DWLBC REPORT

Preliminary assessment of the impacts of water resource development on Burra Creek Catchment

2008/01

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

Preliminary assessment of the impacts of water resource development on Burra Creek Catchment

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

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FOREWORD

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

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

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

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

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EXECUTIVE SUMMARY

A water resources and environmental water requirements assessment was undertaken of the semi-arid Burra Creek Catchment, located in the northwestern corner of the South Australian Murray-Darling Basin. A daily time step surface water model was constructed using the WaterCress modelling platform to evaluate changes to catchment hydrology resulting from farm dam development, and any resulting impacts on flow regime. Considerable uncertainties exist around the calibration and use of the model in the catchment, not only because rainfall intensity data were not available, but also with regard to the permanent baseflow and the lack of suitable calibration data post-1992. Despite limitations, model performance was deemed adequate for the purposes of this preliminary investigation.

RAINFALL

A rainfall dataset representative of conditions in the catchment as a whole was generated to analyse rainfall patterns. For the period 1884–2004, the mean annual rainfall was 417 mm, but inter-annual variability was high, with totals ranging between 172–793 mm. Although some seasonality is evident in monthly rainfall patterns, this is not pronounced and long-term means for the ‘wet season’ months, from May to October, range from 40–54 mm. In reality these do not greatly exceed mean rainfall during lower rainfall months, which ranges from 16–27 mm. This indicates the high relative contribution of episodic storm events to annual rainfall totals.

Historical records suggest that annual rainfall prior to ~1975 was more variable, and the distribution of annual rainfall since this period demonstrates a significant shift towards the long-term average, with fewer extreme wet and dry years. An apparent tendency towards a later onset in seasonal rainfall, although not significant, is also evident in the record since around this time. Both of these trends, if persistent, can over time be expected to produce less surface runoff and groundwater recharge than has been observed historically.

STREAMFLOW

Daily flow data were acquired from a streamflow gauging station for the period 1974–2004. Records indicate that Burra Creek has never ceased to flow at the site during the period. Although the data record is continuous, major siltation at the site during 1992 reduced the low-flow sensitivity, introducing significant uncertainties in streamflow analysis for data post-1992.

Annual total flow volumes are extremely variable, ranging from 611–40 000 ML. Mean annual catchment yield for the period was 5248 ML/y, but the data distribution is extremely skewed, and the median runoff of 2345 ML/y is considered a more indicative measure of centrality in the annual flow data. Mean monthly streamflows reflect the variability of rainfall intensity and the importance of extreme events in generating runoff. Although winter rainfall is more reliable, the highest mean monthly streamflow for the period was for January.

Two characteristics of the streamflow were apparent from the analyses in this report:

- Surface runoff generated within the catchment is extremely unreliable and mean totals are highly influenced by extreme events. In effect there is no such thing as a 'typical' year as far as streamflow generated from surface runoff is concerned.
- In contrast, groundwater discharges (baseflow) to Burra Creek are extremely reliable and provide the constant flow maintaining the perennial reaches of the central catchment. These flows constitute on average 70% of annual streamflow, and inclusion of these volumes in determining a sustainable level of surface water use is arguably misleading and may overestimate the available resource. At the very least, this finding is evidence of the need to manage surface and groundwaters conjunctively in the catchment.

GROUNDWATER RESOURCES

Aquifers in the catchment are predominantly fractured rock in nature, but some sedimentary formations occur to the north of Burra and in the lower catchment, comprised of Murray Group sediments. Although generally low yielding, the Skillogalee Dolomite constitutes a highly faulted and transmissive zone in the regional fractured rock aquifer. The course of Burra Creek has been influenced by this, and follows the zone from Burra township south to Burra Gorge. Discharges from this unit are the source of the extensive perennial reaches of the creek in the central catchment.

A quantitative water balance for the Skillogalee Dolomite is not currently possible, but it clearly represents a major storage. Streamflow records show that discharges to Burra Creek have remained relatively constant, even over periods of below average rainfall enduring for several years. Determining the recharge and subsurface flow processes that support this discharge is arguably the most important knowledge gap for the future management of Burra Creek and the environmental values it supports.

Throughout the gauged catchment, 456 wells are currently listed in the state drillhole database as being either operational or with unknown status. Groundwater is generally quite saline (median salinity 2795 mg/L) and low yielding (median value of 1.0 L/s). Limited groundwater development was identified, and is thought to be almost entirely for stock and domestic use. The exception is some irrigated carob and stone fruits as well as limited lucerne irrigation.

FARM DAM DEVELOPMENT LEVELS

Total dam storage was estimated to be 985 ML, with 609 dams identified. Most are small stock dams and the mean storage capacity is only 1.6 ML. Ninety-five percent of dams are under 5 ML in size, but 23% of farm dam storage is estimated to be contained within the remaining 5% of dams. No irrigation dams were identified within the catchment during field surveys or desktop analyses, but imagery suggests that some flood irrigation of paddocks may be carried out in the central catchment.

Modelling suggests that farm dams are having a major impact on streamflow in all but extreme years. Analysis of adjusted runoff based on observed streamflow suggests that dams intercept up to 70% of total surface runoff during low rainfall years. If the adjusted runoff is based only on the quickflow component of the gauged record, this value increases to 95% capture. There is also evidence that dams may delay the onset of streamflow. Given the low rainfall and modest runoff response of the catchment, dams may not even fill to full supply during many years, meaning that the entire streamflow for the year is being captured.

At catchment scale, dam storage appears to be within the SA MDB NRM Board 30% of average winter runoff criteria (estimated to be 1289 ML/y), but at least two sub-catchments appear to already exceed this level. Questions must be raised however as to whether it is appropriate to adopt policies from higher rainfall areas where seasonal runoff is relatively reliable. The development of policies specific to semi-arid areas to moderate the development of small stock dams is a challenge that needs to be addressed across many areas of South Australia. Ideally this should be based on a quantitative understanding of all components of the catchment water balance.

IMPACTS ON ENVIRONMENTAL WATER REQUIREMENTS

The two components of streamflow exert different influences on the aquatic ecology through their separate flow regimes and water quality characteristics.

Groundwater discharges of moderate water quality support permanent in-stream and riparian habitat. The relatively constant flow rate provides the baseline conditions. Although anecdotal evidence and streamflow data suggest that recent baseflow levels have decreased to the lowest on record, uncertainties over the data quality mean that this cannot currently be confirmed. Protection of this flow characteristic in the central catchment is critical to maintaining the permanent habitat, but is largely a question of sustainable groundwater use. Determining whether human activities currently present any risk to baseflow was beyond the scope of this report.

In contrast to the virtually constant baseflow, streamflow due to surface runoff processes is highly variable, and supports the diverse hydrologic and geomorphic processes that are required to maintain stream habitat in good condition. Modelling indicates that the catchment is under significant hydrological stress in the low flow range and the median flow volume has more than halved across all flow seasons. Other deviations to the flow regime include a decrease in the number of freshes. The environmental benefit of these flow bands would be the provision of good quality, albeit temporary, flowing freshwater habitat, and through producing increases in the diversity and extent of permanent wetted habitat as well as helping to ameliorate the salinity of the perennial system.

1. INTRODUCTION

1.1 PURPOSE

The purpose of this project was to provide a preliminary assessment of the water resource development levels within the Burra Creek Catchment. The major interest was to determine if current development levels are unsustainable, and potentially impacting on the environment, in order to direct future NRM actions and decisions that will ensure the on-going protection of these resources. In support of the project there are community concerns that the water resources and ecological integrity of Burra Creek had been in decline during recent years due to over exploitation.

The report forms a component of two separate Northern and Yorke NRM Board assessment projects entitled *Investigation of the impacts of farm dams and irrigation in priority areas under development pressure* and *Regional investigation of smaller streams to assess whether their environmental water requirements are being met*.

1.2 APPROACH

In undertaking this project it was necessary to estimate the size of the water resources, as well as the levels of use, in order to determine whether existing water resource development could be considered to be sustainable.

The methods employed followed several stages, as follows:

- Collation and initial review of relevant literature and hydrologically relevant data.
- Community consultations including public meetings, surveys, site visits and interviews.
- Acquisition of remotely sensed information including aerial photography and aerial videography of third order (Strahler) and higher watercourses.
- Spatial analysis of imagery using GIS including: digitisation of farm dam full-supply levels, and estimation of dam volumes; farm dam density analyses; and coding of key watercourse ecological features.
- Field surveys of ecologically important sites and groundtruthing of remotely sensed data.
- Desktop analysis of data including data processing and analysis for trends.
- Surface water modelling: development, calibration and scenario evaluation to determine the degree of influence of farm dams on catchment hydrology and environmental water requirements.
- Reporting.

Detailed information on the technical methods employed in the above stages is provided in the relevant appendices to this report.

2. CATCHMENT DESCRIPTION

2.1 OVERVIEW

The Burra Creek Catchment (Fig. 1) is ~200 km north of Adelaide in the northwestern corner of the South Australian Murray-Darling Basin. Whilst considered part of the basin, surface flows from the catchment to the main stem of the river are rare as the lower reaches are essentially floodout plains and lack defined drainage. The last time that catchment-wide flow is known to have reached the River Murray was in 1941, although it is thought to have occurred a number of times prior to this since European settlement (D. Lindner, Landholder, pers. comm., 2005).

Climate in the region is semi-arid but follows broadly Mediterranean patterns of hot, dry summers and cool, relatively wet winters. Although the predominant wet period is during winter–spring, summer storms can deliver large volumes of water during short periods of time. The catchment has occasionally seen the advent of such storms over the previous few decades, sometimes resulting in extreme flood events. The most significant flooding of the past four decades occurred during 1974 and 1992–93 (see Fig. 2). The January 1993 flood event followed catchment-wide rains of over 150 mm. The highest gauged mean daily stage since records began in 1974 was recorded, peaking at over 3.5 m (see Section 8).

Although some confusion exists over the original vegetation in the region, clearance of what native vegetation was present to support mining or agricultural activity greatly increased runoff volumes and velocities, leading to widespread erosion. The effects of this change is evident as deeply incised streams and gully erosion present throughout much of the central catchment. More recently, landholders have responded to the issue of land degradation and erosion through improved land management practice such as minimum tillage, contour banking and increased farm dam development.

Farm dam storages, although relatively modest in volume compared to higher rainfall areas, and comprising in the main only small stock dams, are considered to have the potential to excessively impact on streamflow owing to the semi-arid nature of the catchment. Evidence of impacts was provided by landholders consulted during this project who reported a reduction in the frequency, volume and duration of streamflow events over the last 10 or more years. Landholders consulted generally considered that increased farm dam development was the main contributing factor.

Burra Creek is well known for its environmental values and Burra Gorge (also known as Worlds End Gorge) has been a regular recreational site enjoyed by residents and visitors to the area since European settlement (Fig. 3). In addition to the gorge, a number of other sites of permanent surface water provide valuable aquatic habitat, including a number of ecologically significant permanent pool and baseflow reaches in the middle to lower sections of the creek.

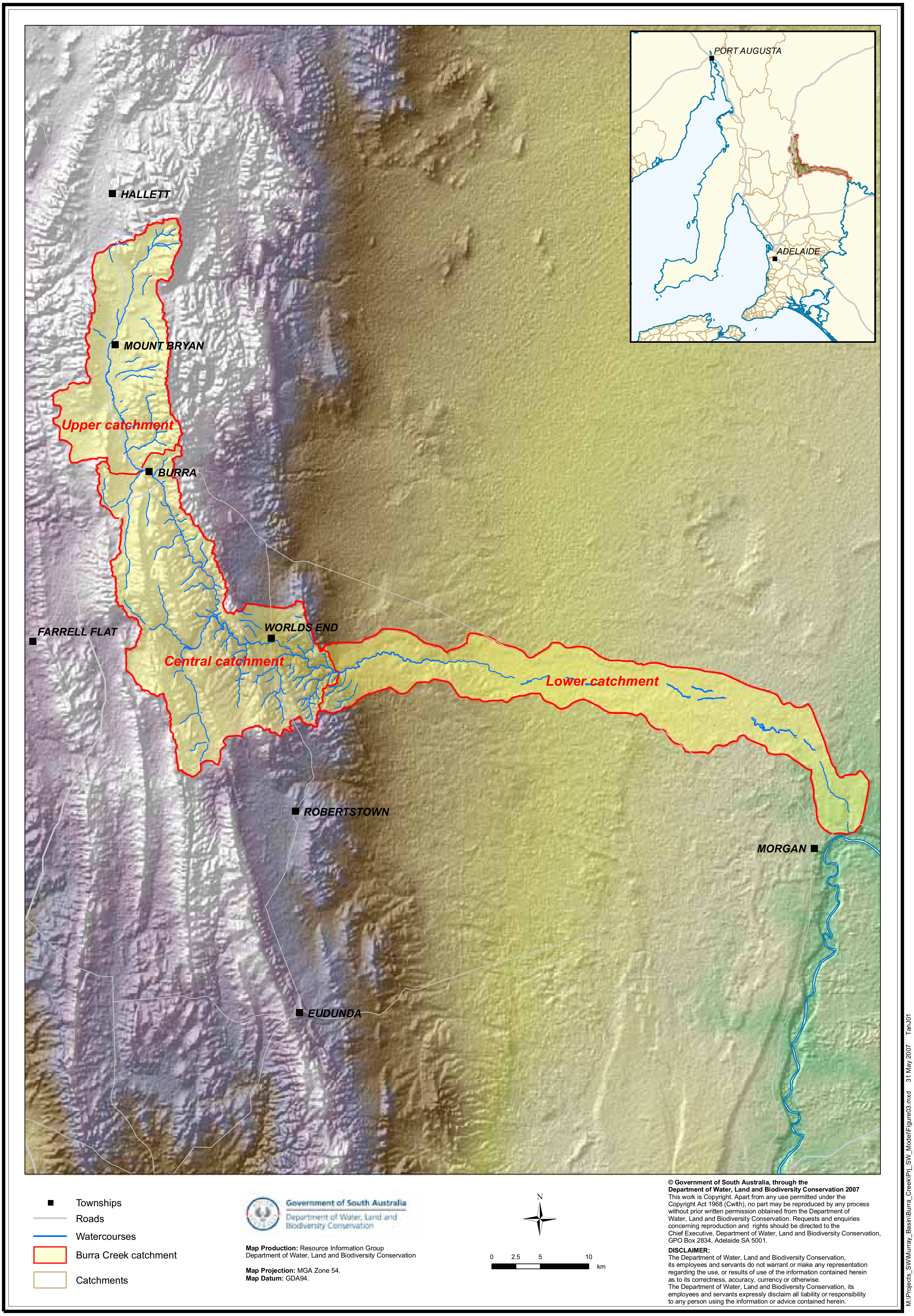


Figure 1. Burra Creek Catchment location

Photos: Courtesy G&T Philips (left); Burra Community Library (right).

Figure 2. Burra Creek in flood, February 1974 (left) and January 1993 (note footbridge)

Photo: Courtesy Burra Community Library.

Figure 3. Visitors to Burra Gorge (c.1920)

2.2 CATCHMENT PHYSICAL CHARACTER

The Burra Creek Catchment is a narrow L-shaped catchment, orientated almost north–south along its vertical limb, which is ~56 km long and 6–15 km wide. Elevation generally declines in the north–south direction, falling from ~550 m AHD in the north to ~290 m AHD at the Worlds End gauging station (site A4260536).

At Burra Gorge, ~5 km west of the gauging station, the creek turns easterly and follows a course slightly south of due east. Theoretically, the watercourse continues for a further 60 km, meeting the River Murray at Nor West Bend, near the township of Morgan. In reality, the flat topography and very low rainfall of the lower catchment produces little runoff and in terms of a clearly defined channel the creek is not discernible for much further than 20 km east of the gauging station.

The catchment can be conceptually considered in three zones, which describe not only the general topography but also the catchment character within each zone:

- The upper catchment, north of Burra township.
- The central catchment from Burra township to the southern catchment divide and including the Burra Gorge, extending to around Worlds End in the east.
- The lower catchment and floodplain, comprising the area to the east of the gauging station at Worlds End.

The upper catchment landscape comprises generally flat to slightly undulating terrain, the catchment boundary being defined by some locally significant relief, including Mount Cone and Mount Bryan to the east, and Hallett Hill to the west.

The central catchment is defined by a series of three north–south-trending ridge lines comprising part of the northern Mount Lofty Ranges. The course of Burra Creek itself is largely fault controlled through this area, following a major north–south-trending fault line to the east of the central range. These parallel ridges create a number of sub-catchments, many of which provide important contributing flows to Burra Creek. Watercourses follow valley floor slopes and may flow north or south and, where topography allows, between valleys. The most notable of these is Logan Creek, which is perennial in its lower reaches, and flows through a gap in the range of the same name, to meet Burra Creek just upstream of Burra Gorge. Between the range and the creek is the same water-bearing formation of Skillogalee Dolomite in which the former Burra Mine is also located (Segnit 1937; see Fig. 4). Most permanent water in the Burra Creek system through the central catchment region is largely sourced from this geological unit. The relationship between surface and groundwater in the catchment is highly significant and is discussed in Section 5.3.

The lower catchment commences to the east of the Worlds End gauging station. In this area there is a well-defined channel with permanent flow. Further to the east, flow becomes discontinuous, and permanent waterholes are irregularly located for ~20 km downstream of the gauging station. Although these become increasingly saline, they are of a significant volume and represent important habitat. With further distance to the east, Burra Creek becomes poorly defined and is essentially a floodout plain, with braided and discontinuous drainage lines. Very little runoff is generated in this area of the catchment due

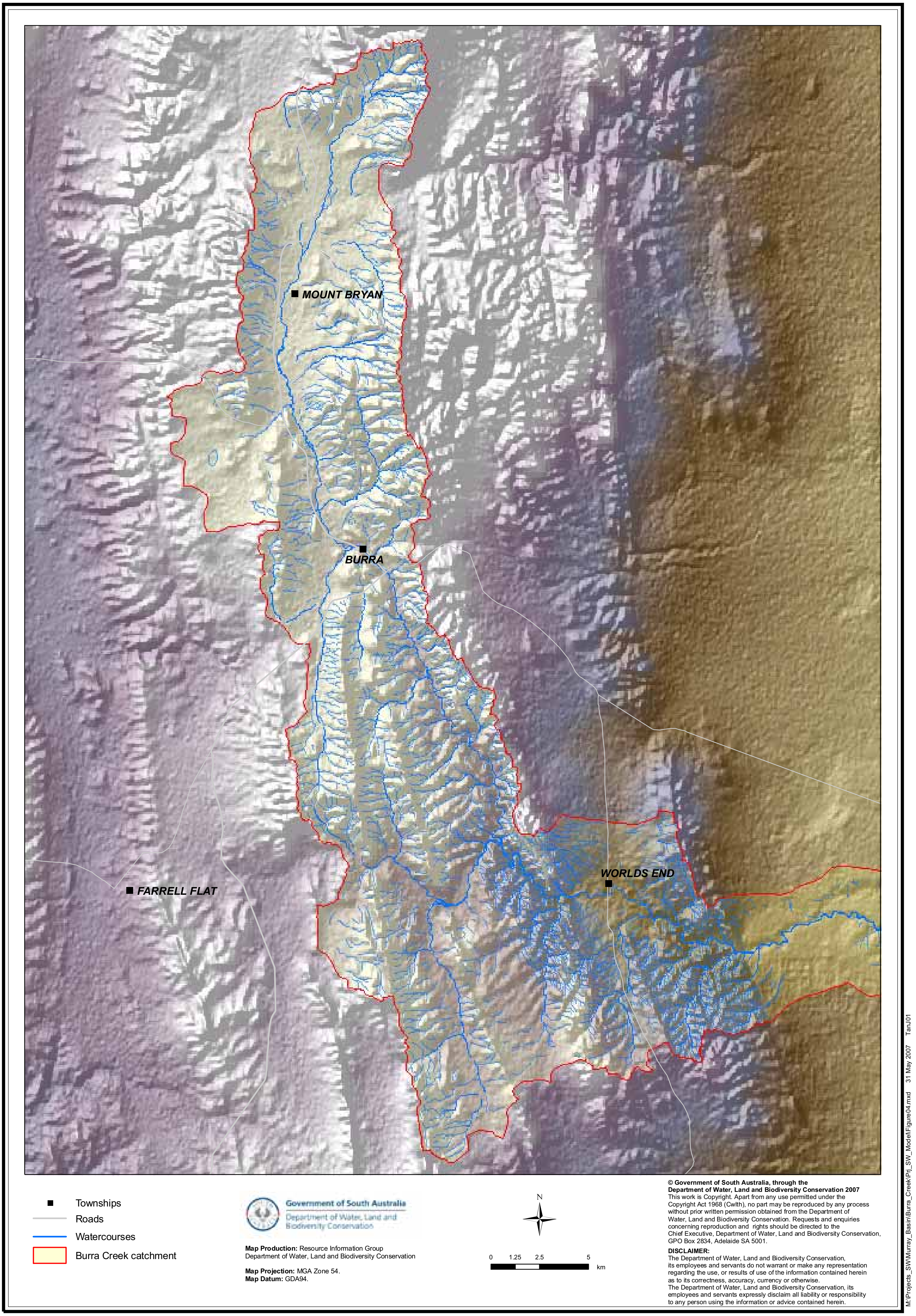


Figure 4. Burra Creek Catchment topography and drainage

to the flat topography, low rainfall and high evaporation. The water balance of this part of the catchment is dependent upon inflows, both surface and groundwater, from the upstream areas.

