles, yet there has not been sufficient investigative work to understand how these influences manifest in community composition. This is compounded by a lack of basic biological data such as the true extent of biological diversity, especially for freshwater macro-algae and hyporheic or other groundwater-dependent organisms. This lack of understanding of intermittent or ephemeral stream ecosystem structure and function is clearly a limitation to current biological monitoring programs such as AUSRIVAS.

Research to address the above gaps in understanding is a prerequisite to the use of biological monitoring to determine the success or otherwise of actions to improve stream ecological conditions. Questions of this nature cannot be answered by a short-term research project, and a key to improve understanding over seasonal cycles within wet and dry climatic phases is the collection of a long-term dataset. This would need to comprise samples collected at least during autumn prior to the commencement of baseflow, and spring towards the end of the flow season, and be supported by information (notably continuous rainfall, streamflow, temperature and salinity data from the sites where biological samples are collected) to help interpret the findings.

Until such time as this improved knowledge is available, it is arguable that regional NRM authorities should focus their stream ecosystem condition monitoring on surrogate measures such as water quality parameters, the degree of stock access to watercourses, structure and condition of riparian vegetation, and the presence and density of invasive exotics. Owing to their iconic status with the general community and groundwater dependence, river red gum condition may be a useful indicator to involve the community in stream ecosystem monitoring.

6. CONCLUSIONS

Watercourses of the Mambray Coast can be considered as comprising three separate components — intermittent and ephemeral upper catchments; ephemeral coastal plains; and tidal estuaries. Ecologically significant groundwater-dependent permanent pool refugia are located in the upper catchment of some of the larger intermittent streams, but no permanent water is located on the plains.

The aquatic ecology of the streams is influenced by two flow signals of varying frequency, duration, water chemistry and volume:

- Groundwater springs from fractured rock aquifers in the ranges provide permanent water in some larger catchments, the extent of which follows seasonal climatic patterns. These contract to small refugia pools over summer, but significant baseflows commence during autumn and continue through to early spring, providing seasonally predictable flows of modest volume and moderate quality that is limited to upper catchment areas.
- Surface water runoff in the higher rainfall upper catchment areas generates less predictable, but at times extensive, surface flows of low salinity. Only the largest of these events can create a connection between the headwaters and the coast. These are not predictable and may not occur each year. They may occur during any season but have greatly increased durations when they occur during winter or spring.

Although there are currently no data to determine the ecological significance of these two flow patterns, disturbance theory suggests that they would produce different effects on community composition. Being seasonally predictable, but of only moderate quality and quantity, groundwater discharges likely dictate the baseline aquatic biodiversity that can be supported within the catchment. The composition of the pools surveyed for this study are thought to be representative of this type of community and consist of physiologically tolerant organisms with generalist habitat and feeding requirements. These organisms retreat to pool refugia over summer and many have life histories enabling them to extend and re-colonise new areas during baseflow periods.

In contrast to groundwater discharges, potentially large volume and low salinity surface flows following periods of high rainfall will provide conditions that are acceptable to less tolerant animals. During extended wet climatic periods, increased rates of groundwater recharge will provide for a greater number of refugia pools of lower salinity, meaning that more sensitive organisms could quite possibly become a regular component of the aquatic community. It is likely that these would begin to move into the catchment during these periods as baseline conditions improved.

In the absence of long-term data sets, this remains a theory that could only be tested by implementation of appropriate monitoring and research. In particular, it would be of interest to establish how critical surface runoff, and the resulting improvement in water quality, is in influencing the more opportunistic aquatic macro-invertebrate community.

The loss of springs and pools throughout the catchment recounted by current landholders during consultations is clearly related to the decreased recharge resulting from the recent dry climatic period. Presumably, if climatic drought continues, at some point the groundwater storages will be unable to maintain surface discharges, leading to the loss of all permanent surface water in the ranges. This is seen as the main threat to permanent surface water habitat and hence to stream ecology as no major water resource development was identified within the ranges.

Although stock access to watercourses is a management issue in some catchments, the most notable threat to stream ecology outside of climatic conditions is that posed by the introduced fish *Gambusia*. Due to the small size of refugia, the high fecundity rate and generalist diet of the species, it appears that the ecological impact of *Gambusia* is the most important factor influencing macro-invertebrate community composition. Although no data were available, the presence of the species also probably exerts pressure on native anuran populations.

From an environmental water requirements perspective, it appears that the refugia-pool-driven aquatic ecosystems located within the ranges are not currently under threat from human activities. In addition, many of the permanent water sites and their surrounding catchments are located in land protected under the South Australian reserve system. The most extensive permanent aquatic habitat outside of conservation areas was the Baroota Reservoir sub-catchment, which is currently under a notice of intent to prescribe. In the preparation of the water allocation plan, the needs of the environment must be taken into account and hence the environmental water requirements of this catchment should be addressed in that process. This issue therefore currently appears to present few problems for ongoing management of the stream ecosystems of the Mambray Coast, and the emphasis should be on ensuring that no major extractive activities threaten this in the future.

Ultimately, the types of knowledge that can be gleaned from a ‘snapshot’ study such as this are limited by the available data. An almost complete lack of stream flow and biological monitoring data was particularly limiting. Additionally, it should be noted that the locations of permanent aquatic habitat identified in this study were based on consultation only. While they are likely to be representative of each catchment in which permanent pools exist, it should not be considered comprehensive. Aerial videography is the best method currently employed in South Australia to record all possible permanent pool and baseflow sites, along with riparian condition, erosion and streamworks. The level of risk presented to stream ecosystems in the study area is not considered high enough to warrant this expenditure at present, given other regional priorities.

The following points relating to future management of the streams of the Mambray Coast are highlighted:

- The use of groundwater or surface water within the ranges for any high-volume use should be avoided.
- The drilling of additional wells in the ranges near to permanent pools should be prevented unless it can be shown that no impact will occur to the hydrology of the pool.
- Further farm dam development within the ranges should be restricted to sustainable levels.
- Any new dams should ideally be sited off-stream but, where this is not possible, the use of low-flow bypasses should be compulsory.
- Development of an ongoing monitoring and research program for aquatic ecosystems is important to gather the long-term datasets necessary to improve understanding of ecosystem patterns and processes.

- Investigations of groundwater flow systems and recharge estimations could help determine sustainable yield volumes, allowing future development to be planned within these levels.
- Investigations of the ecological significance of groundwater flows to estuarine and coastal salt marsh habitat would provide important information to assist in planning for the sustainable use of plains aquifers.
- Development and implementation of an environmental flow release program from Baroota Reservoir as an element of the water allocation planning process. This would provide an opportunity to acquire an understanding of the ecological significance of periodical surface water flows from Mambray Coast streams on the near-shore marine and estuarine habitats, particularly with regard to fish and other marine species breeding responses, aiding marine planning.
- The adjacent nature of the Winninowie Conservation Park and Mt Remarkable National Park would appear to represent an opportunity to create a ‘catchment to coast’ style of conservation reserve. The value of such a remnant patch would require assessment within the overall biodiversity planning for the region before any action was to be considered.

APPENDICES

A. DETAILED FIELD FINDINGS

Telowie Creek

Telowie Creek Catchment is located to the north of Nelshaby Creek Catchment in the southern Mambray Coast. Drainage includes Telowie Creek and unnamed tributaries draining into it. Telowie Creek itself drains through the gorge of the same name, across the coastal plain and discharges to Telowie Beach on Spencer Gulf north of Weeroona Island. Streamflow is typically of insufficient volume and duration to connect to the gulf through recent decades, and it is not known when this last occurred.

Much of the catchment is contained within Telowie Gorge Conservation Park. This status affords the watercourse protection from water resource development or land uses such as grazing that might impact on aquatic ecosystems. Telowie Creek is classified as a Wild River.

Figure 20. Small pool within Telowie Gorge.