2.3 LAND USE

The catchment is predominantly under a grazing regime, Burra being known as a prominent Merino sheep producing area. Cereal cropping, often in a grazing rotation, also occurs, more commonly in the upper catchment.

A number of irrigation paddocks, largely irrigated sown grasses, were recorded by the Bureau of Rural Sciences in a land-use survey during 1999. Presumably the source of water at this time would have been groundwater, but it appears that irrigation activity has greatly decreased in recent years as only one area of irrigated grasses was observed during field surveys in 2005. Irrigation of lucerne is thought to have been quite widespread in the region to the north of Burra township up until the early 1990s (D. Lindner, landholder, pers. comm., 2005). It is unknown whether the absence of such activity over more recent times is economically driven, due to declines in the capacity of the groundwater resource to support irrigation, or due to some other factor.

Some small orchards have been established within the catchment but the salinity of the groundwater resource and scarcity of surface runoff limit the available range of irrigated horticulture using native water. Table 1 shows simplified categories of land use identified during field surveys undertaken by the Bureau of Rural Sciences during 1999.

Table 1. Land-use categories and areas for Burra Creek gauged catchment

Land use	**Area** (ha)	% of catchment
Grazing	35 813	66.2
Cropping–grazing rotation	12 895	23.8
Legumes, oil seeds	2 950	5.5
Irrigated grasses	294	0.54
Residential, services, manufacturing	204	0.4
Irrigated fruit trees	38	0.07
Other	1 950	3.6
Total	**54 141**	**100**

Source: Adapted from BRS (1999).

2.4 ENVIRONMENTAL VALUE

The catchment supports extensive areas of continuous permanent surface water, extending for 17 km along the creek from south of Burra township to Burra Gorge and consisting of numerous deep pools connected by year-round flow. Perennial flow through the reach is maintained by permanent groundwater discharge referred to as baseflow.

The extent of this permanent aquatic habitat is effectively unique in semi-arid South Australia and is therefore of intrinsic value. Section 8 shows the location of ecological habitat assets identified in the catchment such as permanent pools, and discusses the aquatic biota and flow-related ecology. The potential for current surface water development to impact on water-dependent ecosystems is also examined through modelling.

2.5 SUB-CATCHMENT AREAS

The three conceptual catchment areas discussed above describe the broad nature of the system, but in order to model and assess the hydrology of a catchment it is necessary to divide it into smaller study areas. The size of the study areas will depend on the question being addressed by the assessment, the heterogeneity of the catchment and the available information.

During this study it was necessary to divide the catchment into gauged and ungauged areas. This is dependent on the location of the streamflow gauging station — the area contributing flow to this point is referred to as the ‘gauged catchment’ and this area forms the focus of the hydrological assessment aspects of this report. Runoff from areas that will not pass the site of the station are precluded from quantitative assessment, but the impacts of over-development in the gauged catchment will also affect the downstream areas, and where appropriate are described in a qualitative sense.

To effectively model the gauged catchment it is necessary to further divide this into a number of sub-catchment areas, each of which is represented in the model as a node. (Further detail on model construction is provided in Section 6). These subdivisions are generally based on aspects such as their location relative to the stream gauging network, the distribution of rainfall, land use and so on. Seven such areas were determined for use in the model, and these are referred to as the ‘model sub-catchments’.

As the model sub-catchments were considered to be too large to present effective information relating to the concentration of farm dam development, further subdivisions were undertaken in which a relatively small number of individual reaches were included. These areas were used for farm dam capture spatial analysis, and are referred to as ‘reach-scale sub-catchments’.

Figure 5 shows all of the catchment boundaries as discussed above, and Appendix B provides relevant information about these areas such as average rainfall, total dam storage volume, proportion of the catchment that is estimated to be free to flow, and estimated runoff.

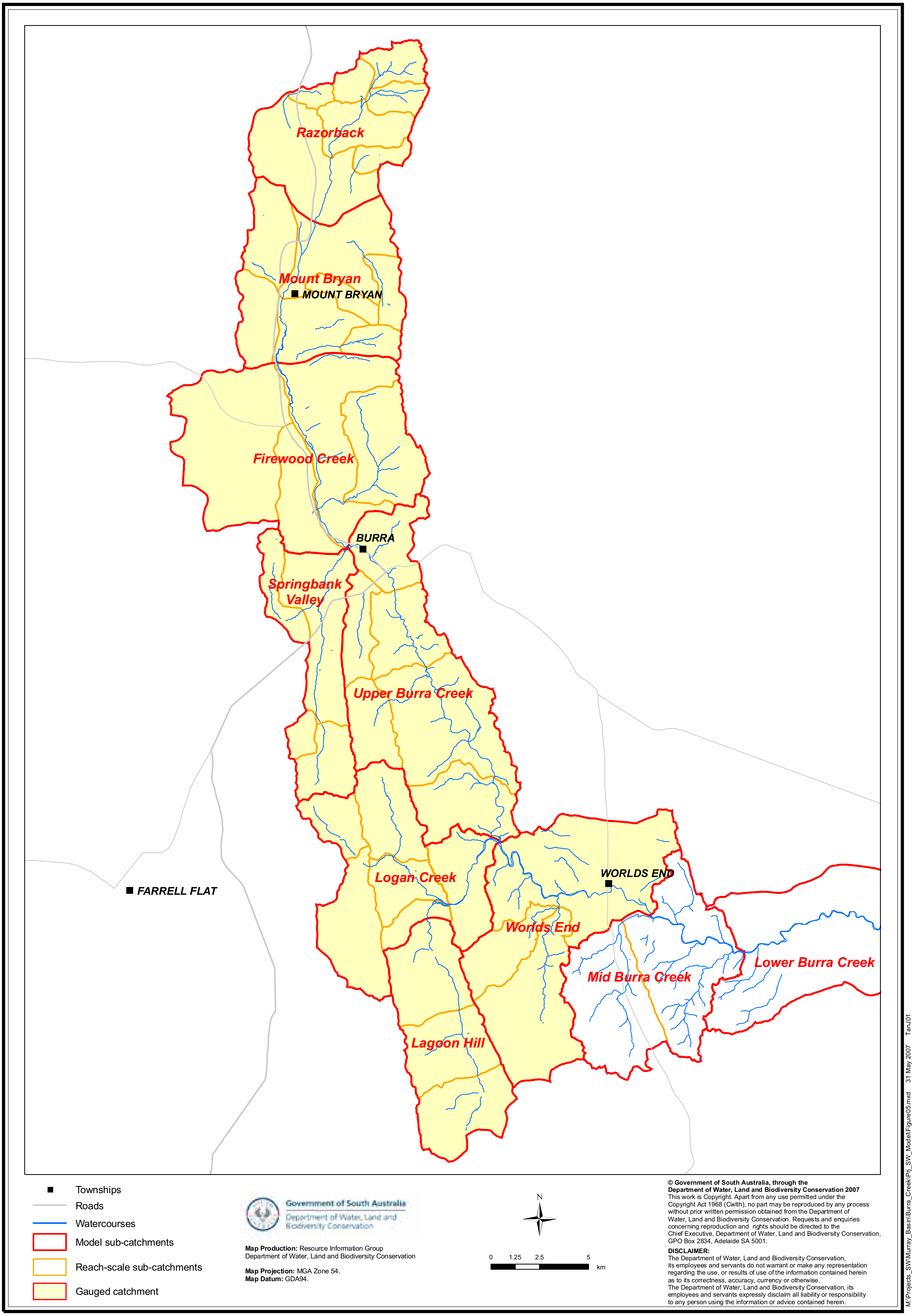


Figure 5. Burra Creek sub-catchment boundaries used in this assessment

3. WATER RESOURCE DEVELOPMENT

3.1 SURFACE WATER DEVELOPMENT

3.1.1 OVERVIEW

Climatic conditions impose natural limits on the development of surface water for agricultural or commercial applications. Generally, catchment runoff in semi-arid areas is low, but perhaps more importantly it is also highly unpredictable. By necessity, alternative supplies, usually groundwater, are required to provide water security and support year to year production. Despite this, development of surface water does occur in a number of forms and typically involves opportunistic use of the unpredictable, but at times substantial, volumes available.

By far the most common is the typical farm dam storage, usually a mounded earth wall constructed on a low order stream or perhaps a similar structure diverting and capturing roadside runoff. Other forms of surface water development include the use of in-stream diversion structures to inundate paddocks during streamflow events (referred to herein as flood irrigation), and the direct pumping of permanent waterholes. Some flood irrigation is suspected but no evidence of direct pumping of waterholes was found during this assessment within Burra Creek, although this activity is known to occur in nearby catchments.

Over recent decades, land management practice has improved considerably. Techniques often focus on the retention and use of water where it falls on the catchment rather than allowing it to run off bare paddocks, creating erosion problems. The widespread implementation of contour banking, often used in conjunction with small dam storages, as well as practices such as minimum tillage and reductions in grazing intensity, will inevitably reduce runoff volumes.

The need for careful management of surface and groundwater resources is well established in South Australia. Accordingly, the assessment of farm dam storage volumes and comparisons with sustainable use benchmarks forms a significant component of this report. To the authors' knowledge, no such assessment has previously been attempted in a semi-arid catchment such as Burra Creek within South Australia, and the applicability of existing benchmarks must be considered. This is discussed further in Section 9.

3.2 IMPACTS OF EXCESSIVE FARM DAM DEVELOPMENT

Unsustainably high levels of farm dam development present a significant threat to surface water resources and to downstream users including the environment, and impacts of this nature have previously been identified in South Australia (e.g. Cresswell 1991; Savadamuthu 2002, 2003; Risby et al. 2003; McMurray 2004). Hydrological impacts of over-development typically include a delay in the onset of streamflow (e.g. Champion et al. 1999) and reductions in the volume and duration of streamflow patterns typical of a more natural hydrology, in particular low flows (e.g. Savadamuthu 2003; Heneker 2003).

These changes to the flow regime have the potential for significant ecological impacts as many organisms link phases of their life histories such as recruitment to the natural timing of flow events (Bunn & Arthington 2002). Processes such as the siltation of waterholes or other aquatic habitat such as riffles, overgrowth of reeds in stream channels, and loss of riparian vegetation may also be exacerbated due to the resulting alteration to flow hydraulics. Reduced streamflows may therefore result in the loss of aquatic biodiversity or even aquatic habitat, as well as contributing to major watercourse management issues.

Medium to higher flows are typically less affected by farm dams, but these events are relatively rare, especially in drier catchments. The time between significant streamflow events can be substantially increased by excessive storages. Low flow volumes are often all that can be expected during the majority of years in more arid catchments. These small volumes can be critical for the aquatic ecology of the watercourse, for example by the maintenance of wetted habitat or improving water quality in refugia pools in the periods between significant connecting flows.

The location as well as the volume of a farm dam may have a significant influence on its hydrological impact. This applies both to its position relative to the watercourse and to its position in the catchment.

Placement of dams on a watercourse (referred to as being 'on-stream') exerts the greatest influence on stream hydrology, requiring the dam be filled to full supply level prior to it allowing any flow to pass downstream. The time taken for on-stream dams to reach full supply level produces the delay in the onset of seasonal flow.

In general, the higher a dam is located within a given catchment the less of the total catchment area it controls, and the less its impact. In this respect, the impacts of a single large dam at the bottom of a catchment can be equivalent to that of a large number of small dams in the upper reaches by controlling entire catchments. The important point to consider is the proportion of watercourses within a catchment that are 'free-to-flow' and this should be maintained as large as possible to minimise impacts. Free-to-flow areas were estimated using a manual gridded approach and appear for each sub-catchment in Appendix B.

It is of concern to note that farm dam design in much of the study catchment appeared to be based on the basic 'tank dam' design. Unlike designs found in other parts of the state such as the Mount Lofty Ranges, in many cases no overflow was apparent to indicate the full supply level. This implies that dams rarely fill to capacity and hence are capable of capturing all streamflow in the majority of flow events.

3.2.1 NUMBER AND STORAGE CAPACITY

The number of farm dams within the catchment was determined from 1:40 000 colour aerial photography provided by the SA MDB NRM Board. The imagery was imported to a GIS, the full supply level determined and the corresponding surface area digitised.

From the surface area, formulae developed for use by DWLBC in the Mount Lofty Ranges (McMurray 2004) were applied to give a volumetric storage based on this area. Further information on the procedure is provided in Appendix A. The method has acknowledged uncertainties but has been widely applied in South Australia. In the absence of detailed field surveys, this remains the only cost-effective method to obtain a reasonable estimate of dam storages for the catchment.

Information on farm dams referred to in the body of this report are specifically related to those found within the gauged catchment as this is the area where the impact of farm dams on catchment hydrology can be assessed. Information on dam storages outside of the gauged catchment is provided in Appendix C, but no attempt has been made to assess their impact on hydrology.

Summary information relating to farm dams within the gauged catchment can be seen in Figure 6. The majority of dam storages are small, with the mean storage capacity determined to be only 1.6 ML. More than 95% of dams are <5 ML and these hold 77% of the total potential storage volume. Based on the volume, these dams are almost certainly entirely for stock use.

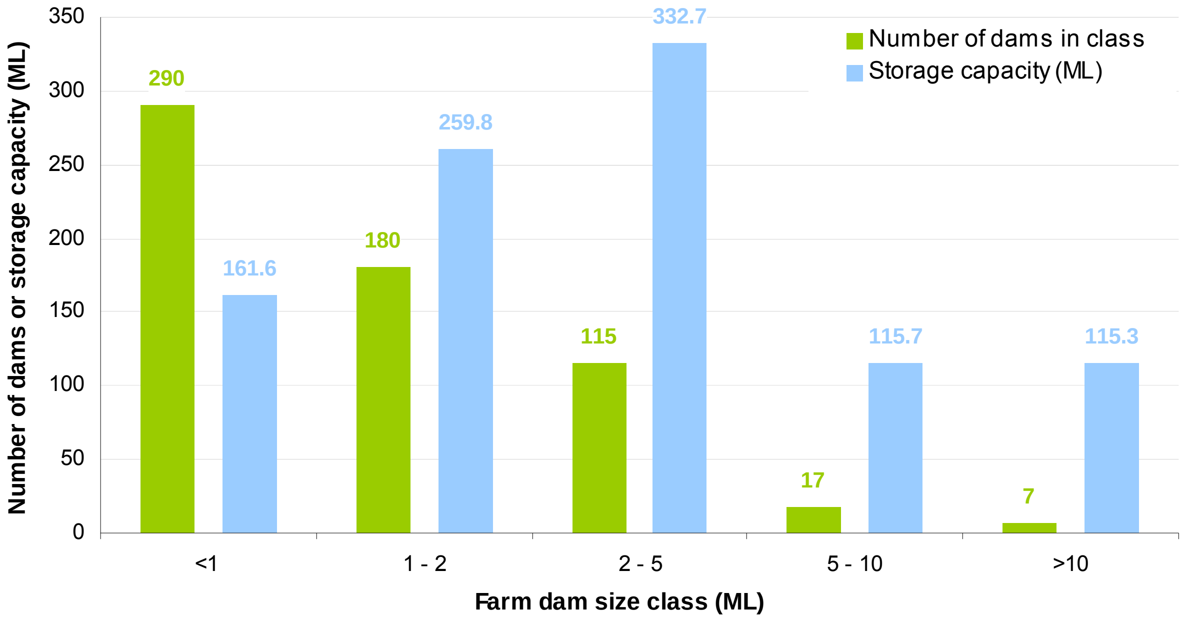


Figure 6. Farm dam size classes and storage capacity, Burra Creek gauged catchment

Of the larger farm dams, although there is the potential for storages holding greater than 5 ML to be used in irrigation activities, no such land use was observed. Use of such dams for irrigation in the study areas seems unlikely for reasons already mentioned — the unpredictability of rainfall does not warrant a significant investment in irrigation infrastructure as capture of sufficient volumes is not reliable enough. Larger storages were often constructed at the confluence of two or more low order watercourses, presumably to optimise the catchment area concerned. This approach also greatly increases the surface area and potential impact of the storage and creates a highly irregular full supply level geometry. It has not been assessed how well the surface area:volume formula used in this study is capable of predicting storages of this nature. On-ground measurements possibly including bathymetry and volumetric analysis would be required to accurately determine volumes of such storages to a high degree of certainty.

A small number of in-stream diversion structures were identified from aerial videography in non-permanent reaches of watercourses in the central catchment, suggesting the opportunistic use of flood irrigation. This approach does not require any significant investment in infrastructure and is more suited to the opportunistic use of such an irregular supply. Consultations with landholders did not indicate that this was a well-known or widespread activity. It is likely to be limited to only one or two landholders. Despite the relatively few structures observed, there is a high probability that where they occur, stream diversions are affecting streamflow patterns. Estimates of use for this activity are among the largest in this assessment, but are associated with a high degree of uncertainty. Risby et al. (2003) also experienced difficulties in developing firm estimates, but found that large volumes were captured from tributaries to the Willochra Catchment by only a few landholders using similar techniques. It is important for future work to identify all flood irrigation within the catchment and improve estimates of water use.

Taken at catchment scale, the 609 dams identified represent little more than one dam per square kilometre. Dams are not evenly distributed through the catchment however, and examination of the spatial patterns of farm dam development and the resultant effects on streamflow is the subject of Section 7.2.

3.2.2 FARM DAM DENSITY

In order to make accurate comparisons with other areas, it is useful to consider the density of farm dam development. This also helps to determine ‘hotspots’ where development might be excessive. Farm dam density values are typically reported in units of megalitres of storage per square kilometre (ML/km^2).

Burra Creek gauged catchment has a total area of 541 km^2, and an estimated total dam storage of 985 ML. The resulting dam density of 1.82 ML/km^2 compares with the Upper Marne River Catchment at 10.1 ML/km^2 (Savadamuthu 2002) and the southern Willochra Creek at 1.2 ML/km^2 (Risby et al. 2003). Both of these catchments have higher mean annual rainfall than Burra Creek and, in addition, studies were limited to higher rainfall areas of the catchment where higher densities of storage can be expected, increasing the storage density. The Marne River density values also reflect the presence of large irrigation dams, none of which were identified in Willochra or Burra Creeks.

A single catchment-wide storage density value masks smaller scale variations that indicate areas of greater or lesser density. To provide an improved indication of these spatial variations, a farm dam storage volume density surface is shown in Figure 7. This indicates a number of areas where development activity is focused, in particular within the Mount Bryan and Lagoon Hill sub-catchments.

While the density surface provides a simple representation of the distribution of storage density in the catchment, to determine whether the observed development levels are sustainable the actual impact on runoff volumes must be determined. This analysis is undertaken in Section 7, where adjusted runoff volumes are used to determine the level of hydrological impact based on the proportion of total catchment runoff intercepted. The likely impact of farm dam storages on the environmental water requirements of the catchment is provided in Section 8.

3.3 GROUNDWATER DEVELOPMENT

Groundwater development is limited by the nature of the resource itself, with wells being generally of low yield and poor to moderate water quality (see Section 4.4). In addition to these problems, the dominant fractured rock aquifers of the region are notoriously difficult to predict. There is a relatively high risk and cost associated with undertaking the necessary

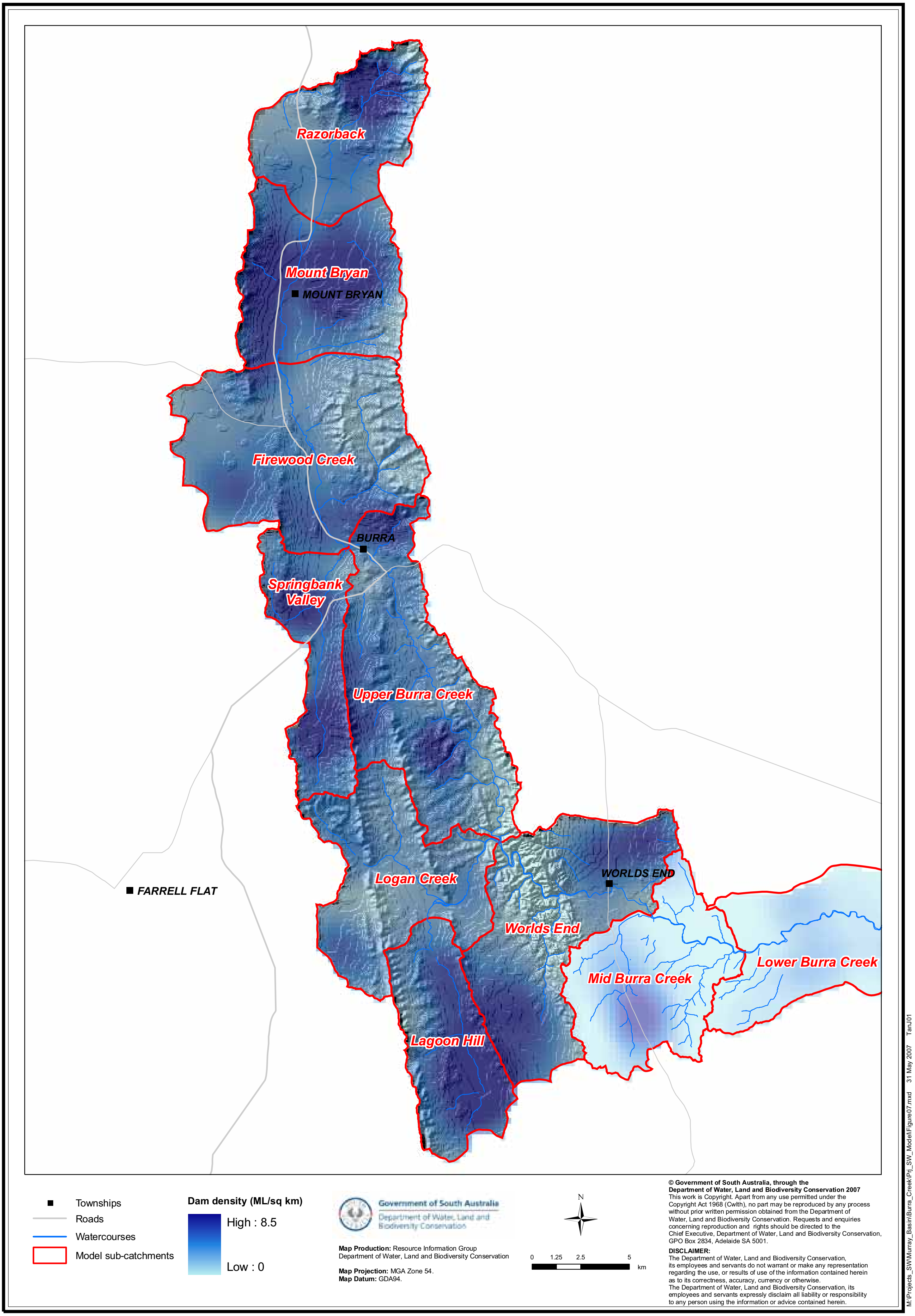


Figure 7. Farm dam density, Burra Creek Catchment

exploratory drilling to find a useable supply. The potential alternative and secure supply of River Murray water is also available to some landholders, and is accessed via a direct feed from the Morgan–Whyalla pipeline.

These factors, along with the presence of permanent surface flows along Burra Creek and other watercourses, combine to limit the use of groundwater for many purposes in the region. Many landholders adopt a multiple-source approach to solve their water supply issues, relying on various combinations of groundwater, pipeline water, permanent springs or streams, and opportunistic or seasonal use of farm dams.

3.3.1 DRILLING ACTIVITY

A review of the drilling records in the state drillhole database (SA Geodata) was undertaken to gauge the levels of groundwater development in the catchment. There are currently up to 456 operational wells in the gauged catchment. Whilst the database is constantly updated with new drilling records, there is no formal process for obligatory updating of well status or latest water quality data. Hence, some proportion of these wells may no longer be used, but the information has not been made available for their records to be updated in the database. To improve on the estimates of water use made in this report, it will be necessary to conduct a detailed well audit and determine the operational status in addition to the level of use for each of the wells.

Figure 8 shows the location of wells within the Burra Creek Catchment, which are concentrated in the area around Burra and to the north around Mount Bryan. Many of these township wells are likely to be for domestic supply. Table 2 lists the primary purpose for wells drilled in the catchment and shows that a significant proportion (>40%) are designated as being for stock or domestic use.

Table 2. Primary purpose of wells in the Burra Creek Catchment

Primary purpose	Count	%
Domestic	64	14%
Stock	129	28%
Irrigation	37	8%
Observation	23	5%
Unknown	133	29%
Exploration*	32	7%
Other	38	8%
Total	**456**	**100%**

Source SA Geodata (2006).

*Exploration drillholes are not necessarily water supply wells.

It is notable that 37 wells are listed with a primary purpose of irrigation, but only very limited irrigation development was observed in the catchment during field survey, and it is assumed that the majority of these wells are either no longer operational or are now restricted to stock or domestic uses. Of these wells, 26 were drilled prior to 1990 and no wells with a primary purpose of irrigation have been drilled since 2001.

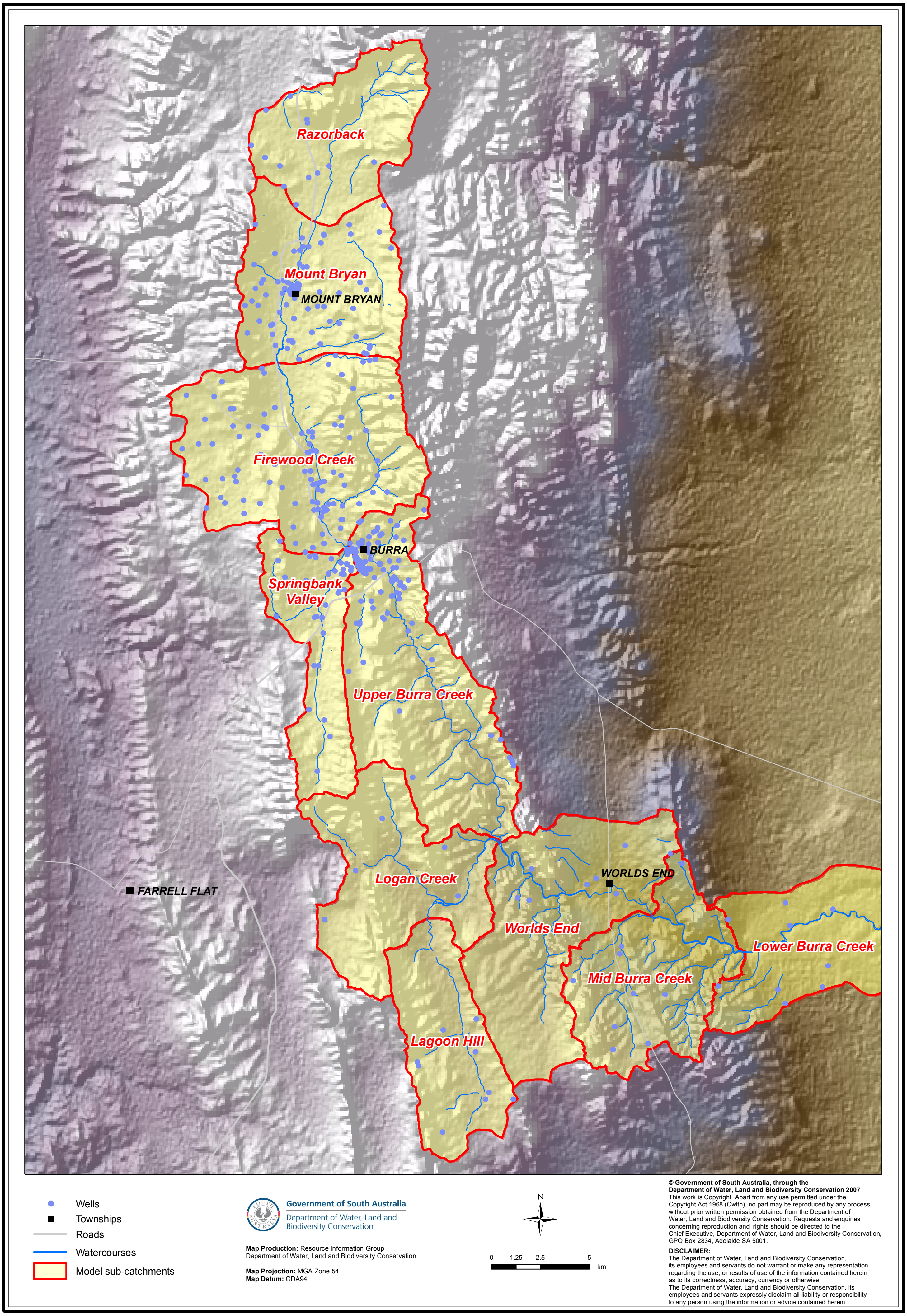
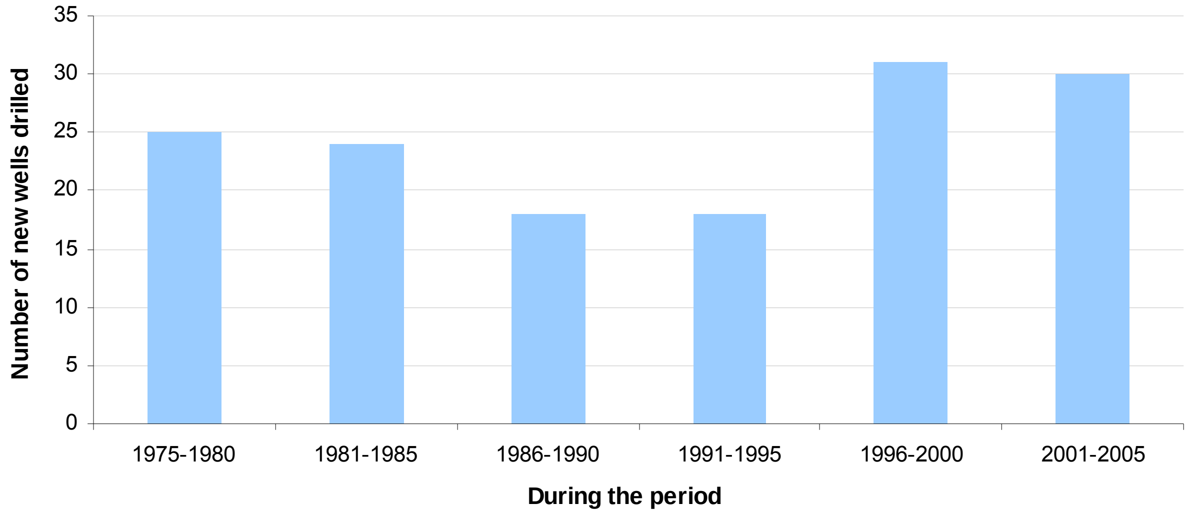


Figure 8. Location of wells within the Burra Creek gauged catchment

An analysis of the date of construction for recently drilled wells was undertaken to determine whether drilling activity has increased over recent years, which might indicate increased pressure on the resource. Figure 9 shows the drilling activity in the catchment over five year periods since 1975. No significant trend in drilling activity can be observed and on average less than six new wells are drilled per year. There is some suggestion that drilling activity may have increased slightly over the last decade but this cannot necessarily be taken to mean increased water use as many wells may simply be replacement wells.



Source SA Geodata (2006).

Figure 9. Drilling activity during five year periods since 1975, Burra Creek Catchment

3.3.2 ESTIMATED GROUNDWATER USE

Table 3 lists the simplified BRS (1999) land-use categories and predicted water use in the gauged catchment. A total draw on all groundwater resources within the gauged catchment is estimated at 1895 ML/y. Limited information on actual water use was available however, and it was necessary to make several assumptions as outlined below to develop these indicative estimates.

Table 3. Land-use areas and estimated water use, Burra Creek gauged catchment

Land use	Area	Multiplication factor	Estimated water use (ML/y)
Domestic use	–	50% of estimated stock usage	118
Stock use	35 813	Area x 2.6 DSE x 6 L/DSE/d	200
Cropping–grazing rotation	12 895	0.5 area x 2.6 DSE x 6 L/DSE/d	36
Wastage or evaporation from troughs	–	30% of stock use	71
Irrigated grasses	294	5	1470
Total	–	–	**1895**

Source: Adapted from BRS (1999). DSE — Dry Sheep Equivalent.

As no significant irrigation was detected during field surveys, current irrigation use of groundwater is considered to be negligible. This appears to have changed over recent years as landholders recalled that lucerne pastures were common between Burra township and north of Mount Bryan (D. Lindner, landholder, pers. comm., 2005). Whether this may be due to economic drivers or a decline in the quality or quantity of the available water resource was not clarified during this project.

To develop a 'worst-case' scenario for irrigation water use, areas designated as being under irrigation during the BRS survey in 1999 are assumed to be sourced from groundwater, with water use estimated at 5 ML/ha. This value is based on work undertaken elsewhere in the Mid-North, including nearby Booborowie Valley, where landholder water-use survey forms were completed. The rate of 5 ML/ha was typical of that for irrigated lucerne in similar studies (see Magarey & Deane 2005; Deane 2005). The water for irrigated fruit trees referred to in the BRS study is not thought to be derived from groundwater as the quality is not likely to be suitable, and this water use was excluded from the study.

By far the most widespread groundwater usage in the catchment is for stock and domestic purposes. An estimate of the volumetric stock use was obtained by combining grazed areas from the BRS (1999) land-use survey with an average stocking rate of 2.6 Dry Sheep Equivalents (DSE) obtained from landholder surveys (LWA 2003), and estimated daily water-use requirements of 6 L/DSE/d (from consultations, in Deane 2005). A 30% allowance has been made over and above estimated stock use for wastage and evaporation. It should be borne in mind that the water use for stock will vary greatly depending on a range of factors including the fodder source, prevailing season and the availability of alternative sources. The values derived here would need to be substantiated through surveys to improve the certainty in the analysis.

Domestic use is also difficult to estimate without a catchment-wide water-use survey, and in the absence of such data an allowance of 50% of the total stock-use volume has been employed. This produces a total water-use estimate of 425 ML/y for stock and domestic purposes.

The total value for stock and domestic water use was compared to the current number of stock or domestic wells in the catchment to determine whether the estimate is reasonable. The best available data listed in Table 3 suggests there are currently up to 456 operational wells in the catchment. Assuming all 'unknown' wells are operational and used for stock and domestic purposes, this represents an estimated 350 wells. If the value suggested above for stock and domestic use were correct, this would mean that average extraction from each bore would be ~1.2 ML/y. This value may be low as, given the median yield value of 1 L/s shown in Section 5.2, this would correspond to an average of only one pumping hour per day at the median yield.

The estimate does not take into account alternative sources of stock water such as farm dams, permanent pools, and River Murray water from the Morgan–Whyalla pipeline where it is available, all of which would reduce the demand for native groundwater.

It should also be noted that the estimated area planted to irrigated grasses cannot be confirmed from field survey and is considered an absolute maximum figure. Even allowing for this full volume, averaged over the gauged catchment this assumes a maximum usage of around 3.3 mm or <1% of rainfall. This is unlikely to be causing undue pressure on the resource when considered in a regional context, but the potential for over-development at local scales still exists. For example, as discussed throughout this report, arguably the most important groundwater resource is that associated with the Skillogalee Dolomite. The above analysis cannot be considered to remove concern over the pressure on this specific resource. The following section refers to information on the historical behaviour on this resource in response to pumping, and compares this to the current situation.

3.3.3 PUMPING OF GROUNDWATER FROM THE BURRA MINE (SKILLOGALEE DOLOMITE)

The permanent water in the Burra Mine open cut on the western outskirts of Burra township is an expression of the local watertable within the dominant fractured rock dolomite aquifer of the region (Segnit 1937; Read 1980). Discharge from this highly transmissive zone was identified as the source of the series of springs in Burra Creek south of the township, and was traced to at least Princess Royal Station to the south by the Assistant Government Geologist R.W. Segnit in 1937. (See Section 5.3 for further information on the significance of this formation to the hydrology and ecology of Burra Creek.)

Over time, groundwater has been both a source of problems during mining periods and a significant resource to Burra township, and is still in use today. Historical annual groundwater extraction volumes from the vicinity of the mine are presented in Table 4 and described below.

Table 4. History of annual extraction volumes from the Burra Mine aquifer

Period	Estimated volume removed (ML/y)	Usage
1849–77	3000[2]	Mine de-watering (pumped to the creek)
1877–84	–	No use identified
1884–1966	74[1]	Town water supply
1966–75	–	No use identified
1975–81	3600–4500[2]	Mine de-watering (pumped to the creek)
1981–present	73–368[2,3]	Maintain recreational lake

Source: [1]Segnit (1937, based on 1917–37 data); [2]Morris (1983); [3]Durkay (2002).

Mining of copper in the vicinity of present day Burra township dates back to 1845 (Morris 1983). During mine operations it was necessary to lower the watertable from the natural pre-mining level of ~36 m below the surface to allow access for mine shafts to over 180 m depth (Morris 1983). Hence, de-watering of the open cut presented a constant challenge. Removal of water from the mine occurred during the two major mining periods of 1849–77 and 1975–81.

The aquifer has also provided water for domestic use, and between 1884 and 1966 water was pumped from the (at the time) completely flooded, 180 m deep Bon Accord Shaft a few hundred metres to the north of the Burra Mine to provide a town supply (Morris 1983). This arrangement ceased in 1966 when the township was connected to the River Murray pipeline.

Segnit (1937) analysed town supply water-use data and found that on average ~74 ML/y were used for this purpose between the years 1917 and 1937 . It was additionally determined that, although average rainfall years had occurred during the period, the water level in the mine had fallen by an average of 0.25 m/y leading to the conclusion that the aquifer was being used beyond its recovery capacity at this volume. It is of interest to note that the usage during this period was less than 5% of mine de-watering volumes, yet was apparently beyond a sustainable yield at this location within the formation.