Two small springs were formerly located at the entrance of the park, on either side of the fence (K. Pole & N. Davis, landholders, D. Evans, Representative of the Nukunu People, pers. comm., 2005). During the field survey, evidence of a spring was located at the footslopes of the gorge, south of the entrance. This was found to have no surface water, although the ground was boggy and stands of cumbungi (*Typha* spp) were observed. In places, the emergent macrophytes were dying back in the vicinity of what was formerly a permanent spring-fed pool (D. Evans, Representative of the Nukunu People, pers. comm., 2005), and flows from the spring appear to have reduced in recent times. Drying of these springs may not be unusual though as Parkes (1961) states that during January 1928, which was the middle year in the driest 3-year period on record[1], 'many of the natural springs at Telowie dried up'. Mr Neville Davis also recalls that these springs have dried during his lifetime.

Stream character within the gorge environment was that of a partly confined watercourse of relatively steep longitudinal profile. Large amounts of terrestrial vegetative debris were present throughout the gorge. Piles of woody debris provided evidence that significant flows do occur through the gorge, but when visited the channel was completely dry for several kilometres.

The watercourse planform was dictated by overall gorge morphology. Within the valley floor, bedrock outcrops were controlling features and also commonly associated with steps and scour features. Stream channels were at times not well defined, but typically comprised of a range of substrate sizes from sand and cobble, to boulders and bedrock. Limited development of depositional features has occurred in places, with floodplain pockets, vegetated islands and other depositional features comprising a range of sediment sizes down to fine sands.

The nature and density of the riparian cover depended on the degree of sedimentation that had occurred, and varied from sparse to absent in some bedrock dominant areas to dense within isolated depositional features. Very few weed species were observed. Some aquatic sedges and rushes were observed, but these were limited in number and extent, typically growing within small pockets of sediment within the channel.

A series of roughly circular scour features such as plunge pools and potholes created in outcropping bedrock and the streambed occur in Telowie Gorge. These features will naturally collect and hold surface water both during rains and as streamflow recedes after flow events. Water was found in several small pools and the largest of these, known as the Wagon Wheel, is considered to be permanent and as a result it is considered to be groundwater fed. Various anecdotal reports suggested that the pool is at times extensive, suitable for swimming during summer. It is also thought to have previously contained small fish (K. Pole & N. Davis, landholders, L. Pearson, former Waterwatch coordinator, NYNRMB, pers. comm., 2005).

When visited during June 2005 (Fig. 20), the pool was found to have a small surface area of around 8–10 m^2, but still with a depth of at least 1 m in the deepest part. Terrestrial organic matter was present, with leaf litter and a few small branches observed. No fringing or submerged vegetation was present.

[1] See section on Hydrology

Ponded water was observed in a number of small pools within scour formations in bedrock. The electrical conductivity at these sites was the lowest recorded for the catchment at 0.57 mS/cm (~360 mg/L). The pH of 7.9 supports the theory that groundwater is the source of the water. Turbidity was quite high in the pool, presumably due to suspended particles from the decomposition of organic matter, as there was no opportunity for mixing of the water. Photic depth was restricted to ~30 cm.

Dissolved oxygen was extremely low (1.75 mg/L, 17% saturated) as would be expected in a still and turbid pool where decomposition processes were dominant. Photosynthetic activity would largely be restricted to benthic algal films within the photic zone of the pool, which was limited to the edges, and on woody debris within the pool.

At least 10 large tadpoles of ~70 mm in length were observed, and these appeared to be using aquatic surface respiration (ASR) to compensate for the low oxygen concentration. Based on the size of the tadpoles, the time of year, the habitat and known distribution patterns (Tyler 1977; Walker et al. 1998), it is considered that they were most likely those of the Eastern Banjo Frog (*Limnodynastes dumerili*).

No evidence of fish was found during the field survey and in the condition observed the habitat would be unlikely to support any self-sustaining populations of native fish. The introduced *Gambusia* may be capable of surviving through the use of ASR, for which it is known. The observations of local community members may mean that formerly present native fish have been unable to persist through the drought period. It is also possible that tadpoles of this size could have previously been mistaken for fish if the pool was deeper.

Field data sheet: Telowie Creek, Telowie Gorge

Site physical features: Narrow winding gorge-confined valley environment with multiple stream channels and occasional floodplain pockets. Valley walls were steep hill slopes to sheer rocky outcrops. Valley floor comprised a mixture of boulders, cobbles, pebbles with sandy floodplain pockets.

Site hydrological features: Only one pool small pool was located in Telowie Creek during the field survey in June 2005.

Substrate type: Mixed substrate of boulders, sand, gravel and cobbles.

Site habitat: Rockhole — permanent pool 3x3 m.

Stream cover: 70% cover.

Vegetation condition, land use: conservation — vegetation intact.

Plants within the gorge consist largely of a mixture of terrestrial and emergent macrophyte species, plus various small shrubs. Structural formation could be described as open forest (30–70% cover) including river red gum (*Eucalyptus camaldulensis*), *Callitris* spp, canopy and understorey of *Myoporum* spp; the woody weed rosebriar was recorded at permanent pool.

No emergent or submerged plants in the rockhole.

Emergent species were sparse and species observed in the vicinity of the site included *Baumea juncea* and *Cyperus vaginatus*.

Water quality:

- Conductivity (mS/cm) — 0.572
- Temperature — 13°C
- Transparency (m) — ~30 cm.
- PH — 7.9
- Dissolved oxygen — 1.75 mg/L (17% saturated).

Fish: No fish present. Numerous tadpoles of ~70 mm length were observed.

Macro-invertebrates: The 3x3 m permanent pool was not big enough for MHRI sampling. Diving beetles and water boatmen were observed within the pool.

Back Creek (Port Germein Gorge)

The upper Back Creek Catchment flows into Port Germein Gorge, the channel then following a tightly confined path that is shared with the main road through the gorge. Once reaching the plains, the creek broadens into a braided channel ~80 m wide, later narrowing to ~5 m before becoming discontinuous. The only survey work other than a brief field inspection undertaken as part of this study was fish sampling; no fish were located during June 2005.

Permanent shallow baseflow was observed in the upper section of Port Germein Gorge north of the step weir, and this maintains a few small stands of emergent reeds, notably *Typha* spp. Winter baseflow supports a shallow section containing several pools and extending for 2–3 km along the stream. Consultation evidence suggests that this area has experienced greatly reduced flows over the last year or so.

Figure 21. Small step weir in Port Germein Gorge.

The catchment is grazed virtually throughout and has poor riparian vegetation in the grazing and cropping areas in the upper catchment, with pepper trees, rosebriar, fennel and olive infestation observed. Weed control is therefore a key management issue throughout Port Germein Gorge. Additionally, controlling stock access to the watercourses would also benefit the riverine ecosystem. Runoff from the road through the gorge enters the stream directly, and is likely to be a source of pollutants. Although much of the streambed is bedrock controlled, it is also likely to present possible erosion problems where concentrated runoff enters susceptible reaches of the creek during storm events.

Baroota Creek Catchment

Figure 22. Baroota Reservoir looking north towards Baroota Creek Catchment.

Baroota Reservoir collects the flow from Baroota Creek and several other tributaries. The catchment is clearly the largest in the study area, and at 138 km^2 represents ~10% of total catchment area. The upper catchment features some of the highest topography and rainfall in the region. Major drainage includes Waterfall Creek in the south, Separation Creek which drains westerly, and Baroota Creek which drains the northern catchment through the upland areas. These creeks all discharge into the reservoir.

The reservoir overflow follows the original Baroota Creek channel onto the plains and discharges to the gulf at Port Germein. Permanent baseflow and waterholes were found in both Waterfall and Baroota Creeks well upstream of the reservoir.