Following cessation of the second period of mining in 1981, the aquifer has been the source of water for the artificial lake in Burra township. Investigations immediately prior to this time showed that a 5 km wide cone of depression had formed, centred on the mine. At least one local user of groundwater had to be compensated when their supply well had dried completely (Read 1980). The extent of the lowering of the watertable during this period was not as significant as might be expected comparing the volumes between de-watering and use as a town water. This is possibly because much of the water pumped to the creek in de-watering operations probably infiltrated through the creek bed back into the aquifer (see following Section) and unlike town water supply use was not lost to the system.

3.3.4 CURRENT WATER USE

Since the cessation of mining, water has been pumped from two wells near the recreational lake in Burra township to maintain lake levels. The lake has historically had an extremely high loss rate, which was investigated in 2002 for the Regional Council of Goyder which maintains the lake. Durkay (2002) concluded that the northernmost section of the lake is constructed on a highly faulted zone and water leaks from the lake bed back to the limestone aquifer at a rate of 368 ML/y. Although this is a significant volume, it does not represent a loss to the system as the water extracted for the maintenance of the lake is thought to largely recharge the same water-bearing formation; losses are limited to evaporation (Durkay 2002). Additionally, no significant volumes of surface water are added to the streamflow outside of the township, with only minimal overflow occurring. Hence, no allowance for this operation has been made within the modelling for the catchment and it is not considered for the purposes of this study.

The pumping rate to the lake was reported in Morris (1983) as being ~4500 kL/d, but Durkay (2002) stated the yield of the two wells is 1438 and 685 kL/d. Both wells were reportedly used, suggesting that ~2000 kL/d or 730 ML/y are pumped to maintain the recreational lake.

Goyder Council staff report that pumping volumes are not metered but estimated that ~200 kL/d, or 73 ML/y is currently sufficient to maintain the water level (T. Wood, Regional Council of Goyder, pers. comm., 2006). Clearly this volume would not cover the estimated 368 ML reported by Durkay (2002) to percolate through the lake bed each year. Council officers reported that the infiltration rate has decreased considerably over recent years and the volume required to maintain water levels has reduced accordingly.

This decrease in infiltration is most likely due to a build up of silt, or possibly organic detritus and other fine sediments, in the interstitial spaces within the lake sediments. This effect, known as colmation, has been shown to increase greatly where bed sediment transport is reduced (Lange 2005; Rehg et al. 2005), as is the case in an impoundment such as the lake.

It is important to clarify the water balance of the lake in terms of how the feature alters natural recharge processes, and the extent of any losses it represents to the groundwater system. In particular, any impact this may be having on discharge volumes and the direction of flow paths within the aquifer is of interest, owing to the environmental significance of the springs it supports to the south. If the water is largely lost to the system, even the current minimal usage of 73 ML/y represents a volume roughly equivalent of that observed by Segnit (1937) to be drawing watertables down consistently in the town supply. This behaviour was observed during a period of average rainfall and when dam capture volumes were almost certainly much lower than current levels.

It is of note that as a means of rectifying the problem of leakage, Durkay (2002) proposed that the lake in the loss zone could be lined to prevent recharge to the aquifer through its bed. Infiltration losses of water pumped to the lake form part of a more or less closed system, cycling large volumes of water to and from the aquifer. The reach of Burra Creek that the lake represents however remains part of the natural drainage of the catchment. During streamflow events, this zone represents a source of recharge to the Skillogalee Dolomite.

Irrespective of any system losses, the recharge characteristics of the natural channel, which would not have featured permanent water, have been altered. For example, mounding of groundwater under the lake bed will reduce further infiltration as water is required to move laterally as well as vertically. The relative importance of this recharge pathway as opposed to others such as direct infiltration from rainfall has not been quantified, but is likely to be high (see Section 5.4).

In light of the lack of certainty in pumped volumes, lack of groundwater level data, poor understanding of total losses and of the influence of this transmissive zone within the aquifer on catchment hydrology, it is suggested that the process of maintaining the lake warrants increased management effort.

A more detailed study of the lake within the context of overall catchment hydrology is suggested. The metering of pumped volumes and monitoring of groundwater and lake surface water levels should ideally be commenced as soon as possible to provide supporting information. Ideally, this assessment should form part of an overall assessment of surface water – groundwater interactions within the Skillogalee Dolomite, and include such data as chemical tracer studies to provide more certainty as to the source of the discharges and the location of springs and seeps.

At a minimum, prior to any changes being made to the characteristics of the creek bed within the lake, it is highly recommended that the potential for a change to the flow rate of the springs to the south of the township is evaluated. Additionally, the loss of water from the system in the maintenance of the lake (e.g. through flow to waste) should be further evaluated and minimised to prevent unnecessary impacts on downstream springs and dependent ecosystems.

4. CATCHMENT HYDROLOGY

4.1 RAINFALL

In order to understand and model the behaviour of a catchment, it is essential to obtain an estimate of the rainfall inputs. Rainfall patterns vary both temporally and spatially, and the best possible estimates of these variations across the catchment are required to interpret catchment behaviour.

4.1.1 DATA AVAILABILITY AND PROCESSING

Daily rainfall data in South Australia are collected by the Bureau of Meteorology (BoM) and DWLBC. Fifteen BoM stations were identified as being located either within or near to the gauged catchment study area, and were assessed for their suitability to be used in this study.

Analysis of the station records showed that only two of these were of suitable duration for use in rainfall analyses and modelling. These were located at Mount Bryan (BoM station 021034) in the north, and Worlds End (021086) in the south of the catchment. Both stations had continuous daily records dating back to 1884.

A third long-term record for the central catchment was created from two stations closely located within Burra township with a period of overlapping record enabling extension of the current station (021077, Burra Community School) back to 1884. The record extension of station 021077 (operational 1960 to present) was achieved by establishing the proportionality between the sites during the concurrent period of record (1960–64). Values originally recorded at station 021011 (operational 1884–1964) were adjusted using the proportionality factor. Details of this and other rainfall analyses are provided in Appendices D and E.

The stations that were used to provide the rainfall input for hydrological modelling are shown in Figure 10. Data from these stations were used to determine rainfall for the gauged catchment, and all minor sub-catchments.

Whilst latitudinal variation is fairly well represented by the three stations used in this analysis, patterns due to changes in longitude and elevation within the catchment could not be assessed due to a lack of stations in suitable locations. This is a limitation of the work as rainfall isohyets interpolated during prior investigations from all available data indicate that these are influential factors upon rainfall distribution in the catchment.

As the gauged catchment is narrow in width and orientated along a north–south axis, this limitation in the data is not considered to be a major problem at whole of catchment scale. Local variations in rainfall due to the effects of topographic features in the south of the catchment are likely to be significant, but cannot be analysed using existing data. Future work to refine runoff estimates would need to consider this source of variation.

Rainfall records were prepared and analysed for the period 1884–2004. Daily rainfall data require significant inspection, preparation and verification to ensure that the record is complete. Preparation of a dataset requires values for any gaps in the record to be established and the completed record tested for homogeneity, or consistency over time. The process for data preparation involves:

- Disaggregation of records representative of two or more days of rainfall that have been lumped together into a single record, due to daily readings not having been taken (accumulated data).
- Infilling of gaps in the data, typically due to short-term periods where, for whatever reasons, no daily recording is available.

SKM (2000) disaggregated the rainfall data at many stations in South Australia for the period up to 1998 using the method described in Porter and Ladson (1993), and the same method was employed for this study for stations that had not been disaggregated, and for the period since 1998. The method involves the use of multiple concurrent records from nearby stations, using the assumption that geographically closer stations are more likely to have received a similar rainfall than those more distant. The method reflects this by placing higher emphasis on closer records (see App. D for the full procedure).

In theory, use of a number of nearby stations reduces the uncertainty involved with using data from a single station and this method was employed wherever possible. In reality, for the area of interest, often only a single station record was available within 50 km, if any at all, especially in the historical records still requiring disaggregation. In the case that only a single record was available, rainfall was distributed proportionally across the accumulated days. Where no station was available upon which to base a reasonable estimate of rainfall distribution, accumulated data were divided equally across the period.

In the case of missing data that was not due to accumulated records, the station with the highest correlation of daily records was used to estimate the rainfall using the long-term proportionality between the two sites.

In addition to completing the dataset by disaggregating and infilling data, the completed record must be checked to ensure that it is invariant with respect to other stations over time. This is the process of homogeneity testing and correction.

Homogeneity of individual station records was tested against regional averages using the double mass curve technique (Grayson et al. 1996). The double mass curve is constructed by plotting the accumulated values of two time series against each other to determine any break in the slope of the relationship that indicates a change in the conditions at the site in question. This may be due, for example, to local tree canopy overgrowth or construction of a building that changes the exposure of the gauge.

In this study, the consistency of each rainfall record was confirmed by constructing a double mass curve using an average of the monthly rainfall from three nearby stations. Any deviation of greater than 5% from the average record was corrected. The full procedure and analysis are presented in Appendix F.

The final disaggregated, infilled and homogenous records were used in the analysis described in the following section and in surface water modelling.

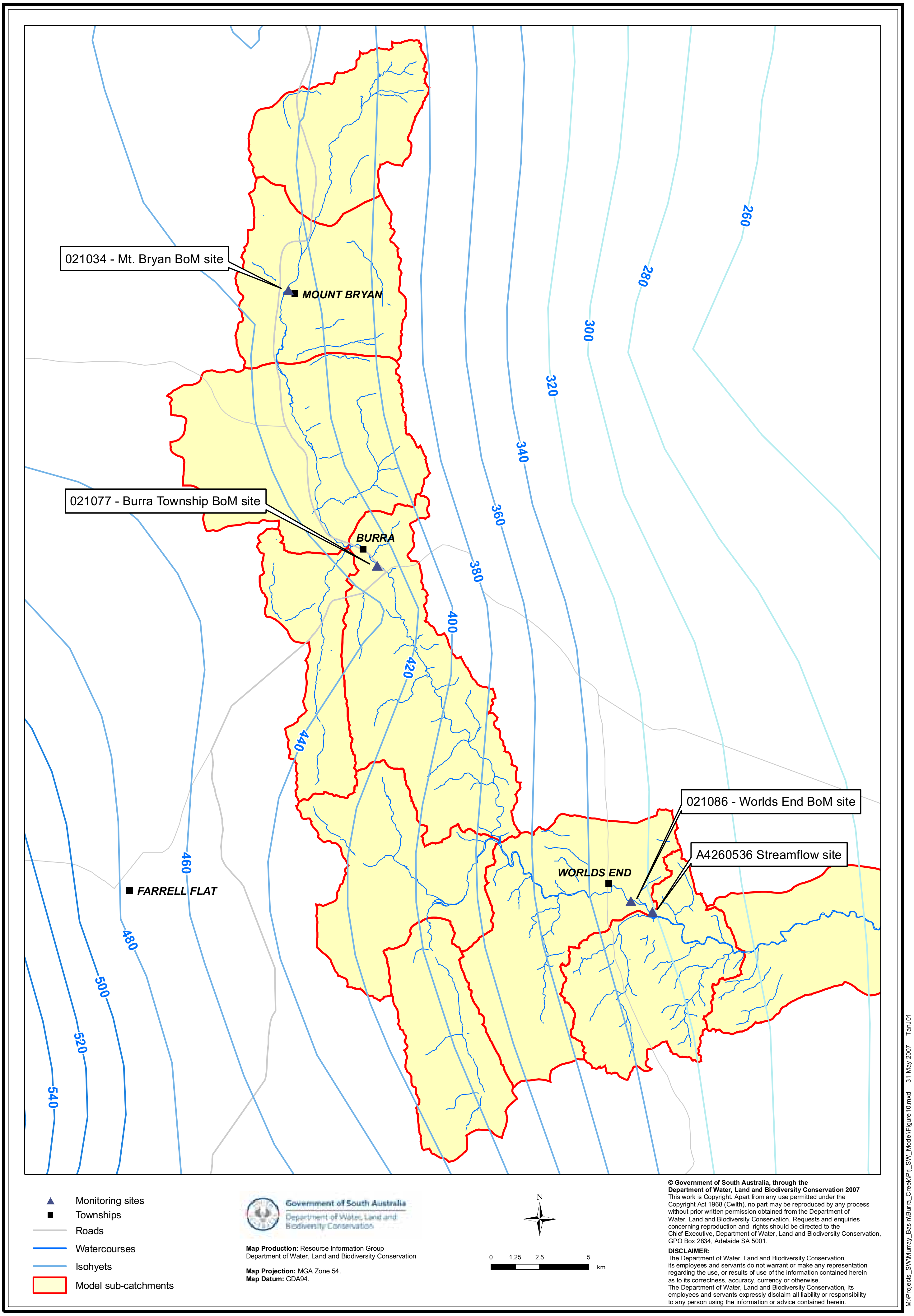


Figure 10. Rainfall isohyets and BoM stations, Burra Creek Catchment

4.1.2 DATA ANALYSIS

The analysis within this section is intended to report on trends and patterns at a regional level and utilises a regional average catchment rainfall calculated from the three long-term stations shown in Figure 10. This record was developed using Theissen polygons to combine the individual daily rainfall records. Annual mean rainfall estimated from the data (417 mm) compared well to a catchment mean rainfall determined using the isohyetal method (405 mm). Analysis of the regional rainfall record was undertaken at a range of time scales in order to identify patterns and trends within the data:

- Monthly analysis was used to assess seasonality of rainfall and any implied changes to these patterns over the period of record.
- Annual rainfall is a convenient and commonly used time step, allowing for periods of deviation from the long-term mean that may indicate persistent inter-annual and longer term trends to be assessed.
- Decadal patterns can add weight to any periodic cycle apparent that may be obscured by examination of shorter time periods. Smoothing techniques such as use of decadal and 10 year rolling averages were applied to assist in clarifying periodicity.

4.1.2.1 Annual rainfall

Figure 9 shows the rainfall isohyets (lines of equal average annual rainfall) for the region. This information is based on gridded annual rainfall point data, interpolated using a standard BoM procedure from all available station records.

As the distribution of rainfall stations is limited outside of the more urbanised areas, this information is likely to be insensitive to small-scale variations in topography or other factors. Despite these limitations, at the time of writing it remains the best such information available and is considered to reflect broad trends in rainfall distribution. The data were used in generating the average catchment and sub-catchment rainfall totals used in modelling and analysis.

The isohyets indicate that mean annual rainfall is expected to vary little with distance to the north within the gauged catchment. BoM stations at Mount Bryan (021034) in the north, and centrally located Burra (021077), lie on similar longitudes and have recorded long-term average rainfalls of 432 and 435 mm, respectively. A zonal rainfall gradient is clearly evident, with rapid declines in annual rainfall totals in an easterly direction. Worlds End (021086) at the outflow of the gauged catchment receives only 318 mm.

Most rain-bearing cloud formations during the late spring to early autumn months are monsoonal depressions and move across the continent from the north to northwest. These systems are irregular in occurrence, but capable of delivering large volumes of water at high intensities and may generate extreme flood events. The irregular influence of systems of this nature can be seen in the atypical seasonality of the rainfall and streamflow record of Burra Creek.

The movement of frontal systems from the Southern Ocean during winter months brings cool, moist southern maritime air masses over the continent, resulting in cloudy weather and drizzle, with larger volumes of rainfall due to orographic lifting (Sturman & Tapper 1996). The modest winter rains in the Burra catchment, despite the high elevations in the north, are a result of the decreased productivity of these systems as they move inland. Runoff during this period is more likely to occur due to the saturation of soil profiles from persistent relatively low intensity rain and the much lower evapotranspiration rates during this period (see Section 4.2).

Figure 11 shows annual rainfall totals for the period 1884–2004 for the regional rainfall dataset. The wettest year on record was in 1974, when ~790 mm fell, and the driest was in 1967, with ~170 mm received. A least squares linear regression trend line fitted to the data is shown in black, and demonstrates little deviation from the mean. The slight positive slope was not statistically significant at a 90% confidence level.

Also shown in Figure 11 is the long-term mean annual rainfall for the period 1884–2004 of 417 mm. Deviations from this value represent periods of above or below average annual totals, and are shown by use of a plot of the cumulative deviation from the mean, also known as the residual mass (red line). Periods of above average rainfall were received where the slope of the residual mass curve is positive (upwards) and, conversely, negative or downward sloping sections indicate below average periods. A horizontal section therefore indicates average conditions.

Periods of generally above average rainfall occurred at the end of the 19th century and between 1915 through until the early 1920s. This latter period corresponds to the wettest decade on record (see Decadal Rainfall). Periods of generally below average annual rainfall occurred during the periods 1894–1902, 1924–45, 1981–91 and 1997–2004.

These periods of generally above or below average conditions were further investigated through use of data smoothing techniques in the later section on Decadal Rainfall.

Of note in the recent record is the reduced frequency of extremely wet years. Earlier periods in the record were characterised by extreme wet and dry years, which often occurred together. In the 120 year record there have been eight occasions where regional annual rainfall has exceeded the long-term average by more than 150 mm, a probability of 0.067. This annual total has only been exceeded once in the past 30 years, although at the observed probability for the entire record it would be expected to have occurred twice. Conversely, there have been seven years where rainfall was at least 150 mm below average, and in the previous 30 years this has occurred twice, slightly more than predicted over such a period using the long-term probability of 0.06.

These trends are clearly apparent in Figure 12, where annual rainfall records are ranked for the periods 1884–1974 and 1975–2004. Annual rainfall in the period 1975–2004 has been less variable than the long-term record, with more totals close to the long-term average of 417 mm. The indicated decrease in extreme years, both wet and dry, has produced a less than 3% difference in the mean rainfall for the two periods.

The two distributions were compared using the non-parametric Kolmogorov–Smirnov (KS) Test, a goodness-of-fit test applicable to unbinned distributions of a single variable used to determine whether two distributions are the same (Press et al. 1992). The KS statistic is defined as the maximum absolute difference between the two cumulative distributions. This is then tested for significance through the use of an additional statistic (Press et al. 1992). The KS test was applied to the rainfall record for the periods 1884–1974 and 1975–2004, and the result was statistically significant ($p < 0.05$).