Anecdotal and historical evidence suggests that Baroota Creek was a significant contributor of flow to Spencer Gulf. Reports of permanent pools near Port Germein where fish were regularly caught are of interest. These pools would have required regular flow to be maintained although it is unclear whether flow was permanent or only the pools were permanent, which could have been due to shallow groundwater tables. They may also have been tidal pools maintained by periodic high flows from Baroota Creek Catchment through scouring of any sediment build-up. The fish described would presumably have been estuarine or marine species, but no detail was available. Surface water flows have not reached Port Germein since construction of the Baroota Reservoir in 1921. The section on Baroota Reservoir discusses the potential for environmental releases to recreate a periodic hydrological connection with the gulf.

Permanent aquatic habitat is found on Waterfall and Baroota Creeks in the form of spring-fed pools located within watercourse channels, which persist through the summer–autumn dry periods with little or no actual flow. During winter, the flow rate to these pools is greatly increased, creating extensive baseflow reaches, in some cases linking pools and generally greatly increasing aquatic extent and habitat diversity. Any surface runoff that results from winter rainfall will increase this effect and improve water quality.

The following sections detail the survey findings of one such site on Waterfall Creek and describe another on Baroota Creek that was inspected during June 2005, after baseflow had commenced.

Waterfall Creek

Waterfall Creek is a tributary to Baroota Creek, and contains at least two permanent pool refugia. The site surveyed is directly upstream of Baroota Reservoir on land belonging to Nukunu, which is currently leased by local graziers. The site was visited twice during this study, in February and June 2005. During the first visit the only site of permanent water located was a small shallow pool a few metres in length. No survey work was undertaken at this time.

By the time of the second visit during June, the flow rate from the springs had increased dramatically. Flow along the creek itself was small, varying ~2–5 L/s, but was sufficient to support a continuous baseflow reach along several kilometres of watercourse. This flow extended both up and downstream of the survey site, suggesting it is likely that other permanent pools may have been present upstream on the adjacent property during summer.

No significant rainfall had occurred at the time of survey and it is thought that the flows were due to the seasonal rising of groundwater springs observed in many parts of South Australia as evapotranspiration rates begin to fall.

The site was of particular interest as it was located on a property boundary and grazing pressure was considerably higher on the downstream reach. This allowed comparison between the character of the site under grazed and ungrazed condition.

In places, the stream channel had been disturbed where stock had been watering, and this contributed to some turbidity and damage to the streambed observed. Compared to watercourses from other grazed areas the damage of this nature was modest, probably due to a combination of the low stocking rates and easy stock access to the watercourse.

Riparian vegetation for both reaches had an overstorey of river red gum (*Eucalyptus camaldulensis*) ranging from 30 to 70% cover with sedge and rush understorey. Typical species were *Cyperus gymnocaulus*, *Juncus* spp and *Isolepsis* spp. Submerged aquatic charophtyes and unbranched filamentous macro-algae were also present on both sites.

Notably absent at both grazed and ungrazed sites was the presence of any shrub layer understorey. It is expected that at least *Myoporum* and *Acacia* species would have been present originally. Presumably this vegetation has been cleared from the area to aid in mustering and shows no sign of recovery. Red gum regeneration was evident within the ungrazed reach, with 2–5 m high young trees observed.

The ungrazed reach was relatively natural in general appearance, with a fairly continuous riparian canopy and emergent sedge and rush cover (Fig. 24). The grazed reach appeared to feature the same species association, but the density was much lower and persisting reeds, sedges and tussock grasses had been eaten down close to ground level (Fig. 25). This form of grazing will remove any flowering structures prior to seed set, meaning that regeneration or expansion within the grazed reach is reliant on vegetative propagation through organs such as tubers and rhizomes. Upstream sources of seeds from the ungrazed reach may help compensate for a lack of local seed, but trampling and grazing of seedlings by stock may also prevent establishment of aquatic sedges or rushes from seed.

A more diverse range of aquatic habitats was present in the ungrazed reach, largely due to the relatively intact riparian vegetation. Overhanging sedges and tussock grasses, and reed beds were evident, providing increased habitat complexity.

There was a high load of leaf litter within the pools, and woody debris of varying ages. Virtually all surfaces were covered in a thick layer of fine sediment and organic detritus, which once disturbed did not settle out. Flows at the time were not sufficient to mobilise this fine material, which was commonly present as a deep layer in the pools. The only substrate free of fine sediments was associated with very small bedrock controls over which flows scoured the substrate. These bare substrates were typically covered in filamentous green algae. No true riffle habitat was observed and this may be in part due to a lack of mid-high flows necessary to mobilise these finer sediments and expose gravel beneath. These fine sediments may present a threat to hyporheic habitats, as sediment build up within this environment, particularly at sites where downwelling is likely to occur, will compromise the ecology of organisms within it (Boulton & Williams 1996).

Figure 23. Waterfall Creek pool showing good habitat — reed bed, overhanging sedges, boulders and woody debris.

Figure 24. Permanent pool on Waterfall Creek looking upstream — ungrazed site.

Figure 25. Waterfall Creek looking downstream — grazed reach.

Field data sheet: Waterfall Creek, Baroota Creek Catchment

Site location: 54H: 0225929mN, 6460973mE.

Assessment officers: Laura Phipps, David Deane and Paul Magarey (DWLBC); Simon Westergaard (Native Fish SA).

Date, time assessment: 27/5/03, 12–3 pm.

Site photos: Laura Phipps.

Site physical features: Gorge environment. Series of rocky outcrops with areas of gravel beds (riffles) and bars. Stream unincised.

Surveyed water body is shaded from ~2:30 pm at this time of year.

- Pool dimensions (m) — 10x3x1 – 1.5 (within a reach of ~70 m length).

Site hydrological features: Main pool area fed by a slow baseflow of ~1–2L/s.

Substrate type: Bedrock with silt–clay and some cobbles and gravel at the start of the pool.

Site habitat: Rocky gorge.

Submerged vegetation: Macro-algae only inc. *Spirogyra* sp, *Chara* sp and *Nitella* sp.

Emergent macrophytes: *Isolepis* spp., *Cyperus gymnocaulos, Juncus sp.*

Stream cover: 60% rock, 30% submerged vegetation, 5% bank overhang.

Vegetation condition, land use: Light pastoral grazing.

Water quality:

- Conductivity (mS/cm) — 4.50 (pool), 11.27 (backwater)
- Temperature — 14.3°C
- Transparency — 1.5 m
- PH — 9.27
- Dissolved oxygen — 8.14 mg/L
- Other — Tannins present.

Fish:

Method of sampling:

- fish traps 3 x 1 hour, baited with commercial cat food
- dip netting.

Fish species recorded:

Fish species	Trap 1	Trap 2	Trap 3	Dip net
Gambusia holbrookii	0	0	0	80

Note: Hundreds of *Gambusia* were sighted.

Macro-invertebrates: 10 m autumn edge habitat sampled according to AUSRIVAS protocols in main pool.

Field data sheet: Baroota Creek Reservoir

**Fish sampling site only*

Assessment officers: Laura Phipps (DWLBC), Simon Westergaard (Native Fish SA).

Date, time assessment: 27/5/03, 4:30 pm.

Site habitat: Open water, with flooded vegetation.

Stream cover: 100% muddy substrate. No overhanging vegetation, but skeletons of flooded small trees and woody shrubs provided some 3D habitat complexity.

Method of sampling:

- 3 x 5 m single wing Fyke nets deployed overnight.

Fish species recorded: None.

Upper Baroota Creek

Landholder Mr Tony Said has property in the north of Baroota Creek Catchment, adjoining the southern boundary of the Mount Remarkable National Park. Similar baseflow-driven aquatic habitat to that found on Waterfall Creek is also found in upper Baroota Creek. This site was only visited during June when springs were already flowing, but evidently a number of permanent pools do exist.

Springs are numerous within the northern catchment during winter, occurring in a range of locations both within the watercourse, and at the time of visiting continuous baseflows extended along the creek for several kilometres. Groundwater surface discharges were not limited to topographical lows and seeps were present in several locations at mid-slope and even near the top of hills.

No sites were sampled for water quality or biological parameters, but a brief site visual inspection was undertaken. Diversity of habitat was at least as good as that found at the Waterfall Creek site (Figs 27, 28). No fish were observed during the brief visit but it is likely that *Gambusia* would be present, as the Baroota Reservoir would provide a dispersal pathway between Waterfall Creek and other tributaries during connecting flows. Nippers from the yabbie (*Cherax destructor*) were found.

Gluepot Spring is a mid-slope seep located at an elevation of 500 m that at one time supported an extensive pool (T. Said, landholder, pers. comm., 2005). The site still maintains a small stand of *Cyperus gymnocaulos* but no ponded surface water was present.

Figure 26. Gluepot Spring, upper Baroota Creek Catchment.

Figure 27. Baroota Creek on Tony Said's property.

Figure 28. Baroota Creek on Tony Said's property.

Baroota Reservoir

(Completed in 1921, capacity 6100 ML)

From an ecological perspective, the effects of the reservoir construction on the mid-lower reaches of Baroota Creek and its estuary would have been profound. Community consultations suggest that the creek flowed permanently and at times supported significant extractive uses on the plains.

Today, leakage has a fundamental influence on the area immediately downstream but this is only felt close to the reservoir. The volume of leakage varies in accordance with reservoir level, but has been estimated at an average of 2 ML/day (Clarke 1989). Even when the reservoir was dry in 1935, a streamflow downstream of the reservoir of 1 ML/day was recorded.

The overflow channel downstream of the reservoir provides an additional aquatic habitat. Immediately downstream the channel is largely choked with reedbeds (mostly *Typha*) but presumably when the reservoir fills, resulting scour from high overflow volumes would remove the reeds from the main channel, resetting the habitat.

Potential for environmental releases

Prior to reservoir construction, the creek was permanent at Port Germein. During this period fish were caught in pools and flood irrigation was undertaken by plains landholders (K. Pole & N. Davis, landholders, pers. comm., 2005). Based on the fact that they were reportedly species of angling interest, the fish referred to were presumably estuarine or marine species. Outflows from the creek almost certainly would have been ecologically significant to the estuary, delivering both nutrient and sediment supplies.

Other potential changes to the downstream watercourse likely include increased water stress on groundwater-dependent riparian vegetation, notably river red gums, which appear in poor condition. Prior to construction of the reservoir, flows from the ranges would have recharged the watertable aquifer on the plains, which the trees would access directly. The loss of this recharge may have lowered watertables below the root zone. During dry periods, this form of stress may currently also be exacerbated by irrigation withdrawals further increasing the depth to the watertable.

With the exception of uncontrolled leakage from the reservoir, currently very little water reaches Baroota Creek downstream of the dam wall. A permanent pool occurs immediately downstream of the reservoir, and earthworks appear to have been utilised to constrict flow downstream to maintain this. Irrespective of this, it is unlikely that the modest flows would reach far along the watercourse due to losses to groundwater.

It is acknowledged in state and federal policy relating to natural resources that the environment is a legitimate user of water. In the case of fully regulated watercourses, releases are essential to maintain the condition of aquatic ecosystems downstream of major storages. The impacts of storages on riverine systems include:

- delay in onset of seasonal flows
- reduced incidence and magnitude of flooding
- increased duration and severity of low or no-flow conditions
- changes to sediment transport regimes

- alteration of the physical and chemical character of water — temperature, salinity, turbidity, dissolved oxygen
- loss of the drift vector for downstream distribution of aquatic organisms or their propagules
- prevention of migration of aquatic organisms (up and downstream).

Based on the recollections of some local residents, the ecological nature of lower Baroota Creek was fundamentally altered by the creation of the reservoir, most notably through the loss of lower catchment permanent pools. The reduction in freshwater outflows to the gulf can also be expected to have had effects on the ecology and geomorphology of coastal and near-shore marine environments. Although the original character cannot be restored, the potential exists for a seasonal link to the gulf to be restored through environmental releases from Baroota Reservoir.

Provision of connecting flows may be difficult to achieve, as Baroota Creek downstream of the reservoir, like the rest of the plains catchment, is strongly losing in nature. Clarke (1989) estimated flows during a reservoir overflow event in 1989. A flow estimated at 100 L/s (~8.6 M L/d) was observed half a kilometre downstream of the reservoir. The estimated flow volume had reduced to only 20 L/s by the time it had travelled 4 km downstream. As the distance to the gulf is ~13 km, environmental releases of this or a lesser volume would presumably not be capable of achieving connection with gulf waters. This area does correspond to a zone of faulting however, where loss rates can be expected to be much higher.

Using these values and assuming a linear rate of loss, a flow of ~22 ML/d should be capable of reaching the gulf, particularly if maintained over a few days. The maximum discharge rate from Baroota via the outlet scour valves, using only the difference in hydraulic head, is around 38 ML/d (Purton & Davies 2005). Hence, from a cursory consideration, it would appear theoretically possible to recreate a seasonal connection with the gulf.

The volumes that might be available for environmental releases are understood to be subject to consideration. The South Australian Water Corporation recently commissioned a study to investigate the potential for environmental releases within the context of overall yield analysis from the three northern reservoirs (Purton & Davies 2005). The total volume of water available for environmental release is not discussed, although flows in the 5–20% of total intake range were considered within the modelled scenarios. Flows in this range were not considered to impact significantly on the usable water yield for off-takes (Purton & Davies 2005). During an average runoff year, a volume equating to 200–800 ML should therefore be available for an environmental flow release, which would present considerable scope to tailor a release regime for a range of environmental outcomes.

Regional demand for irrigation may well reduce the levels of groundwater below that required to maintain the riparian river red gums along Baroota Creek. Whilst quantitative surveys were not conducted, some level of stress indicated by epicormic shoots and canopy dieback was observed during field surveys throughout the catchment, including Baroota Creek downstream of the reservoir. In the latter case, impacts appeared to increase with distance from the reservoir. A minimum environmental release objective that was met in most years would ensure that shallow Quaternary aquifers supporting riparian vegetation such as river red gums are replenished. Germination and recruitment of red gums will require more significant flows and could be a goal for higher rainfall years.

Any environmental flows should be part of an overall release strategy and considered within water allocation planning for the Baroota irrigation area prescription. As with all environmental flows, a detailed multidisciplinary planning investigation should be undertaken, which will require hydrological, ecological and engineering input as well as community support and involvement. This will determine the effects of a release on downstream hydrology and hydrogeology as well as evaluating the potential ecological goals in both the stream and coastal ecosystems that this might achieve. Strategic and effective use of the releases will then require monitoring, evaluation and adaptive management approaches to continually improve knowledge on ideal release scenarios.

Mambray Creek

Upland areas of the Mambray Creek Catchment comprise an elongate basin with an upturned rim known as the Alligator Gorge Syncline. The more extensive northern part of the basin is known as Alligator Gorge and is drained by the southerly flowing Alligator Creek. The two creeks join at the Mambray Creek Gorge and run southwesterly as the Mambray Creek, which drains the southern basin. This watercourse flows onto the plains and to Spencer Gulf.

Several permanent pools maintained by groundwater are present in the catchment including at Kingfisher Flat and Pine Flat on Alligator Creek, and Mambray Creek north of the picnic area (Figs 29, 30). In winter, a combination of rains and rising groundwater produces baseflow along Alligator Creek and upper Mambray Creek, which connects pools and creates small sections of riffle. This drainage has been classified as a Wild River.

A site survey was conducted at a permanent pool upstream of the picnic ground in Mambray Creek. This is near to the site where the EPA collect macro-invertebrate samples as part of the Ambient Water Quality Monitoring Program. The site was visited twice during the project in February and June 2005.