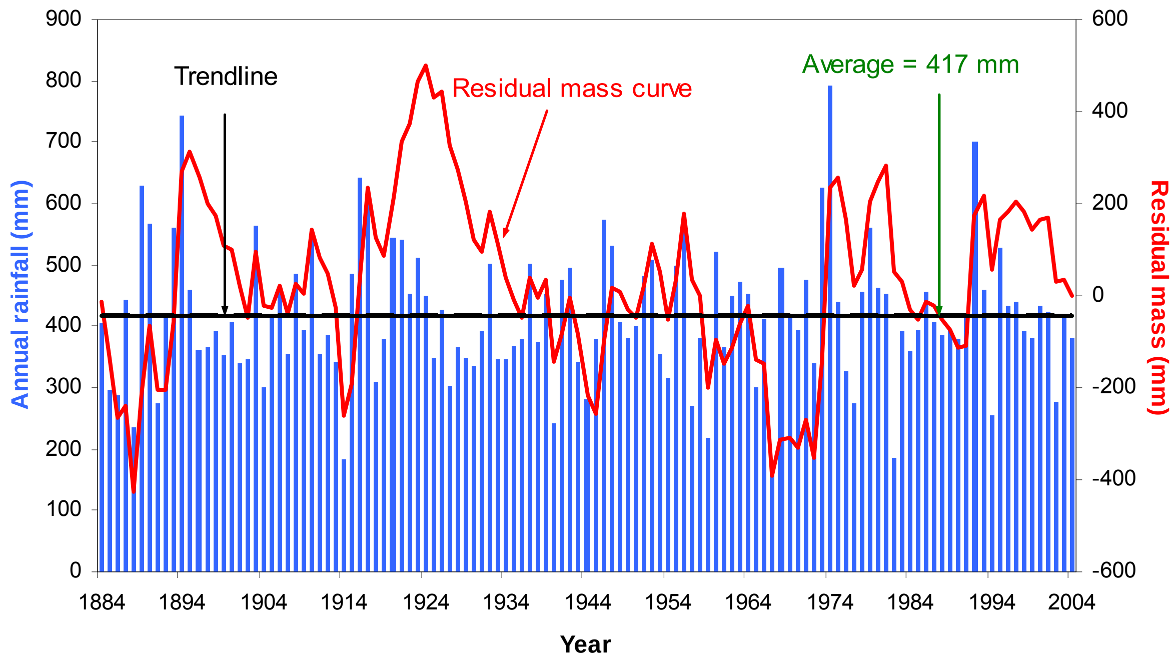


Figure 11. Annual catchment averaged rainfall, trend and residual mass, Burra Creek Catchment

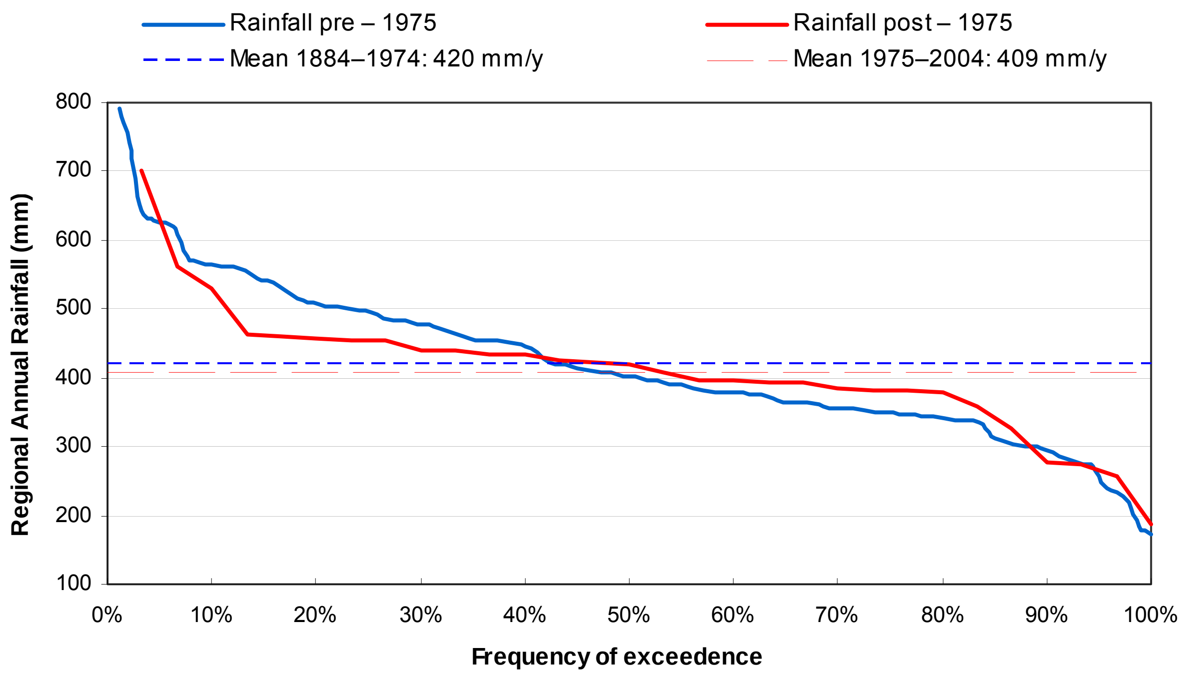


Figure 12. Frequency of regional annual rainfall — 1884–1974 and 1975–2004, Burra Creek Catchment

Despite the similarity in mean annual totals, in semi-arid regions where runoff is unpredictable, extreme years are important to ensure substantial recharge to groundwater stores and to generate significant streamflow events. In addition to a considerable contribution to groundwater recharge, larger streamflow events are important for their geomorphic influence on the catchment, removing built up sediment to scour out pools and resetting other ecologically important habitat such as riffles. The reduced frequency of these years during recent times is almost certainly a source of hydrological stress to local systems, exacerbating impacts as a result of human activities. Times of drought are also likely periods where increased or additional surface storages are often constructed, or groundwater use expanded in an attempt to provide improved security of supply.

4.1.2.2 Number of days where rain falls

The number of days where rain has been recorded annually was analysed for trends. The mean number of days per year when rain falls was around 97 days; the results for all years are presented in Figure 13. There is a clear and statistically significant decreasing trend over the period of record ($p < 0.05$). The data presented suggest that the average number of days during each year on which rain can be expected to fall has been decreasing.

These data were further examined for monthly and seasonal trends. With the exception of February and November, which exhibited no trend, all months and seasons were declining. Decreases in the number of rain days therefore appear to be consistent across the year, and not limited to any particular season.

Although the aggregation of daily rainfall records during the recording process presents a limitation to the certainty of this analysis, the disaggregation process should remove most of the errors in this dataset, provided that data have been correctly coded. Additionally, the advent of automated rainfall stations in recent decades has largely removed the uncertainties in the disaggregation of daily rainfall data. Hence, any expected bias in the dataset should favour the opposite trend to that observed, increasing the confidence in the information. Nonetheless, the information should be considered indicative and viewed with appropriate caution.

4.1.2.3 Monthly rainfall

Figure 14 shows the long-term mean monthly totals and standard deviations for regional average rainfall from 1884–2004. The months of November through April are the driest, with a break in season evident during May. The drier months are also the most variable, as indicated by the relative values of the standard deviation and the mean.

The dominant rainfall season is from May through to October. August is the wettest month and March is the driest. Compared to higher rainfall areas to the south, there is only a modest difference in the expected mean monthly rainfall between the more reliable winter–spring months and the dry summer months.

Figure 15 shows the mean monthly rainfall for the three meteorological stations used in rainfall analysis for this assessment, with the location of the sites indicated in Figure 10. There is little difference between Mount Bryan and Burra, which experience very similar monthly mean rainfall totals throughout the year. Worlds End receives the lowest mean totals for all stations assessed, and for all months of the year, but this difference is most pronounced during winter months. This relatively low winter rainfall component accounts for the considerably reduced annual rainfall totals measured at the site, and is indicative of the elevation and topography of the lower catchment, which also lies in the rain shadow of the northern Mount Lofty Ranges.

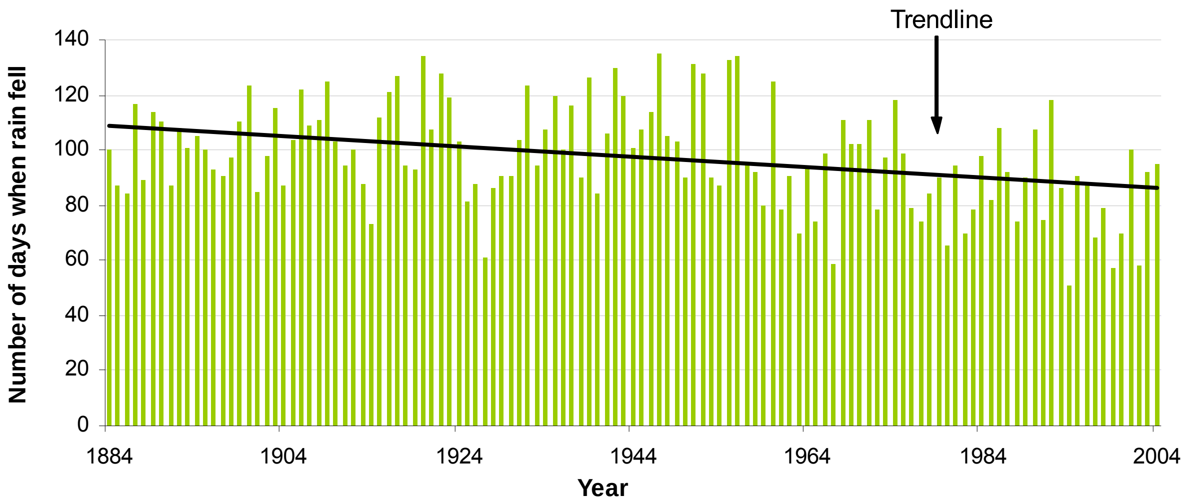


Figure 13. Total annual number of days where rain fell, 1884–2004, Burra Creek Catchment

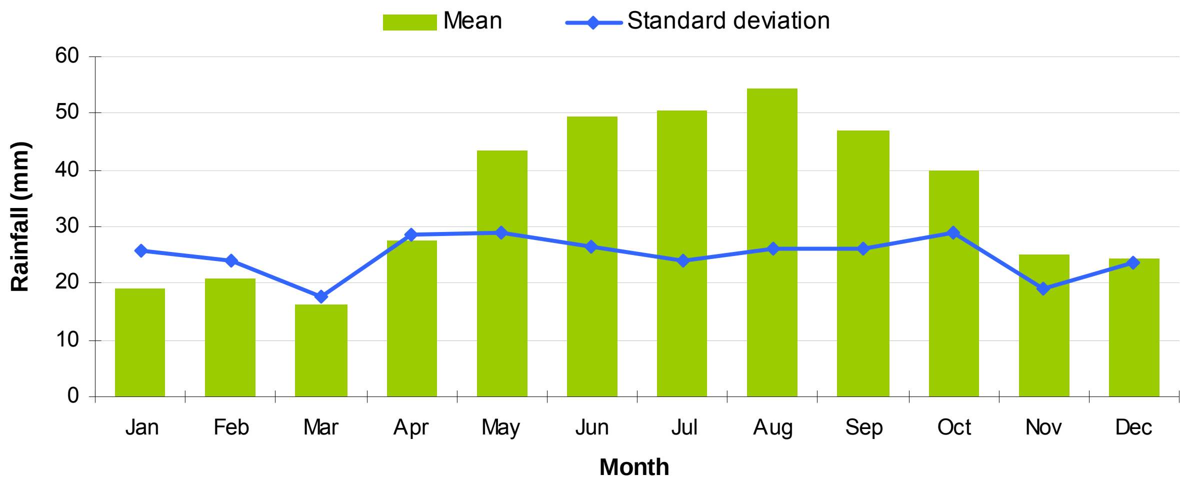


Figure 14. Regional mean monthly rainfall and standard deviations, Burra Creek Catchment

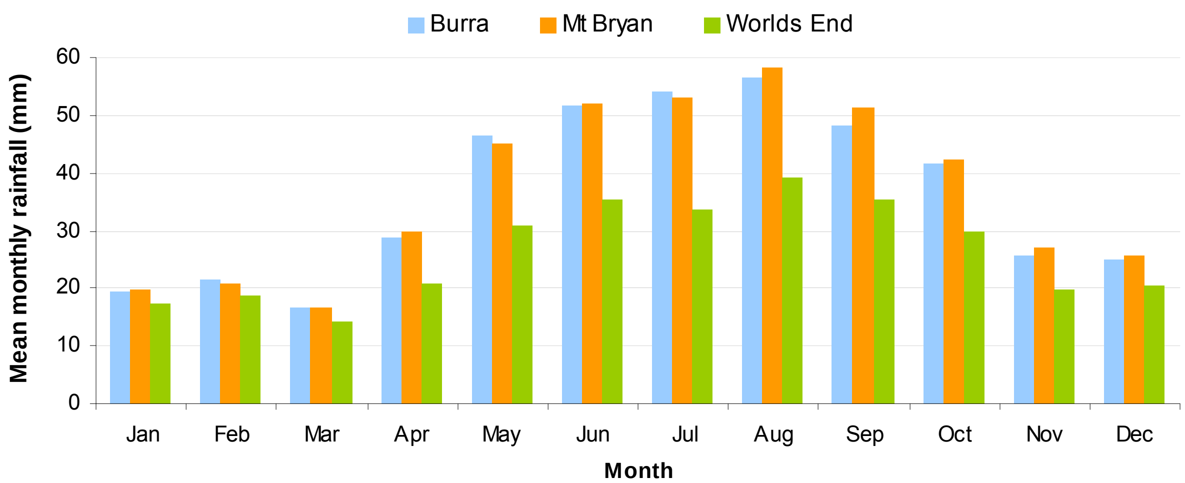


Figure 15. Monthly rainfall at BoM stations used in modelling, Burra Creek Catchment

Monthly residual mass curves for individual stations and for the regional average rainfall dataset were assessed to determine whether any trends were evident in monthly rainfall. This analysis suggested a shift towards a later onset in seasonal rains, evident as a marked decrease in the rainfall for some autumn months and a modest increase in some spring months. These trends were common to all sites, and selected data are presented below from the regional average monthly rainfall record to illustrate this.

Figure 16 shows the residual mass curves for months where a decreasing trend is evident over recent years. April and May monthly rainfall demonstrate this most clearly and, as shown, the trend since around 1980 has been towards below average rainfall for these months. Prior to the 1960s, these months commonly exhibited opposite trends, but since this time they have been 'in phase', both increasing until around the 1980s but decreasing since that time.

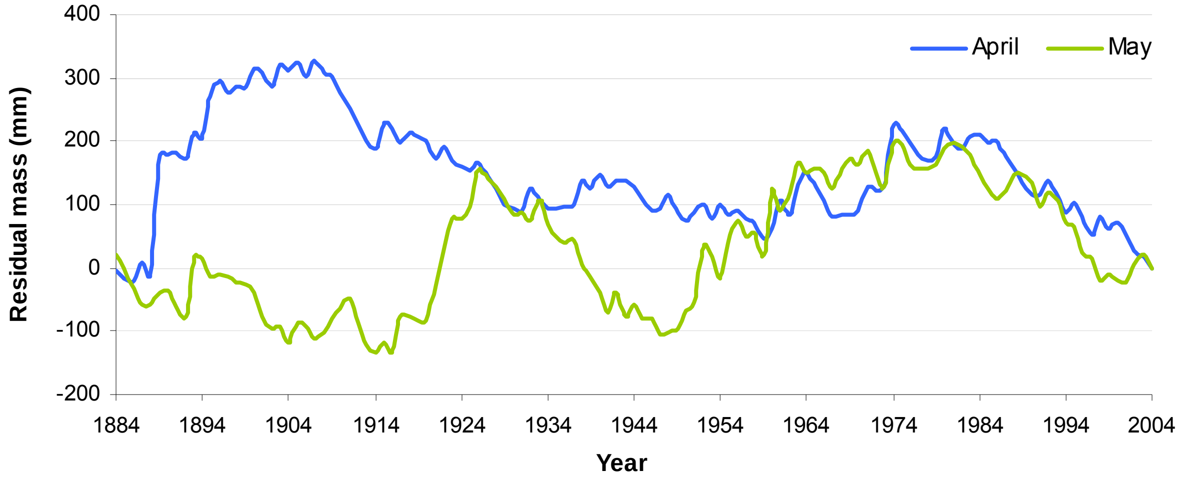


Figure 16. Residual mass curves for months showing a decreasing trend, Burra Creek Catchment

Figure 17 shows months where the recent trend has been for rainfall above the long-term average. June rainfall has demonstrated clear wetter and drier cycles, where prior to around 1925 June rainfall was typically higher than the long-term average, after which time it was consistently lower, until around the mid-1980s. Since this time it has not exhibited any consistent pattern, but has generally been above average.

November rainfall totals show a small but clear increasing trend since the 1940s, and September, although more variable, also seems to be generally above average, particularly since the mid 1990s.

Other months did not appear to demonstrate any clear patterns, although many reflect the recent drier than average conditions and have been generally below average since the turn of the century.

Monthly rainfall totals were also tested for statistical trends by fitting least squares linear regression trendlines to the data. The most pronounced trends were the increasing rainfall in November and the decreasing trend for June (Fig. 18). These results were not significant at the 95% level, but were at the 82 and 85% confidence levels, respectively.

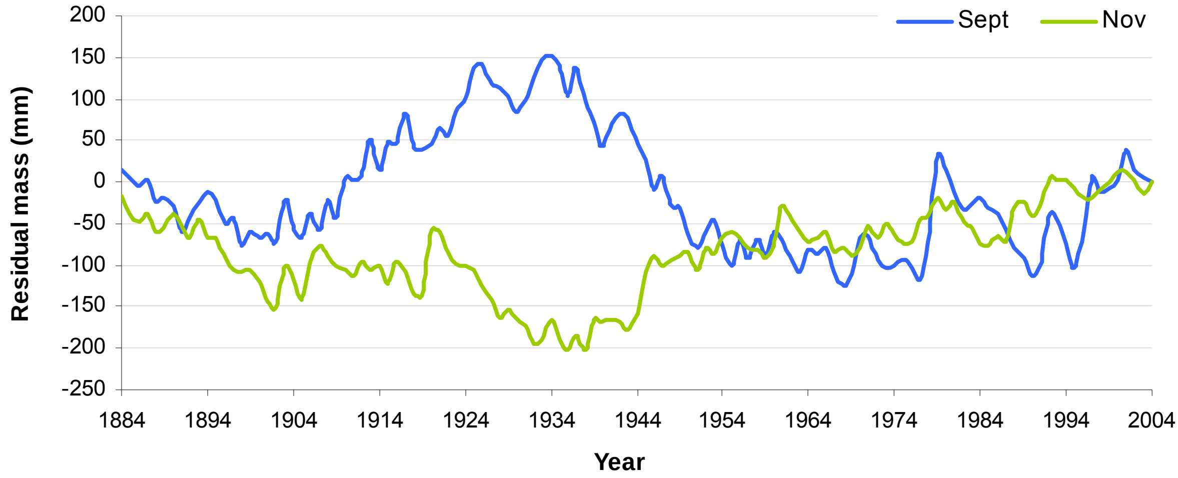


Figure 17. Residual mass curves for months showing an increasing trend, Burra Creek Catchment

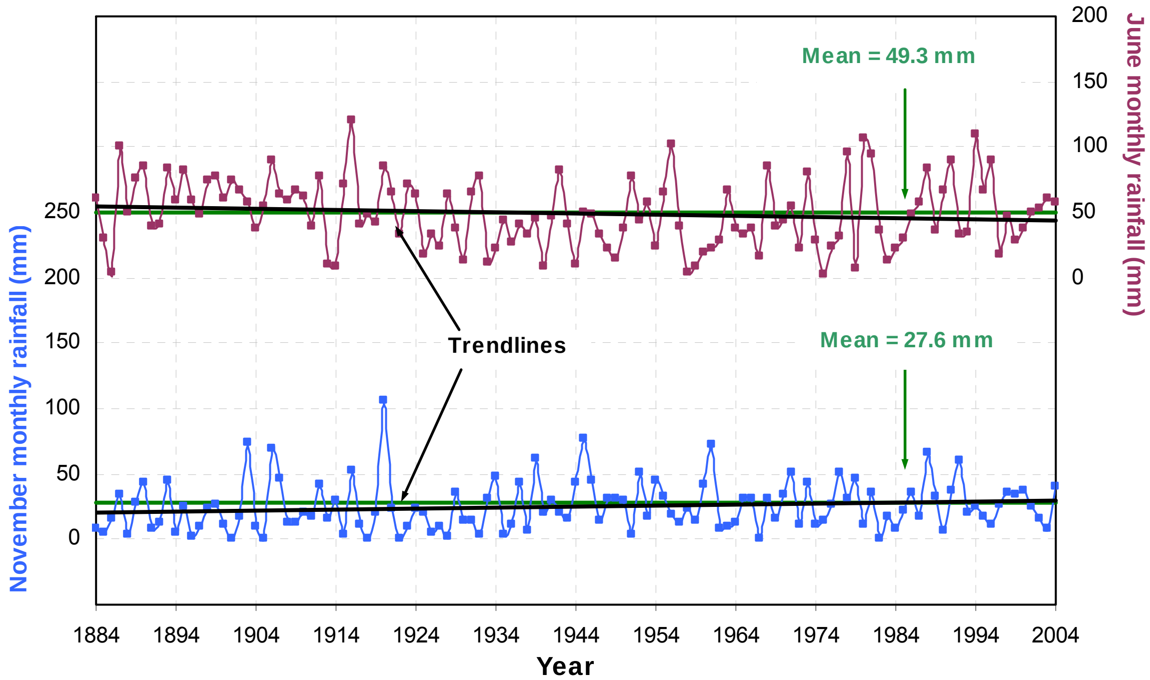


Figure 18. Trends in June and November rainfall, Burra Creek Catchment

Evidence from the above discussion suggests that early season monthly rainfall may have been decreasing since at least the 1970s, and this was further assessed by plotting mean monthly rainfall over the last 30 years, along with the same data for the full period of record. This is presented graphically in Figure 19.