The site was located within a dry creek bed ~100 m wide and consisting of at least two channels. No evidence of flow events during the last few years was apparent. The majority substrate range was from gravel to cobble within the main channels. Vegetated mid-channel islands and benches were also present and featured a wide range of substrate size from silt to cobble.

Spring flows created three apparently permanent aquatic habitat classes — a small pool (~3 m^2) with open water, present in a channel scour depression at the edge of the main channel; a reedbed of ~200 m length and 3–5 m width following the channel course (but providing no open water apart from a ford where water was flowing across the road); and, downstream of the ford the reedbed thinned and water appeared to spread out from a less defined channel to form a swampy floodout area dominated by sedges. The substrate within the reed bed and sedgelands was predominantly sand and silt. The sedgeland in particular provided good habitat for frogs, and Common froglet (*Crinia signifera*) calls were heard during June.

Vegetation within the river valley was predominantly terrestrial in nature including Eucalypts *(E. camaldulensis, E. leucoxylon*) and Callitris overstorey and understorey including *Acacia* spp (*incl. A. notabilis*) and *Bursaria spinosa;* young native pine and Eucalypts*; Myoporum montanum*, and *Exocarpus cupressiformis* (Native cherry). The reed bed vegetation consisted virtually entirely of *Typha* spp. Emergent macrophytes within the sedgelands included *Baumea juncea, Juncus flavidus* and *Cyperus vaginatus.*

The canopy cover was 50–80% and this contributed a large organic load to the valley floor. Leaf litter and woody debris were present in large quantities. Large woody debris such as logs were also present and a log jam had apparently produced the scour feature in the streambed during high flow events. Spring flows to the local depression in the channel support the permanent pool.

Figure 29. Mambray Creek spring-fed pool, looking upstream. Note the scour feature downstream of the log jam.

The pool was very low in dissolved oxygen and provided limited habitat value as a result. Very little vegetation was observed apart from some algal growth, and the decomposition of organic matter accounts for the low oxygen tension. Despite the low flow rates, salinity was moderate within the pool, suggesting that the groundwater inflows are of relatively good quality compared to the rest of the catchment. This in turn implies that it is relatively close to the site of recharge.

Permanent pools within the Alligator Creek section of the catchment were not visited during drier months and by August there were extensive baseflow reaches present. The exact location of permanent pools within these reaches is not known but appeared to be most likely within the bedrock controlled sections. A more diverse range of habitat values appears to be supported by pools within this area of the catchment, which is also likely to have higher quality and quantity of groundwater.

Figure 30. Alligator Creek pool.

Field data sheet: Mambray Creek upstream of camping ground

Site location: 54H: 225891mN, 6362751mE
Assessment officers: Laura Phipps, David Deane, and Paul Magarey (DWLBC).
Date, time assessment: 27/5/03, 4:00 pm.
Site photos: Laura Phipps.

Site description:
Located in the Mambray Creek National Park, in a gorge ~1500 m upstream from camping ground. The spring-fed isolated pool was 1 m deep, 1x3 m diameter.

Site physical features:
Gorge environment.
Series of rocky uplift with disjointed small pools.
Surveyed site is a small rocky pool:

- pool dimensions — 2x1.5 m
- pool depth — 1 m.

Site hydrological features:

Baseflow maintained permanent pool. Pool overflowed to support a swampy reed bed without any apparent surface water, ~100 m long, 2–5 m wide.

Substrate type: Cobble, boulder, mixed sand and gravel.

Site habitat: Rocky gorge.
Stream cover:
Site was in a well-vegetated multiple channel, with in-stream vegetated islands and bars. Eucalyptus canopy, and was also shaded by the log jam, which no doubt helped scour the pool out. Shade cover ~80%.

Vegetation condition, land use: Conservation.
The riparian area was open woodland with an shrub understorey and native grasses, sedges.
Submerged vegetation: limited to periphyton.
Other vegetation: largely terrestrial.

Water quality:

- Conductivity (mS/cm) — 1055
- Temperature — 15.5°C
- Transparency — >1 m
- Dissolved oxygen — 0.58 mg/L
- PH — 6.8.

Fish: Fish surveying was not conducted due to anaerobic conditions and small size of the permanent pool.

Macro-invertebrates: No sampling undertaken, diving beetles observed.

Frogs: *Crinia* spp. were present, with low numbers heard calling.

Birds: Date, time of waterbird survey: 6 June 2005, 1600–1620 hours
Results of waterbird survey: No species of waterbirds were observed in the area.

Nectar Brook Catchment

Nectar Brook is the most northerly catchment where permanent water was located within the Mambray Coast. The creek formerly supported a reservoir located in the foothills, built in 1892 on a natural swamp. The reservoir naturally leaked owing to construction on a fault line, and its use ceased in 1988 as it became too salty. The reservoir was last full in 1992, and when full takes around two weeks to empty (G. Herde, landholder, pers. comm., 2005).

The creek has not reached the gulf to the knowledge of third-generation Mambray Coast farmer and current landholder Graham Herde. Despite this, it contains a number of permanent pools within the middle reaches located in the ranges, and at one stage these formed part of the government water supply constructed in the 1800s. Derelict infrastructure from the water supply can be found upstream in the channel, including a weir structure.

The site was visited on two occasions, during February and June 2005. During the February visit, a number of small waterholes were observed, the most substantial formed by a deep rockhole within the watercourse, which was the lowest permanent water on the creek. This pool was ~4 m deep, providing substantial aquatic habitat, although it was modest in surface area, perhaps 4x2 m.

Further upstream, the watercourse followed a narrow, partly confined alluvial valley with pockets of floodplain development and terracing on one side of the stream. During the June visit, a significant rise in the flow rate from the springs within the creek had created extensive baseflow reaches, flowing at ~2–4 L/s. However, these were not continuous within the stream, even during June, and flows alternated between the surface and subsurface. At upwelling and downwelling sites, it is likely that hyporheic macro-invertebrate fauna may be present.

Nectar Brook drains a generally more arid catchment than other sites where permanent water was found, and this was evident in both the riparian species and density observed. The riparian structure was predominantly river red gum canopy with a sparse shrub layer understorey. Some isolated sedges were also present. Canopy cover varied from >70% to ~30% (at the survey site) or less. Some sparse river red gum regeneration was apparent, with juveniles to ~2 m observed.

The understorey was sparse to absent, and comprised terrestrial species where present. There was effectively no vegetative groundcover for ~50% or more of riparian areas, and these were largely rocky or bare soil. The surrounding hills provided an indication of the lower rainfall of the catchment and also of the relatively poor soil type. Vegetation on the surrounding slopes varied between tall, very open shrubland (at survey site) to low Eucalyptus woodland. The predominant species was *Acacia victoriae*.

A range of aquatic habitat was found within the survey site and in the upstream baseflow reach. This included open water habitat to around 1 m in depth and fringing *Typha* spp. reed beds. Colonial mat-forming algae were present, and the emergent vascular plant watercress formed extensive monocover stands covering several square metres in very shallow waters over cobble and sandy substrate.

Figure 31. Nectar Brook survey site looking downstream. Note the woody debris against the river red gum indicating previous flow stage.

Submerged aquatic vegetation also provided three dimensional complexity, and included filamentous green algae and Charophyte spp. Isolated clumps of sedges, notably *Cyperus vaginatus*, were also present, especially on exposed mud banks, but these did not occur in the continuous riparian cover found in other baseflow stream sites within the Baroota Creek Catchment.

Despite the relatively arid nature of the catchment, the aquatic habitat diversity was arguably as high as found at other sites within the region. Based on the AUSRIVAS rating (Band A), the habitat is in better condition than that found at the Waterfall Creek site, which scored Band B (slightly impaired). This may be attributed to a combination of the lower salinity and the absence of *Gambusia* (see Section 5.1).

Figure 32. Nectar Brook survey site.

Figure 33. Upstream of permanent pool, Nectar Brook, looking upstream. Note arid nature of landscape. Baseflow was present up and downstream.

Field data sheet: Nectar Brook

Site location: 54H: 217733mN, 6377727mE.

Assessment officers: Laura Phipps, David Deane and Paul Magarey (DWLBC); Simon Westergaard (Native Fish SA).

Date, time assessment: 29/06/05, 2:00 pm.

Site photos: Laura Phipps.

Site description: Located on private land in the ranges behind Nectar Brook property.

Site physical features:

Confined valley, series of connected pools within reach.

- pool dimensions — 10x4 m
- pool depth — 1 m.

Site hydrological features: Baseflow-fed permanent pool flowing at ~1–2 L/s.

Substrate type: Diverse (see Stream cover).

Site habitat: Pool and riffle (note flow rate insufficient to create true riffles; rather shallow laminar flow between pools).

Stream cover: Bedrock 20%, boulder 10%, cobble 20%, pebble 20%, gravel, 10%, sand, 5%, silt and clay 15%.

Vegetation condition, Land use: Grazing.

Riparian structure was predominantly comprised of a river red gum canopy and sparse shrub layer. Canopy cover varied from >70% to ~30% (at the survey site) or less. Some red gum regeneration was apparent with juveniles to ~2 m observed in low densities. Understorey species were sparse to absent and comprised of terrestrial species where present. Ground was effectively without any vegetative cover for ~50% or more of riparian areas.

Surrounding hill slopes varied between tall very open shrubland (at survey site) to low woodland. Predominant species was *Acacia victoriae*.

<u>Aquatic macrophytes:</u>

Submerged: Macro-algae including *Chara* spp.; unbranched filamentous algae; Brown–green algal scum and mats.

Emergents: Typha spp formed a monocover stand around the pool surveyed, with a small deeper open water pool.

Cyperus vaginatus was present in areas outside the monocover of *Typha* sp, in small clumps on bare mud banks.

Water quality:

- Conductivity (mS/cm) — 2.61 (Lab result = 2.56)
- Dissolved oxygen — 5.65 mg/L
- Temperature — 18.6°C
- Transparency — 5 cm
- pH — 7.91.

Fish: Dip netting carried out on 8/6/05. No fish recorded.

Macro-invertebrates: 10 m autumn edge habitat sampled according to AUSRIVAS protocols in main pool.

Date, time of waterbird survey: 29/06/05, 1530–1550 hours.
Results: No species of waterbirds were observed in the area.

Frogs: *Crinia signifera* heard.

B. MACRO-INVERTEBRATE REPORT

Report: Mid-North Macro-invertebrate Sample Analysis (AUSRIVAS) and Results

Compiled by: Sally Maxwell

Submission date: 15th August 2005

For: Department of Land Water and Biodiversity

AUSRIVAS band widths

The AUSRIVAS models function by using chemical and physical variables to classify a sample and then predict the families that should be present in that sample if it were from a reference site based on the classification group probabilities. This predicted (or "***E****xpected*") number of families is then compared with the number of families collected (or "***O****bserved*") in the sample. The comparison is in the form of a ratio of the Observed: Expected number of families – or OE in AUSRIVAS (Anon 2001). The models make frequent use of a 50% probability of taxon occurrence at a site. This is because those taxa with a >50% chance of occurring are considered the most useful for detecting a real decline in the number of taxa (Coysh et al. 2000). The AUSRIVAS output used in this report is the OE50 which is the observed: expected ratio for families predicted at greater than 50% probability for a sample. The OE50 ratio can be simplified to a band. Band ratings are X (higher than expected observed number of taxa), A (equivalent to reference), B (reduced number of families and therefore significantly impaired), C (severely impaired) and D (extremely impaired). The probabilities which determine the boundaries between bands may be different for each model season, as they are based on percentiles.

Site MAM03, Nectar Brook, was determined as A Band by the Autumn Edge AUSRIVAS model indicating the site was equivalent to reference condition.

Site MAM02, Waterfall Creek, had a reduced number of families and was therefore rated as B Band by the model.

Table 1: OE50 and Band ratings for sites sampled in June 2005

Site	OE50	BAND
MAM02	0.66	B
MAM03	0.93	A

Missing taxa

Missing taxa are determined by comparing the taxa that are predicted at a probability of greater than 50% with those that are actually found in the sample. The table below shows which taxa were missing from each sample and the total number of taxa missing overall.

Correspondingly the sites which had the highest number of missing taxa were also the ones that recorded B ratings.

Table 2: Missing taxa in sites sampled June 2005

Site	MAM02	MAM03
Nematoda	✕	✕
Hydrobiidae	✕	✕
Acarina		
Ceinidae	✕	
Atyidae	✕	✕
Collembola	✕	
Ceratopogonidae		
Orthocladiinae	✕	
Corixidae	✕	
Hydroptilidae	✕	
Leptoceridae	✕	✕
Total no. missing	**9**	**4**

References

Anonymous (updated September 2001) SOUTH AUSTRALIA AUStralian RIVer Assessment System Sampling and Processing Manual http://AUSRIVAS.canberra.edu.au/man/SA/SA_Training _Manual.pdf

Coysh, J., Nichols, S., Ransom, J., Simpson, J., Norris, R., Barmuta, L. and Chessman' B. (2000). Macro-invertebrates bioassessment Predictive modelling manual. http://AUSRIVAS.canberra. edu.au/Bioassessment/Macro-invertebrates/Man/Pred/

Macro-invertebrate Identification Sheet

Sample Alphanumeric		MAM02	MAM03
Date		7-Jun-05	8-Jun-05
Site Name		Waterfall Creek	Nectar Brook
Habitat		Edge	Edge
# of Taxa		27	34
Total Abundance		264	1127
number of vials sorted		23	13
processing time		9.67	11.58
operator name		SB	SM
Family			
Nematoda	Nematoda spp.	20	
Hydrobiidae	Hydrobiidae spp.		
) Oligochaeta	Oligochaeta spp.	3	17
Ceinidae	Austrochiltonia australis		61
Parastacidae	Cherax destructor		2
) Hypogastruridae	Hypogastruridae spp.	4	
Ceratopogonidae	Culicoides sp.	6	178
Tanypodinae	Procladius sp.	4	6
Tanypodinae	Paramerina sp.	1	15
Chironominae	Cladotanytarsus sp.	96	
Chironominae	Tanytarsus sp.	5	7
Chironominae	Paratanytarsus sp.	5	
Tanytarsini	Tanytarsini sp.	44	
Chironominae	Cryptochironomus sp.	1	
Baetidae	Cloeon sp.	5	7
Baetidae	Baetidae spp.	13	37
Caenidae	Tasmanocoenis tillyardi	34	
Aeshnidae	Aeshna brevistyla		1
Hydroptilidae	Hellyethira simplex		16

Chemistry Data

SITE	**SAMPDTE**	**ALKALINITY** AS CALCIUM CARBONATE :: CALCULATION mg/L	**BICARBONATE** :: AUTO POTENTIOMETRIC TITRE pH 4_5 mg/L	**CONDUCTIVITY** :: CONDUCTIVITY METER (CHEM LAB) uS/cm	**TOTAL DISSOLVED SOLIDS (BY EC)** :: CALCULATION mg/L
MAM02	07-Jun-05	434	529	4500	2500
MAM03	08-Jun-05	496	605	2560	1400

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

~	equals approximate to
EC	electrical conductivity (µS/cm)
pH	acidity
ppm	parts per million
ppb	parts per billion
TDS	total dissolved solids (mg/L)

GLOSSARY

Anurans — Frogs and toads. Strictly amphibians of the order Anura, characterised by the lack of a tail.

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

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

Arid lands — In South Australia, arid lands are usually considered to be areas with an average rainfall of less than 250 mm and support pastoral activities instead of broadacre cropping.