The most notable difference is in January totals, although this is mostly due to the influence of three extreme years when January rainfall exceeded 100 mm. April and May totals are lower than the long-term means and September and October totals are higher, further suggesting that recent conditions have tended towards rain falling later in the year.

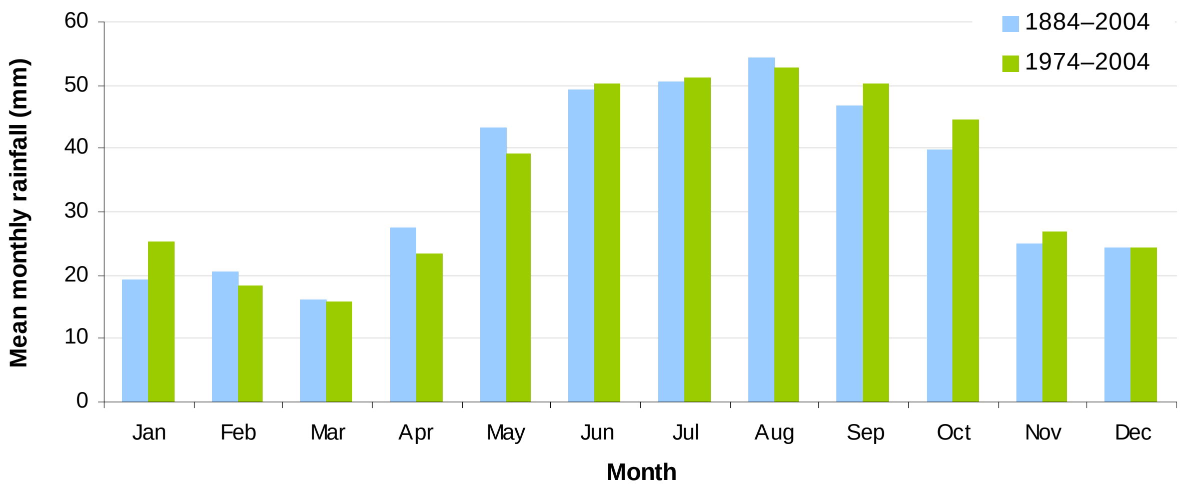


Figure 19. Comparison of long-term and recent mean monthly regional rainfalls, Burra Creek Catchment

Several recent studies in South Australia have found a trend towards later season rainfall, and which are still producing annual totals around the long-term mean (e.g. Risby et al. 2003; Heneker 2003; Deane 2005). Despite annual rainfall being close to average, the seasonality of rainfall can have a major influence on the resulting volumes of streamflow and groundwater recharge. Rainfall received during months with a higher evaporation rate increases the proportion of rainfall that is lost to evaporation, a reduction in the effective rainfall (see Fig. 22). In a winter-dominant system such as the focus area, a shift towards later season rainfall may produce less runoff for the same rainfall input averaged over the year, irrespective of other factors. The implications for users of water resources is that the level of sustainable use that can be supported will decrease accordingly.

4.1.2.4 Decadal analysis

One of the issues associated with hydrological investigation is the separation of human-induced changes from natural climatic cycles. Analysis of the full period of rainfall record for underlying patterns can shed light on the cyclic nature of the climate and allow further insight into the current conditions. Persistence is a term used to describe the tendency for wet years and dry years to cluster together into periods. These patterns can often be more clearly detected using smoothing functions such as the rolling averages and block means employed below. It should be borne in mind however that records extend only 120 years into the past, and longer term cycles cannot be elucidated through the rainfall record.

Figure 20 shows a graph of the 10 year rolling average annual rainfall (the average of each year calculated as the central point in a 10 year period) and the decadal mean (the average for each 10 year period of record). A clear cycle is evident in both results, with 1915–24 being the wettest period and 1925–34 being the driest.

The mean difference between high peaks of the rolling average is 25 years. The mean difference between troughs is 29 years. Mean peak–trough period is around 14 years. The period of time between consecutive high and low peaks appears to be reducing and it also appears that the current conditions within this cycle are near to a low point. Peak periods seem to be decreasing in magnitude, and the previous two peaks appear truncated. Peak periods seem to be flattening off, rather than exhibiting a single peak as in the early record.

Decadal means commencing mid-decade, rather than chronological decades (i.e. 1905–14 versus 1900–09), produce a clearer indication of cyclic patterns. Figure 20 shows that peak values for these 10 year block averages are decreasing in magnitude and approaching the value of the long-term mean. For example, the periods 1915–24 and 1925–34 deviate much more dramatically from this value than the last two decadal periods. This is a further indication of the reduced variability in annual rainfall as discussed above.

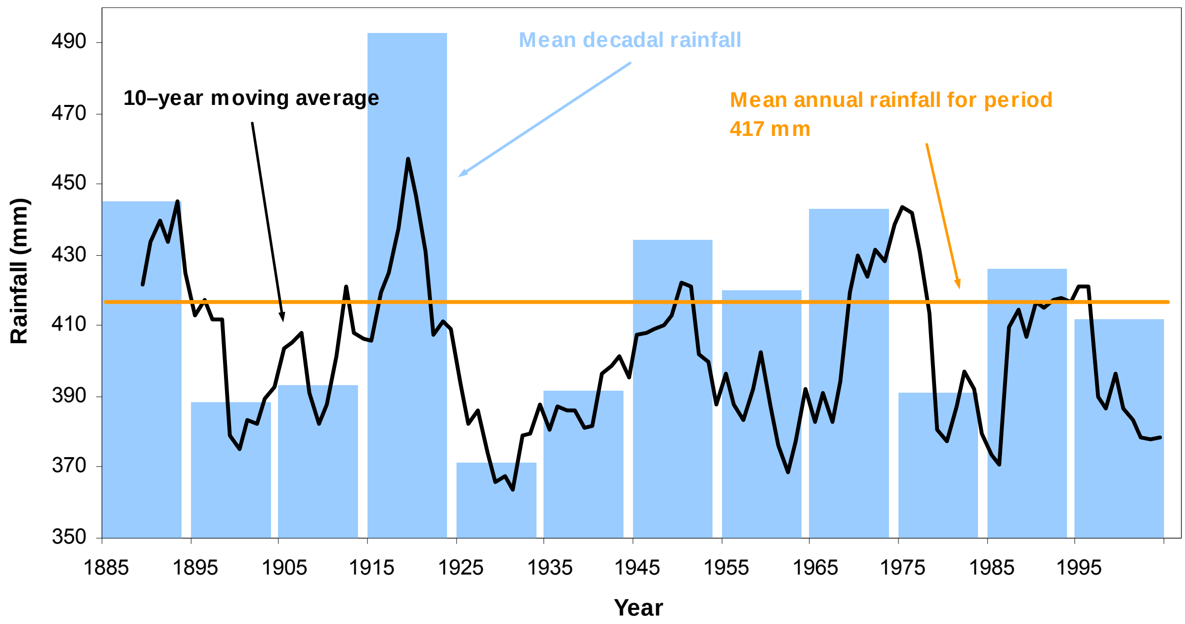


Figure 20. Regional 10 year moving average and decadal rainfall, Burra Creek Catchment

4.2 EVAPORATION

Evaporation, or the conversion of liquid water into water vapour, is an important component of the catchment water balance. For the purposes of this study, the transfer is considered to be a single parameter, whether the source is a free water surface such as a farm dam, from soils or vegetative surfaces, or via plant transpiration processes.

Accurate estimates are essential for water-balance calculations because in the long term the difference between precipitation and evaporation (as defined here) represents the quantities of water available for human and environmental needs.

4.2.1 DATA AVAILABILITY AND PROCESSING

The availability of daily evaporation data is limited in comparison to rainfall data, and this is at least in part due to the relative difficulty in collecting the information. In South Australia the most common method is the use of a standard Class A Pan, which estimates potential evaporation (in mm) by measuring losses from a free water surface. As this value will overestimate total evaporation, a coefficient known as a Pan Factor is then applied to this value to derive an estimate of actual local evaporation. Values for the Pan Factor in South Australia are typically around 0.6–0.7.

Evaporative loss is an important consideration in the management of water supply reservoirs, and evaporation measurements are often taken at these locations to facilitate water-balance calculations. Daily evaporation data for this study were sourced from a single such location, the BoM meteorological station at nearby Bundaleer Reservoir (station 021009).

The daily data record for evaporation extends back to April 1968, but has problems typical of those found with daily read rainfall data. Data were processed in a similar manner, involving disaggregation of accumulated data and infilling of missing data through use of a proportional relationship with other stations in the state.

4.2.2 DATA ANALYSIS

Daily Class A Pan evaporation data collected at Bundaleer Reservoir in the adjacent Broughton River Catchment were analysed on an annual and monthly basis. Insufficient data are available to consider analysis at longer timeframes.

4.2.2.1 Annual evaporation

Figure 21 shows annual evaporation at the Bundaleer Reservoir site since 1969. The decreasing trend observed is statistically significant ($p = 0.05$). Decreasing rates of pan evaporation have also been observed at many other sites in South Australia over the last 30 years (Murdoch 2005). Mean annual potential evaporation for the period is 1914 mm/y, although as a Class A Pan derived value this can be considered to be a theoretical maximum value. The lowest annual total recorded was in 1992 at 1550 mm, and the highest was in 1977 at 2282 mm.

The residual mass curve shows that from ~1973 till the mid-1980s evaporation values were greater than the long-term mean values. Since the early 1990s, the evaporation rate has been below the average rate.

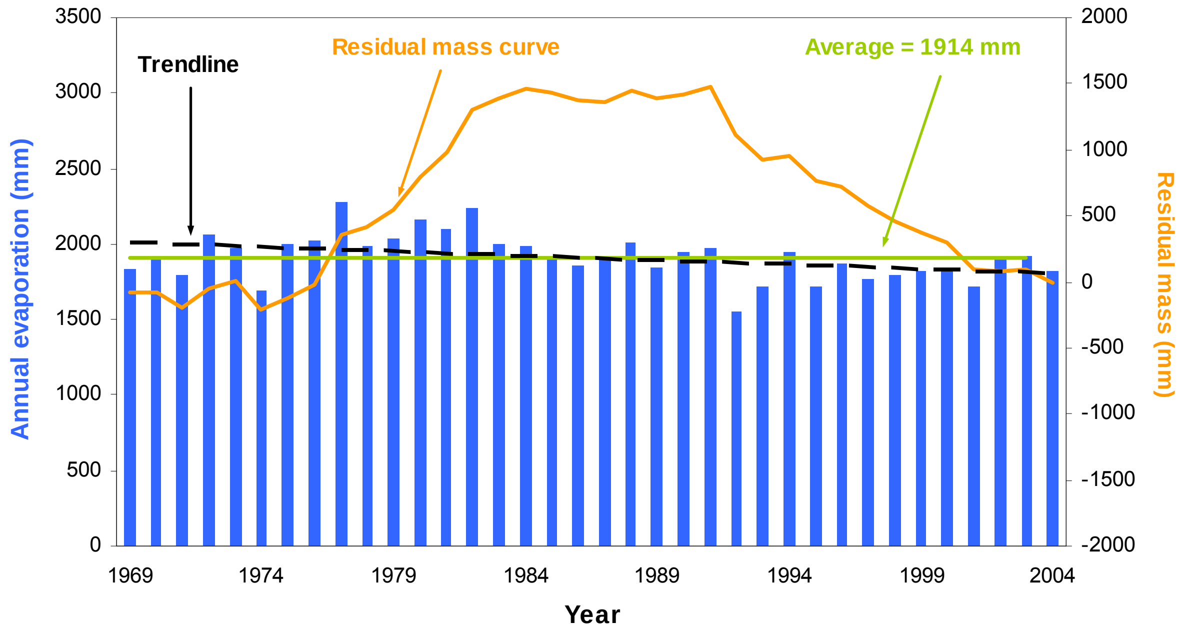


Figure 21. Mean annual evaporation, trend and residual mass, Bundaleer Reservoir

4.2.2.2 Monthly evaporation

Seasonal variations in evaporation rates influence the volumes of runoff generated. The probability of runoff and groundwater recharge occurring is higher where the rainfall exceeds evaporation, and the excess is often referred to as effective rainfall.

Figure 22 shows the long-term mean monthly rainfall for the Burra Creek Catchment and the mean adjusted monthly evaporation from nearby Bundaleer Reservoir. Note that the Bundaleer evaporation rate has been obtained from a Class A Pan, and is a theoretical maximum. The monthly mean has been adjusted to compensate for this by a factor of 0.7.

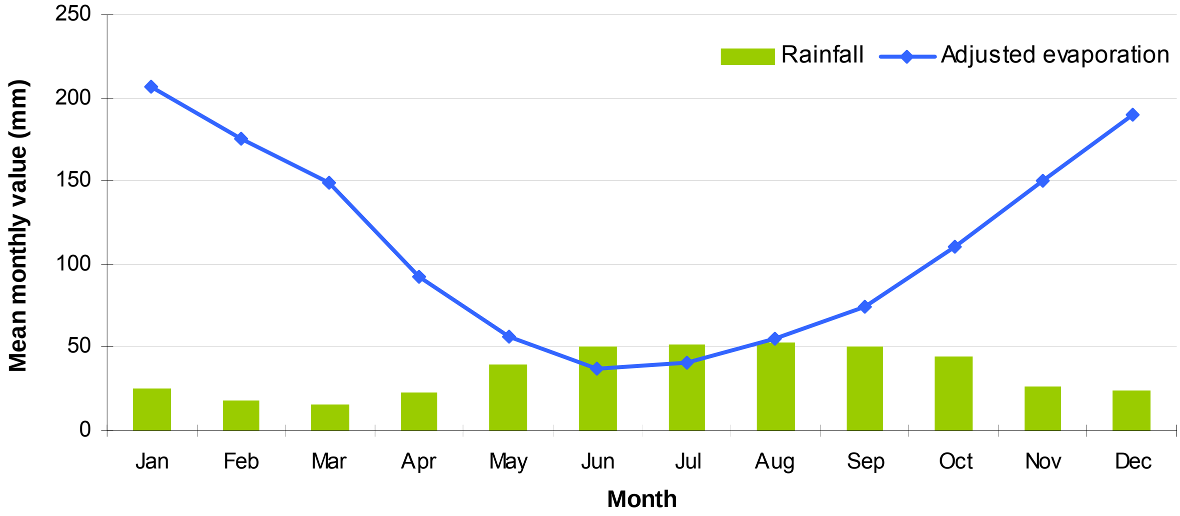


Figure 22. Bundaleer Reservoir mean monthly adjusted evaporation and catchment mean monthly rainfall

As mentioned above, generally it is found that the highest probability for runoff to occur exists in the months where the rainfall value exceeds the evaporation rate. Figure 22 indicates that the highest runoff-generating rainfalls will most likely occur in June and July, but Figure 26 in Section 4.3 shows the highest median streamflows occur during August. This is attributed to increasing streamflow contributions from groundwater as watertables rise in response to rainfall.

4.3 STREAMFLOW

Analysis of streamflow time series provides important insights into catchment runoff processes. Streamflow data are also essential in the calibration phase of model development, with outputs from the model compared with actual streamflow data to ensure that the model is capable of reproducing natural patterns. The following section provides an analysis of the observed streamflow data collected for Burra Creek, and modelled scenarios based on a calibration performed against these data are covered in later sections.

4.3.1 DATA AVAILABILITY AND PROCESSING

DWLBC has operated a continuous streamflow gauging station on Burra Creek at Worlds End since 1974 (site A4260536). The site control is not a pre-calibrated design structure, but an improved natural rock bar and as a result there are some inherent limitations on the precision and accuracy of the flow data. In addition, the site has suffered from extensive siltation during storm events on several occasions, leading to the ‘drowning out’ of the control structure, and further reductions in accuracy, especially for small flow volumes.

On initial inspection the data record appears to be of good quality, with less than 3% of data being of questionable value. Table 5 shows a summary of the data quality parameters associated with the daily streamflow record.

Table 5. Data quality code summary: A4260536 Burra Creek at Worlds End

Days	%	Quality codes
11 323	100.0%	Total records
10 986	97.0%	1 — Good data
81	0.7%	76 — Estimated (reliable estimation)
161	1.4%	103 — Doubtful (unreliable estimation)
95	0.8%	150 — Caution (rating table extended)

Quality codes refer mainly to the confidence that the hydrographers who maintain the site have that the water level recordings accurately reflect the likely level of the watercourse during the time concerned. In assessing the suitability for use of data from any site, it is necessary to consider not only the quality codes but also the nature of the site itself, including the control structure, historical maintenance, frequency and range of flow gaugings, and the instrumentation. All of these factors contribute to how closely the data recorded by the station, which is depth of water, can be related to the main parameter of interest, which is the volume of streamflow. Streamflow volumes are derived from water level recordings by use of theoretical ratings tables, developed from physical gaugings of streamflow during flow events.

Site maintenance records show that it has been difficult to determine the cease-to-flow level at the site, a problem that was largely addressed in 1983 with the installation of a new low-flow control structure. The data collected between 1983 and 1992 is of high quality across a range of low to mid-flows.

During 1992, large floods deposited tonnes of sediment along the creek both up and downstream of the gauging station, fundamentally altering the hydraulic characteristics of the reach. Following this sedimentation it has not been possible to maintain the site clear of silt and reeds, and the resulting alteration to flow and water level at the control structure appears to have compromised the low-flow data record.

The Regional Hydrographer was able to identify four distinct shifts in the rating between 1992 and 2004. These changes to the rating have been entered into the database but the resulting streamflow record suggests that the site has probably not been capable of adequately measuring baseflows since 1992, at least not to the previous level of precision and accuracy.

A check of streamflow record homogeneity (constancy over time) was conducted by double mass curve analysis, comparing the data record with two sites in the adjacent Broughton River Catchment — Hutt River near Spalding (A5070501) and Hill River near Andrews (A5070500). The relationship between the sites correlates very well for the period 1983–92, but diverges outside this period. The double mass curve appears in Appendix F.

Despite the good quality codes for the data record, much of the record is considered to be of limited use for low-flow analyses, particularly with regard to model calibration and baseflow trend analysis. Unfortunately, the period of concern is the most recent 12 years of record since the 1992 sedimentation occurred.

Despite these limitations, the site does provide a good period of record in excess of 30 years for mid- to high flows and a period of good data across all flow ranges recorded prior to 1992. Note that in the following sections, depending on the nature of the analyses, the data employed may be only that recorded up until 1992, or may include the complete dataset.

4.3.2 DATA ANALYSIS

Daily streamflow data from DWLBC gauging station A4260536 (Burra Creek at Worlds End) was analysed on annual, monthly and daily time scales. Daily data for the period 1974–91 were also used to calibrate the model.