AWQC — Australian Water Quality Centre.

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).

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

CWMB — Catchment Water Management Board.

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

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

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.

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

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

Estuaries — Semi-enclosed water bodies at the lower end of a freshwater stream that are subject to marine, freshwater and terrestrial influences, and experience periodic fluctuations and gradients in salinity.

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

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 (e.g. land parcels) to textual data (soil type, land value, ownership). It allows for a range of features, from simple map production to complex data analysis.

GL — *See gigalitre*.

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

Geomorphology — The scientific study of the landforms on the Earth's surface and of the processes that have fashioned them.

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.)*

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

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

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

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

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

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

ML — *See megalitre.*

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

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.

Phreatophytic vegetation — Vegetation that exists in a climate more arid than its normal range by virtue of its access to groundwater.

Phytoplankton — The plant constituent of organisms inhabiting the surface layer of a lake; mainly single-cell algae.

Potentiometric head — The potentiometric head or surface is the level to which water rises in a well due to water pressure in the aquifer.

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.)*

Riffles — Shallow stream section with fast and turbulent flow.

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.

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.

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

Water body — Water bodies 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 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.

REFERENCES

Acuña, V, Muñoz, I, Giorgi, A, Omella, M, Sabater, F & Sabater, S 2005, 'Drought and post-drought recovery cycles in an intermittent Mediterranean stream: structural and functional aspects', *Journal of the North American Benthological Society*, Vol. 24(4), pp.919–933.

Alley, NF & Lindsay, JM 1995, Tertiary: Pirie Basin, in JF Drexel & WV Preiss (eds), *The geology of South Australia, Vol. 2, The Phanerozoic*, Bulletin 54, Geological Survey, Adelaide, pp.175–178.

Bence, JR & Murdock, WW 1986, 'Prey size selection by the mosquitofish: Relation to optimal diet theory', *Ecology*, 67, pp.324–336.

Blyth, B 1994, 'Predation by *Gambusia holbrookii* on anuran larvae at the RGC Wetlands Centre, Capel, WA', *Technical Report (Western Australia, RGC Wetlands Centre) 22*, RGC Mineral Sands, Capel, Western Australia.

Boulton, AJ 2003, 'Parallels and contrasts in the effects of drought on stream macro-invertebrate assemblages', *Freshwater Biology*, 48 (7), pp.1173–1185.

Boulton, AJ, Findlay, S, Marmonier, P, Stanley, MH & Valett, HM 1998, 'The functional significance of the hyporheic zone in streams and rivers', *Annual Review of Ecology and Systematics*, Vol. 29, pp.59-81.

Boulton, AJ & Lake, PS 1992, 'The ecology of two intermittent streams in Victoria', Australia III, Temporal changes in faunal composition, *Freshwater Biology*, 27(1), pp.123–138.

Boulton, AJ & Williams, WD 1996, 'Aquatic biota', in M Davies, CR Twidale & MJ Tyler (eds) *The natural history of the Flinders Ranges,* Department of Environment and Natural Resources, Adelaide, pp.102–112.

Brown, WA & Kraehenbuehl, DN 2000, 'Assessment of riparian vegetation of the Mid North region', unpublished report to Environment Protection Agency, Department for Environment and Heritage, Adelaide.

Brunke, M & Gonser, T 1997, 'The ecological significance of exchange processes between rivers and groundwater', *Freshwater Biology*, 37(1), pp.1–33.

Bunn, S 1988, 'Processing of leaf litter in two northern jarrah forest streams, Western Australia: II. The role of macro-invertebrates and the influence of soluble polyphenols and inorganic sediment', *Hydrobiologia*, 162(3), pp.211–223.

Bunn, SE & Arthington, AH 2002, 'Basic principles and ecological consequences of altered flow regimes for aquatic biodiversity', *Environmental Management*, 30, pp.492–507.

Bunn, S, Davies, PM, Negus, P & Treadwell, S 1999, 'Aquatic Food Webs', in S Lovett & P Price (eds), *Riparian land management technical guidelines, Vol. 1: Principles of sound management*, Land and Water Resources Research Development Corporation, Canberra.

Casanova, MT 2005, 'An overview of *Chara* L. in Australia (Characeae, Charophyta)', *Australian Systematic Botany*, 18(1), pp.25–39.

Chessman, B 2003, SIGNAL 2 — *A scoring system for macro-invertebrate ('water bugs') in Australian rivers*, Monitoring River Heath Initiative Technical Report 31, Commonwealth of Australia, Canberra.

Clarke, DC 1989, *Groundwater and irrigation in the Baroota area, southern Pirie–Torrens Basin*, Report Book 90/39, Department of Mines and Energy, Adelaide.

Closs, GP & Lake PS 1994, ‘Spatial and temporal variation in the structure of an intermittent-stream food web’, *Ecological Monographs*, 64(1), pp.1–21.

Cook, P 2003, *Regional groundwater flow in fractured rock aquifers*, CSIRO Land and Water, Adelaide.

Dingman, SL 2002, *Physical hydrology,* 2nd edn, Prentice Hall, New Jersey.

Downes, BJ, Barmuta, LA, Fairweather, PG, Faith, DP, Keough, MJ, Lake, PS, Mapstone, BD & Quinn, GP 2002, *Monitoring ecological impacts: Concepts and practice in flowing waters*, University Press, Cambridge.

Downes, BJ, Lake, PS, Schreiber, ESG & Glaister, A 1998, ‘Habitat structure and regulation of local species diversity in a stony, upland stream’, *Ecological Monographs*, 68(2), pp.237–257.

EPA & AWQC 2003, *River health in the Flinders Ranges*, (Fact sheet) Environmental Protection Authority, Department for Environment and Heritage, Adelaide.

Favier, D, Rixon, S & Scholz, G 2000, *A river management plan for the Wakefield River Catchment*, Special Projects Group, Evaluations Unit, Environment Protection Authority, Department for Environment and Heritage.

Favier, D, Scholz, G, VanLaarhoven, J, Bradley, J & Phipps, L 2004, *A river management plan for the Broughton River Catchment*, Report DWLBC 2004/16, Department of Water, Land and Biodiversity Conservation, Adelaide.

Figuerola, J & Green, AJ 2002, ‘Dispersal of aquatic organisms by waterbirds: A review of past research and priorities for future studies’, *Freshwater Biology*, 47(3), pp.483–494.

Gooderham, J & Tsyrlin, E 2002, *The waterbug book,* CSIRO Publishing, Collingwood, Victoria.

Gordon, ND, McMahon, TA, Finlayson, BL, Gippel, CJ & Nathan, RJ 2004, *Stream hydrology: An introduction for ecologists,* 2nd edn, John Wiley and Sons Ltd, West Sussex, England.

Hatton, T & Evans, R 1998, *Dependence of ecosystems on groundwater and its significance to Australia*, Occasional Paper 12/98, Land and Water Resources Research Development Corporation, Canberra.

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

Hose, GC, Jones, P & Lim, R 2005, ‘Hyporheic macro-invertebrates in riffle and pool areas of temporary streams in south eastern Australia’, *Hydrobiologia*, 532(1-3), pp.81–90.

Humphries, P & Baldwin, DS 2003, ‘Drought and aquatic ecosystems: An introduction’, *Freshwater Biology*, 48(7), pp.1141–1146.

Hutchinson, MN & Tyler, MJ 1996, ‘Reptiles and amphibians’, in M Davies, CR Twidale, & MJ Tyler (eds), *The natural history of the Flinders Ranges*, Department for Environment and Natural Resources, Adelaide, pp.149–158.

Kimberley, RJ, Cant, J & Ryan, T 2003, ‘Responses of freshwater biota to rising salinity levels and implications for saline water management: A review’, *Australian Journal of Botany*, 51, pp.703–713.