4.3.2.1 Annual streamflow

The annual streamflow time series is provided in Figure 23, with summary and related statistics shown in Table 6. Mean annual flow volume during 1974–2004 is 5248 ML, and median annual flow for the same period is less than half of this volume at 2345 ML. Annual streamflow volumes are extremely variable, ranging over two orders of magnitude from 600 ML to over 40 000 ML.

Table 6. Selected annual streamflow statistics 1974–2004, Burra Creek

Streamflow parameter	Value
Mean flow (depth of runoff)	5248 ML (9.7 mm)
Standard deviation	8397 ML
Mean winter streamflow[1] (% of total annual flow)	3446 ML (63%)
Median (depth of runoff)	2345 ML (4.3 mm)
10th percentile	11 522 ML
90th percentile	925 ML
Average annual runoff coefficient	0.023
Interquartile range	3444 ML
Maximum (year)	40 167 ML (1974)
Minimum (year)	611 ML (2003)
Skewness coefficient	3.09
Geometric mean[2]	2 840 ML
Two-value trimmed mean[3]	3 726 ML

1 Winter in this analysis is considered to be the months May–November inclusive.

2 Geometric mean is the mean of log transformed flow volumes.

3 Trimmed mean is the mean of the remaining values when a number of extreme positive and negative values is removed from the dataset. It is used to reduce the impact of outliers.

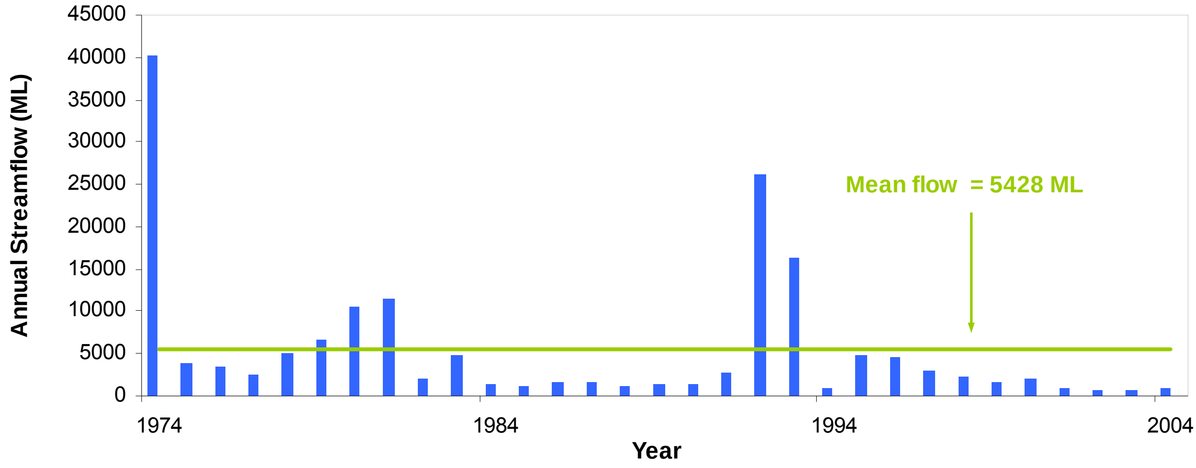


Figure 23. Annual observed streamflow volumes and mean, 1974–2004, Burra Creek

The distribution of annual flow data is positively skewed, as indicated by the difference between the mean and median flows, and the skewness coefficient. Positively skewed patterns are common in hydrology, and are typical of watercourses in low-rainfall, semi-arid systems. The skewness in this case is exaggerated by coincidence of the period of record, which includes two extreme years — 1974 is the wettest rainfall year on record and 1992 the third wettest. These years rank in the top 2% of the long-term annual rainfall record, and the inclusion of two such years in a 30 year gauging record has the effect of elevating mean streamflow considerably.

As a result, the mean flow volume is not a reliable indicator of central tendency for the dataset, with only six years exceeding this flow volume. This is illustrated by the two-value trimmed mean, where removing the two highest and lowest annual values reduces the mean streamflow value by 30%.

Several other alternative measures of centrality in the data are included in Table 6, and these could all be considered more indicative of streamflow volumes that could be expected in a ‘typical’ year. A log-normal distribution (App. G) closely approximates the data and the geometric mean (the mean of the log transformed streamflow volumes, converted back to original units) is perhaps the most defensible measure of central tendency in the data.

The value of the geometric mean is relatively close to the median, which is often used in similar circumstances, and could also be considered to provide an improved indication of central tendency in the data. With a value of 3444 ML, the interquartile range (the difference between the 25^{th} and 75^{th} percentiles in which 50% of values lie) provides a more typical indication of the ‘normal’ ranges of streamflows and further demonstrates the extreme nature of the maximum annual flow of 40 167 ML.

As demonstrated later in Section 5.4, baseflow is estimated to have contributed 40% of the total streamflow volume during the gauged period, and on average constitutes 70% of mean annual streamflow. During dry years, the proportion of streamflow attributable to groundwater discharge is in excess of 90% of gauged flow.

This groundwater contribution is of particular interest as annual baseflow volumes are seemingly not closely linked to climatic conditions. For example, during the period 1984–90 mean annual flow was 1490 ML, but this corresponds to a period of below average rainfall and limited surface runoff (see Fig. 11 and Section 4.1). Baseflow discharge during this six year period showed no sign of decreasing and contributed on average 1200 ML/y (87%) of streamflow. Further consideration of the baseflow component is provided in Section 5.4.

Mean annual flow during the four year period of 2000–04 has only been 798 ML. It is of some concern that four out of the five lowest annual flows on record come from the last five years, especially when it is recognised that only one of these was among the five lowest rainfall years. While it appears from the data that current streamflow (largely baseflow) volumes are the lowest on record, the problems with the low-flow measurement sensitivity of the gauging station decrease the certainty in the volumetric extent of this.

The unpredictable nature of runoff processes in the catchment are illustrated in Figure 24, which shows annual streamflow and annual rainfall. While extremely wet years generally produce extreme runoff (as seen in 1974 and 1992), average rainfall years can be unpredictable. For example, rainfall in 1978 and 1981 was ~435 mm, which is slightly above the long-term average, but 1981 produced almost three times the runoff of 1978. This demonstrates the non-linear relationship between rainfall and runoff in semi-arid climates, where soils are often below field capacity and rainfall intensity is an important factor in generating runoff.

The arid nature of the catchment is illustrated by the average annual runoff coefficient of 0.023. A measure of the average catchment response to rainfall, it can simply be interpreted as indicating that for each 100 mm of rainfall received, around 2.3 mm of runoff is generated. The contribution of the groundwater budget to streamflow gaugings will have the effect of increasing the apparent value for the runoff coefficient, and hence the actual runoff response may be considerably lower. The observed value compares closely to estimates for the southern Willochra Creek Catchment, with an average runoff coefficient of 0.02 (Risby et al. 2003). Comparison to higher rainfall catchments in the upper Torrens River further demonstrates the low catchment yield. Average annual runoff coefficients vary from just above 0.1 to almost 0.2 among these catchments (Heneker 2003), indicating that they generate 5–10 times the amount of runoff per unit area for a given volume of rainfall.

4.3.2.2 Monthly streamflow

Flow in South Australian streams generally occurs mostly during the winter and spring months, with extended periods of no flow during summer, resulting in mean flows for these months being close to zero (e.g. Savadamuthu 2002; Heneker 2003). The mean monthly flows in Burra Creek deviate considerably from this pattern, indicating the relative influence of large storm events and baseflow on the generally low volumes of runoff within the catchment. Median monthly flows demonstrate a more typical pattern but are almost entirely due to the perennial baseflow.

Figure 25 shows the mean and median (50^{th} percentile) monthly streamflows, and the standard deviation of the mean for the period 1974–2004. The most significant feature of the data is that, on average over the period of record, the largest volumes of streamflow occur during January. In addition, while there is a relatively high mean flow for the months July to October, the mean flows during the other summer months of December and February are around half of the mean volume in the high flow season. May also has a high mean flow volume, but June flows are less than those for December.

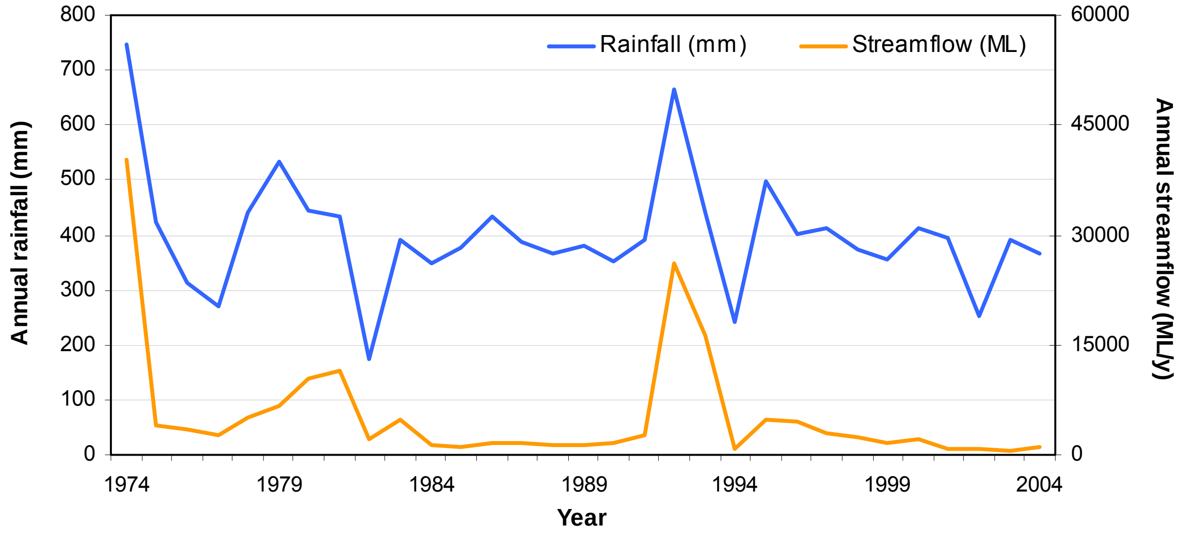


Figure 24. Annual rainfall and streamflow, 1974–2004, Burra Creek Catchment

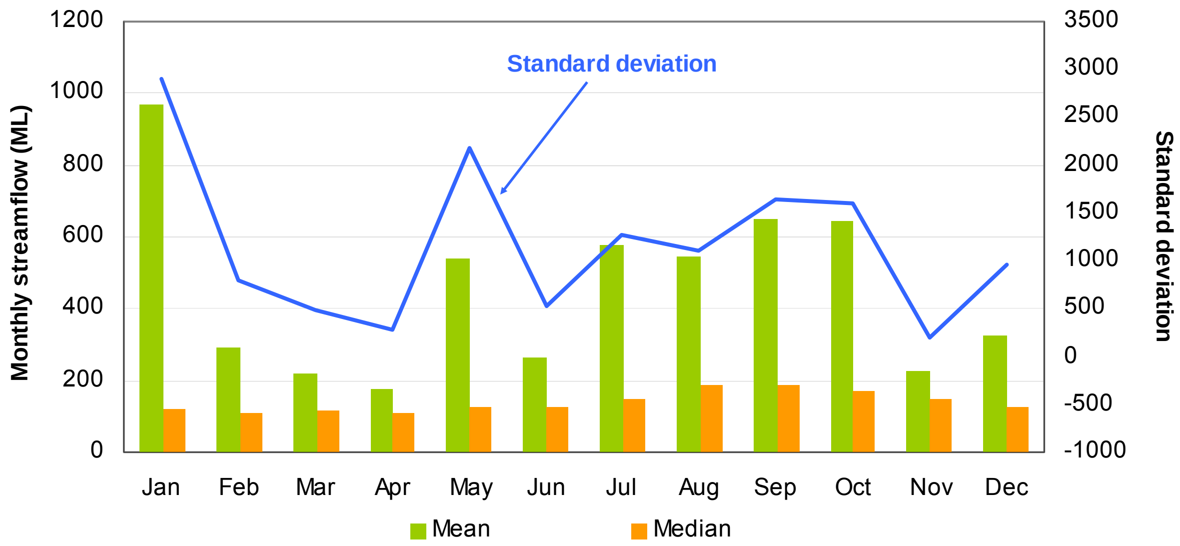


Figure 25. Monthly flow 1974–2004: median, mean and standard deviation of the mean, Burra Creek Catchment

The strongest influence on mean flow in the catchment appears to be the irregular high-intensity storm events. Months where larger or multiple events have occurred during the gauging record have considerably increased mean flow volumes. For example, rainfall has exceeded 100 mm in January on three occasions in the period 1974–2004. For comparison, this has only occurred twice in 120 years during August, which is the wettest month in the long-term rainfall record. This influence of episodic events highlights the generally low response of the catchment to rainfall, and has significant implications for the development of a sustainable approach to water resource management. This is discussed further in Section 9.

Monthly rainfall data presented in Section 4.1 indicate that 73% of annual rainfall occurs during the winter–spring[1] season. Table 6 shows that only 63% of annual streamflow occurs during this period, much lower than many comparable streams in the Mount Lofty Ranges. For example, in the Upper Torrens River Catchment, Heneker (2003) found that 80% of rainfall and 85–95% of streamflow occurred during these seasons (see also Savadamuthu 2003).

Figure 26 again shows median monthly streamflow, along with median monthly rainfall. There is a late winter – early spring peak flow period that lags behind the break in rainfall season, with streamflow not increasing markedly until July. Modelling suggests that this may be due at least in part to the impact of farm dams, which delay the onset of streamflow until filled, with the effect of reducing, in particular, June streamflow from surface runoff. Median flow volumes are extremely consistent across the year. The lowest median monthly flow of 108 ML observed during February is almost 60% of the value of the highest median monthly flow of 189 ML observed during August.

Although the mean monthly streamflow indicates a highly variable surface flow system, in contrast the median monthly flow volumes indicate that the baseflow conditions provide a relatively constant and stable year round environment compared to other streams in the Mount Lofty Ranges. The relatively high median flows across all months are evidence of the importance of the baseflow contribution to the annual catchment surface water budget.

To further illustrate the separate influence of the surface and groundwater streamflow components on total streamflow, Figure 27 shows a monthly analysis of the quickflow component. This volume is that attributed to direct surface runoff and is the volume remaining after baseflow is removed from the streamflow record. Unlike Figure 25, Figure 27 has the standard deviation and the mean shown on a common scale. The most apparent feature of this direct surface runoff component is the variability, as indicated by the error bars. This figure suggests that even during the more reliable winter–spring months, the volume of runoff is extremely difficult to predict.

4.3.2.3 Daily streamflow

Burra Creek has maintained permanent surface flows since gauging records have been kept at the Worlds End station, due to the continuous baseflow that is a feature of the central catchment. The flow duration curve derived from all daily streamflow data for the period 1974–2004 is shown in Figure 28, and daily streamflow data are shown in Figure 29. Of note in the streamflow record is:

- the underlying perennial baseflow (the gauged site has never ceased to flow)
- the cluster of extreme flow events during 1974 and 1992–93.
- the presence of periods where few or no apparent runoff events have occurred and gauged flow is almost entirely attributable to baseflow (e.g. 1982, 1986–90 and 2000–04).

[1]In order to align with SAMDB NRM Board water-use policy, for the purposes of this report, winter–spring rainfall and streamflow are defined as occurring between 1 May and 30 November in any given year.

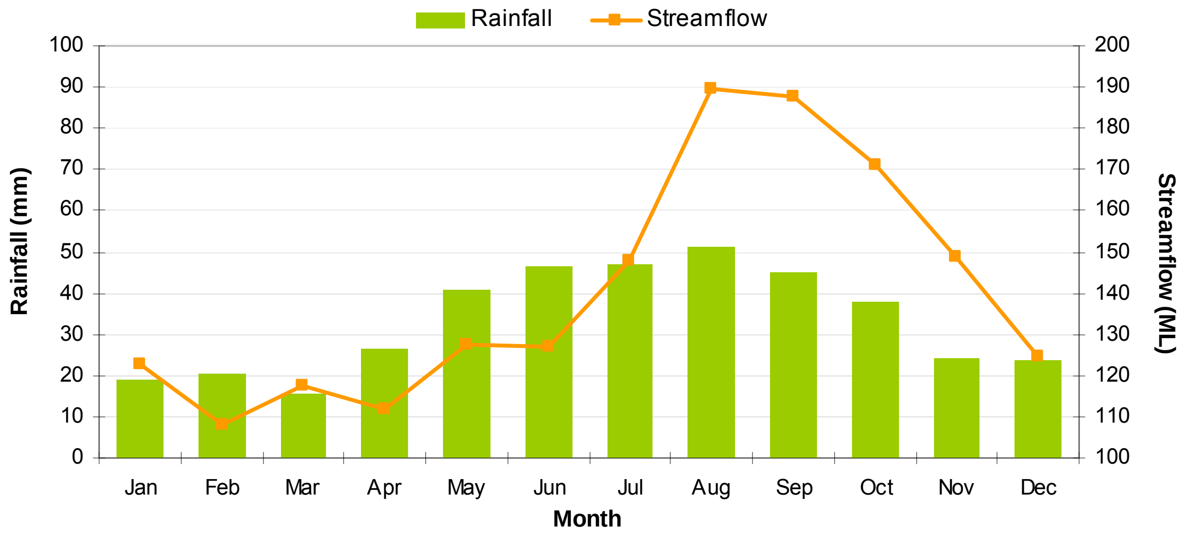


Figure 26. Median monthly rainfall and streamflow relationship, Burra Creek Catchment

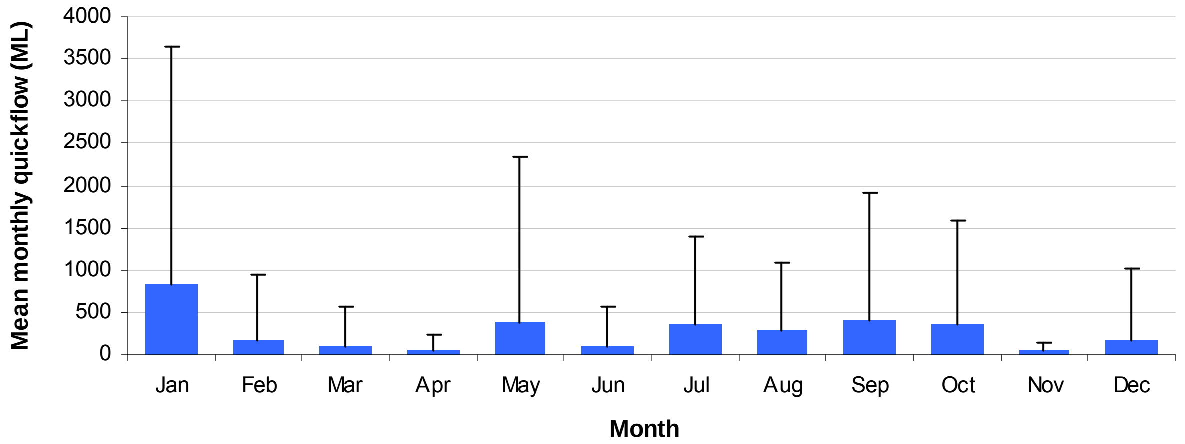
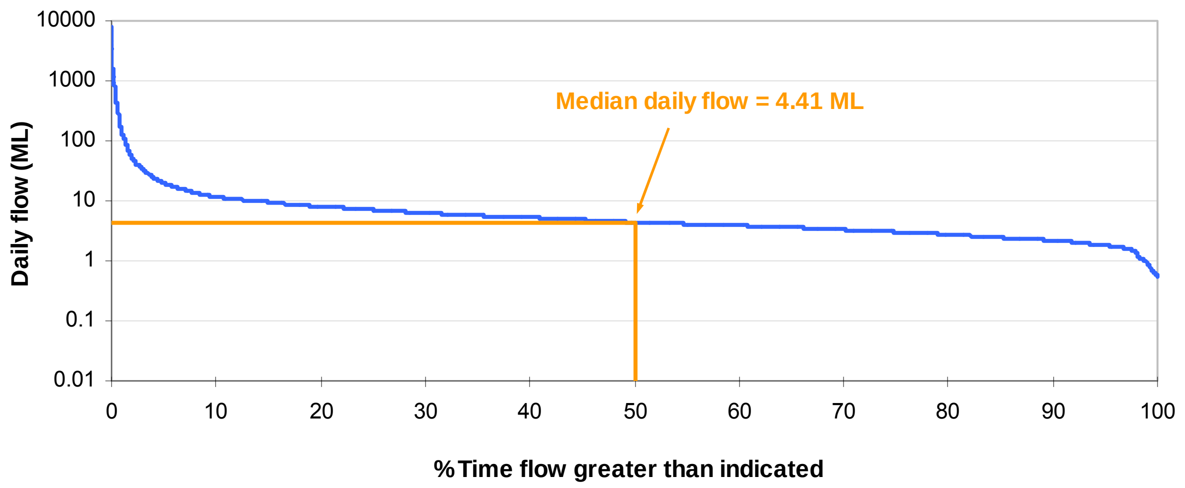


Figure 27. Mean monthly quickflow and standard deviation of the mean, Burra Creek Catchment



Source: Hydstra 2005.