Lake, PS 2000, ‘Disturbance, patchiness, and diversity in streams’, *Journal of the North American Benthological Society*, 19(4), pp.573–592.

Lake, PS 2003, ‘Ecological effects of perturbation by drought in flowing waters’, *Freshwater Biology*, 48(7), pp.1161–1172.

Lloyd, LN 1987, ‘Ecological interactions of *Gambusia holbrookii* with Australian native fishes’, in DA Pollard (ed), *Introduced and translocated fishes and their ecological effects*, Australian Society for Fish Biology, Magnetic Island, Queensland, pp.94–97.

Martin, R, Sereda, A & Clarke, D 1998, *Spencer Regions strategic water management study*, Report Book PIRSA 98/19, Primary Industries and Resources South Australia, Adelaide.

McMurray, D 1996, ‘Farm dam storage assessment — A collection of reports on investigations relating to remote farm dam volume assessment techniques’, Department of Water, Land and Biodiversity Conservation, Adelaide.

McMurray, D 2004, Farm dam volume estimations from simple geometric relationships, Report DWLBC 2004/48, Department of Water, Land and Biodiversity Conservation, Adelaide.

Minshall, GW & Robinson, CT 1998, ‘Macro-invertebrate community structure in relation to measures of lotic habitat heterogeneity’, *Archiv für Hydrobiologie*, 141(2), pp.129–151.

Mosley, MP & McKerchar, AI 1993, ‘Streamflow’, in DR Maidment (ed) *Handbook of hydrology*, McGraw-Hill, New York, pp.8.1–8.39.

Neilsen, DL, Brock, MA, Rees, GN & Baldwin, DS 2003, ‘Effects of increasing salinity on freshwater ecosystems in Australia’, *Australian Journal of Botany*, 51, pp.655-665.

NLWRA 2000, *Australian Water Resources Assessment 2000*, National Land and Water Resources Audit, A program of the Natural Heritage Trust, Canberra.

NLWRA 2002, ‘Australians and Natural Resource Management 2002: Social and economic dimensions of natural resource management based on natural resource accounting and a social profile of rural Australia’, *National Land and Water Resources Audit*, Commonwealth of Australia, p.271.

NPWS 2000, *Winninowie Conservation Park Management Plan,* National Parks and Wildlife, Department for Environment and Heritage, Adelaide.

NPWS 2001. *Mount Remarkable National Park Draft Management Plan,* National Parks and Wildlife, Department for Environment and Heritage, Adelaide.

Parkes, RFW 1961, *Historic souvenir, Port Germein and District,* Automatic Printing Co, Port Pirie.

Phipps, L 2000, ‘Wanted: Gambusia (*Gambusia holbrookii*, Mosquito fish, Gambusia), the tiny destroyers’, *Bookmark Bulletin, Newsletter of the Bookmark Biosphere Program*, No. 11.

Pierce, B, Young, M & Sims, T 2003, ‘Flinders Ranges fishes’, in R Brandle (ed), *Biological survey of the Flinders Ranges*, Department for Environment and Heritage, Adelaide.

Poff, L, Allan J, Bain M, Karr, J, Prestegaard, K & Richter B 1997, ‘The natural flow regime: a paradigm for river conservation and restoration’, *Bioscience*, 47(11), pp.769–784.

Preiss, WV (compiler) 1987, *The Adelaide Geosyncline: Late Proterozoic stratigraphy, sedimentation, palaeontology and tectonics*, Bulletin 53, Geological Survey, Adelaide.

Purton, C & Davies, B 2005, ‘Northern dams yield analysis: Bundaleer, Beetaloo and Baroota Reservoirs’, Report to the South Australian Water Corporation by Tonkins Engineering Science Ref No 2004.0854.

Richter, BD, Baumgartner, JV, Powell, J & Braun, DP 1996, A method for assessing hydrologic alteration within ecosystems, *Conservation Biology*, 10(4), pp.1163–1174.

Risby, L, Scholz, G, Vanlaarhoven, J & Deane, D 2003, *Willochra Catchment hydrological and ecological assessment*, Report DWLBC 2003/20/21, Department of Water, Land and Biodiversity Conservation, Adelaide.

Savadamuthu, K 2002, *Impact of farm dams on streamflow in the Upper Marne Catchment*, Report DWR 02/01/0003, Department for Water Resources, Adelaide.

Seaman, RL 2002, *Wetland inventory of the Northern Agricultural Districts, South Australia*, Department for Environment and Heritage, South Australia.

Smith, R, Jeffree, R, John, J & Clayton, P 2004, 'Review of methods for water quality assessment of temporary stream and lake systems', Final report to Australian Centre for Mining Environmental Research, Kenmore, Queensland.

Timms, BV 1992, 'The conservation status of athalassic lakes in New South Wales, Australia', *Hydrobiologia*, 243-244, pp.435-444.

Tyler, MJ. 1977, *Frogs of South Australia*, 2nd edn, South Australian Museum, Adelaide.

Van den Berg, MS, Coops, H & Simons, J 2001, 'Propagule bank buildup of *Chara aspera* and its significance for colonization of a shallow lake', *Hydrobiologia*, 462(1/3), pp.9–17.

VanLaarhoven, J, Scholz, G, Phipps, L & Favier, D 2004, *A river management plan for the Light Catchment*, Report DWLBC 2004/17, Department of Water, Land and Biodiversity Conservation, Adelaide.

Vannote, RL, Minshall, GW, Cummins, KW, Sedell, JR & Cushing, CE 1980, 'The river continuum concept', *Canadian Journal of Fisheries and Aquatic Sciences*, 37, pp.130–37.

Velasco, J, Millan, A, Vidal-Abarca, MR, Suarez, ML, Guerrero, C & Ortega, M 2003, 'Macrophytic, epipelic and epilithic primary production in a semiarid Mediterranean stream', *Freshwater Biology*, 48(8), pp.1408–1420.

Vinson, MR & Hawkins, CP 1998, 'Biodiversity of stream insects: Variation at local, basin, and regional scales', *Annual Review of Entomology*, 43, pp.271–293.

Wade, S, Corbin, T & McDowell, L 2004, *Critter catalogue: A guide to the aquatic invertebrates of South Australian inland waters*, Environmental Protection Authority, Department for Environment and Heritage, Adelaide.

Walker, KF, Sheldon, F & Puckridge, JT 1995, 'A perspective on dryland river ecosystems', *Regulated Rivers: Research and Management*, 11, pp.85–104.

Walker, SJ, Hill, BM & Goonan, PM 1998, Frog Census 1998: A report on community monitoring of water quality and habitat condition in South Australia using frogs as indicators, Environmental Protection Authority, Adelaide.

Williams, DD 1996, 'Environmental constraints in temporary fresh waters and their consequences for the insect fauna', *Journal of the North American Benthological Society*, 15(4), pp.634–650.

Personal Communications

Agency and NRM Board staff

Stuart Beinke, Head Ranger Mount Remarkable National Park

Dave Clarke, Former regional hydrogeologist, Crystal Brook; Member – Water Implementation Group (WIG) NYNRMB

David Cresswell, Principal Hydrologist, DWLBC

Scott Evans, Principal Hydrogeologist, DWLBC

Lindy Pearson, Former Waterwatch coordinator, NYNRMB

Barry Mudge, Landholder Baroota, Member — WIG NYNRMB

Bruce Murdoch, Senior Hydrographer, DWLBC

Community members

Neville Davis, Lifelong resident of the southern Mambray Coast. Long-term family history in the Telowie Gorge area

Darcy Evans, Nominated representative of the Nukunu people

Graham Herde, 3rd generation farmer in the Mambray Coast, Landholder Nectar Brook

Kevin Pole, Landholder and lifelong resident of the southern Mambray Coast. Long-term family history in the Port Germein – Baroota area

Harvie and Joan Spencer, Landholders on Mambray Creek, long-term residents

Tony Said, Landholder, upper Baroota Creek