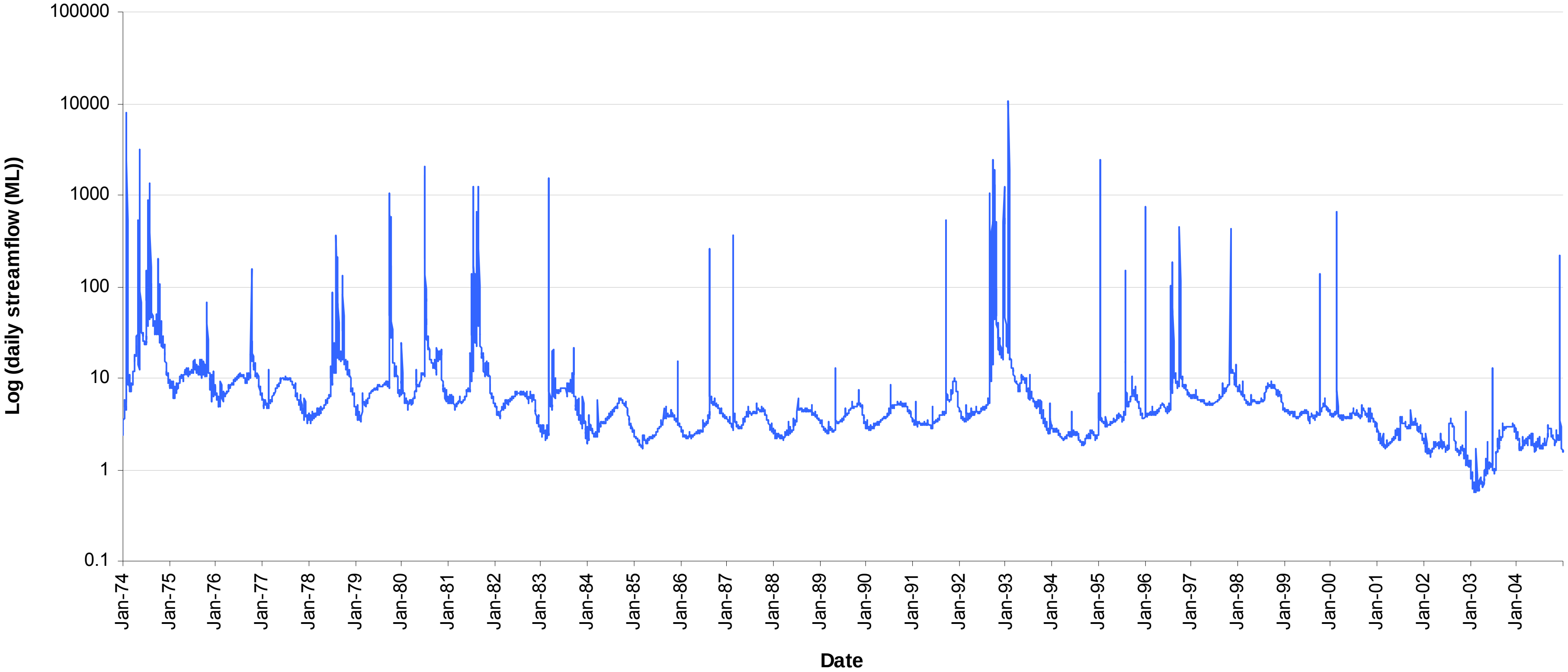
Figure 28. Daily flow duration curve 1974–2004, Burra Creek at Worlds End

Discharge tends to reach a minimum volume late in summer, with peak discharge occurring during spring, typically in September. Figure 29 shows this seasonal variation in baseflow volume, which can be observed as a roughly sinusoidal pattern within the daily streamflow record during the period 1974–92. Following the significant siltation of the gauged reach during the 1992–93 summer storms, sensitivity of the site to these low-flow variations decreased and the seasonal signal is no longer apparent.

Baseflow is generally due to discharge from unconfined aquifers (Dingman 2002) and assuming sufficient aquifer storage, discharge volumes will, to a large extent, depend upon the difference in hydraulic head between the stream bed and the watertable. The pattern observed in the data is probably due to a combination of seasonal variations in evapotranspiration rates (see Fig. 32) and corresponding fluctuations in watertable occurring within the Skillogalee Dolomite that are the source of springs generating the baseflow discharges (see Sections 3.3 and 5.1). Baseflows and low-flow periods are covered in more detail in Sections 5.4 and 8.

Figure 29 also shows that extended periods of up to several years occur where only small episodic surface runoff-driven flow events have occurred. This demonstrates both the importance of the baseflow to maintain the aquatic habitat and that seasonal surface runoff is far from predictable. Notable such periods include much of the 1980s and 2000–04.

Of further interest in this observation is the constancy of the volumes of flow during periods of annual minima. In the absence of significant wet seasons it would be expected that a corresponding decrease in baseflow would be observed, certainly within a number of years. This can be seen following 1974, the wettest year on record, where subsequent annual flow minima decrease until around 1978. It is not clear how in the absence of significant rainfall the baseflow could remain effectively constant for the period 1982–91, a period with only one average year and a mean regional rainfall for the period of only 360 mm. The implication is that the groundwater source has a very large storage volume.



Source: Hydstra 2004.

Figure 29. Daily Flow records, 1974–2004, Burra Creek at Worlds End

There is a clear decline in the annual minima for the period 2001–03, but it is not possible to confirm whether this is an actual event or related to siltation at the site affecting gauged volumes.

Owing to the unusual perennial nature of the baseflow, and the substantial contribution that this makes to daily flow volumes at the gauging station, it was considered important to estimate what proportion of total streamflow is directly attributable to surface runoff. A separation of the baseflow (groundwater discharge to the stream) and quickflow (surface runoff) components of streamflow was undertaken by use of a Lyne-Hollick digital filter (Lyne & Hollick 1979).

Details of the process are provided in Section 5.4; a statistical summary of both streamflow as recorded and the derived quickflow appear in Table 7. The influence on the statistics is considerable; the median daily discharge of 4.4 ML is reduced to 0.2 ML/d when baseflow is removed. A flow of 4.4 ML is exceeded less than 5% of the time when the baseflow component is removed. As would be expected, peak flows are effectively unchanged, but the 75th percentile is lowered from 7.1 ML to only 0.6 ML. On inspection of these statistics it is clear that the perennial baseflow introduces a considerable volume of surface water to the system, and to protect surface flows it is important to consider both surface runoff and groundwater processes.

Table 7. Daily streamflow statistics, Burra Creek, 1974–2004

Parameter	All streamflow	Quickflow component
Mean daily flow	14.9 ML	8.9 ML
Standard deviation	155.6 ML	153.8 ML
Median daily flow	4.4 ML	0.2 ML
25th percentile flow	7.1 ML	0.6 ML
75th percentile flow	3.0 ML	0.1 ML
Maximum (year)	10 865 ML (1993)	10 833 ML (1993)
Minimum (year)	0.6 ML (2003)	0 (all years)

4.4 SURFACE WATER QUALITY

4.4.1 SALINITY DATA

During regular site visits to maintain the gauging station at Worlds End, salinity was opportunistically measured by the hydrographer through use of a hand-held electrical conductivity (EC) meter. Statistics summarising all of the data, and a subset of these recorded during steady baseflow conditions, are summarised in Table 8.

This information only provides a snapshot of salinity concentrations on the particular day of the visit and observations have been made opportunistically at irregular intervals. It does, however, indicate the moderate baseline levels of salinity within the system. Observed streamflow salinity concentrations are closely related to discharge volumes, in particular the relative contributions to the total flow from direct surface runoff and groundwater baseflow.

Table 8. Summary statistics, Burra Creek salinity data 1974–2004

Statistic	EC all samples (µS/cm)	EC samples taken at steady baseflows (µS/cm)
Number of samples	167	63
Mean	4 871	4 993
Standard deviation	1 032	480
Median	5 000	5 100
Maximum	9 000	5 800
Minimum	956	3 571

Source: State Surface Water Archive.

Due to this fact, it is not possible to use data based purely on observation date to determine any trend, as the reading may be artificially reduced due to a major streamflow event occurring immediately prior to the reading.

By filtering the readings through inspection of streamflow data to include only those collected during apparent steady baseflow conditions, it was possible to analyse trends in baseflow salinity over the data collection period. Figure 30 shows data summarised in the right hand column of Table 8, recorded during periods of steady baseflow. As baseflow is believed to be sourced largely from springs within the Skillogalee Dolomite, the chart effectively gives a surrogate indication of trends in groundwater salinity over the period from 1974 to 2004. An increasing trend is apparent in the least squares regression line fitted to the data, which is statistically significant at the 94.5% confidence level.

A monthly and seasonal analysis was also undertaken but there are insufficient data points that are representative of baseflow conditions within each period to account for the natural and measurement variations. Future monitoring at the site should include continuous salinity monitoring in order to determine any trends in salinity concentration and the relationship between flow and salinity in the catchment.

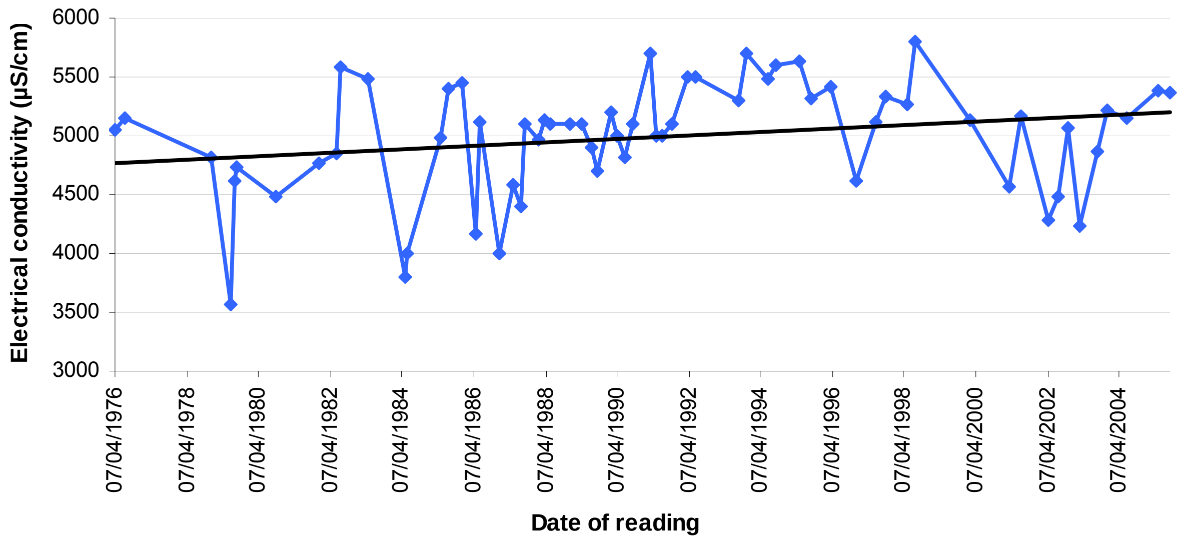


Figure 30. Salinity concentrations and trend in baseflows, Burra Creek 1974–2004

5. GROUNDWATER

5.1 OVERVIEW

Both fractured rock and unconsolidated sedimentary aquifers occur within the gauged catchment, but the dominant aquifer is comprised of fractured slate, sandstone, calcareous siltstone and carbonates (Read 1980). Sedimentary aquifers are found in deposits up to 90 m thick to the north of Burra (Read 1980; Morris 1983) and in the Murray Group sediments east of Worlds End. Wells drilled into the Murray Group sediments of the lower catchment are typically shallow, low yielding and highly saline. The majority of hard rock aquifers are of low porosity and permeability and are hence also low yielding.

Groundwater quality is marginal for most commercial uses and this is compounded by generally low yields, although occasional good supplies can be found. Each fractured rock system is unique, with the behaviour being strongly influenced by highly variable factors relating to the prevailing fracture pattern such as spacing and orientation. This makes it difficult to predict or generalise the behaviour of such systems, presenting challenges for users and managers alike. To compound these problems, the extent, connectivity and recharge processes of the fractured rock systems found throughout the central catchment are poorly known outside of the immediate vicinity of Burra township.

The exception to the low-yielding nature of aquifers is the Skillogalee Dolomite. This represents a localised, highly transmissive zone within the catchment. Localised faulting and dissolution has resulted in increased permeability and therefore groundwater recharge and discharge (Segnit 1937; Morris 1983). The fracture systems developed in this zone will extend into the adjacent lithologies and exhibit hydraulic connection with the groundwater (T. Wilson, DWLBC, pers. comm., 2005). The copper deposits exploited by the Burra open cut mine were also located in this formation and de-watering to allow mining operations was a continual challenge to mine operators owing to the transmissive nature of this rock type.

The open cut, located on the western outskirts of the township, still contains significant quantities of water, the surface of which is thought to represent the level of the watertable (Segnit 1937). The direction of flow in the aquifer at the mine is from north to south (Segnit 1937; Read 1980). At one point the supply was considered as a possible source of water to augment supplies in the nearby Bundaleer Reservoir, but the poor water quality and already major draw on the aquifer for a town supply at that time made this unrealistic (Segnit 1937).

The Skillogalee Dolomite is the source of water pumped into the Burra Creek channel within Burra township to maintain the level of the recreational lake (see Section 3.3). More significantly for catchment hydrology and ecology, discharge from this zone within the regional fractured rock aquifer is the source of the springs that produce the continuous baseflow and permanent waterholes of the creek to the south of the township (Segnit 1937). Due to the importance of the highly transmissive zone within the regional fractured rock aquifer, it is a focus of this report.

Anecdotal reports from landholders suggest that groundwater levels have been declining and salinity increasing over recent years, with salinity increases particularly reported by those with wells in Murray Group sediments of the lower catchment. Landholders near Mount Bryan have reportedly been experiencing drying of wells (D. Lindner, landholder, pers. comm., 2005). Landholder Gavin Philips has a property adjacent to the gorge with a stock well in the foothills of ~180 m depth. Since drilling around 20 years ago, the well yield has reduced from ~600 g/hr (0.75 L/s) at the time of drilling to ~210 g/hr (0.26 L/s) in 1992. In 2005, the well was deepened by ~4 m but is still only capable of 180 g/hr (0.23 L/s) (G. Philips, landholder, pers. comm., 2005).

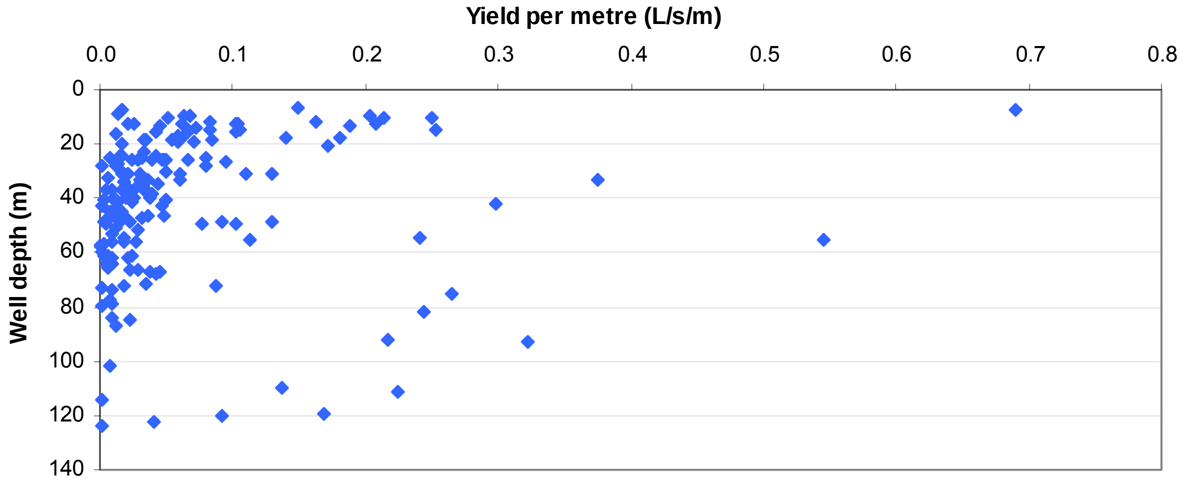
Decreased yields and increased salinity in baseflows and groundwater of the central and lower catchment suggest a reduction in the volumes held in storage. This suggests that extractions, throughflow and discharges have exceeded inflows and recharge over recent years. It is possible that a reduction in groundwater inflows from the higher rainfall and hence lower groundwater salinity areas of the catchment is contributing to the observed increases in salinity in lower rainfall areas. However, it is not possible with existing information to state the level to which this is attributable purely to climatic conditions and to what extent, if any, human use of ground or surface water may contribute. The interaction between the fractured rock aquifer, surface flows within the creek and the sedimentary aquifers of the lower catchment are presently not known. In the absence of improved understanding of the relative impacts of climate and extractive use, a causal mechanism for the perceived rise in groundwater salinity and reduced baseflow cannot be clarified.

The lack of any groundwater monitoring information available particularly hampers any investigative work. Outside the immediate area of the Burra Mine, no monitoring network has ever been established in the area, although some isolated ad hoc project data are available. This lack of focus on active management such as monitoring and assessment is due at least in part to the generally low volume uses to which groundwater is currently subjected. Typically, areas under pressure for high water use development attract investigations, but cropping and grazing areas are not considered to be at risk. From an environmental perspective, the discharges supporting the permanent flow in Burra Creek from springs within the Skillogalee Dolomite should be seen as a significant asset. The currently poorly understood recharge and discharge processes supporting this process, and the unpredictable, semi-arid nature of the climate, means that even limited development can potentially be unsustainable. An increase in management effort to better define a sustainable yield and monitor impacts from current activity warrants consideration.

5.2 NATURE OF GROUNDWATER RESOURCES

Table 9 presents some summary statistics relating to groundwater of the catchment, indicating the poor yields and water quality associated with the resource. These limitations generally do not affect the grazing sector and is well within the required supply quantity and quality for the provision of stock water. The low and unpredictable supply does limit irrigation activity however, and the poor quality restricts both the choice of potential irrigated crops and the range of domestic uses for groundwater.

Figure 31 shows well yield as a function of well depth and there is an apparent trend of higher yield values for wells of a depth less than 20 m. This pattern is observed for other fractured rock systems in the Mid-North of South Australia (see Love et al. 2002; Deane



Source: SA Geodata 2006.

Figure 31. Well yield per unit depth, Burra Creek Catchment

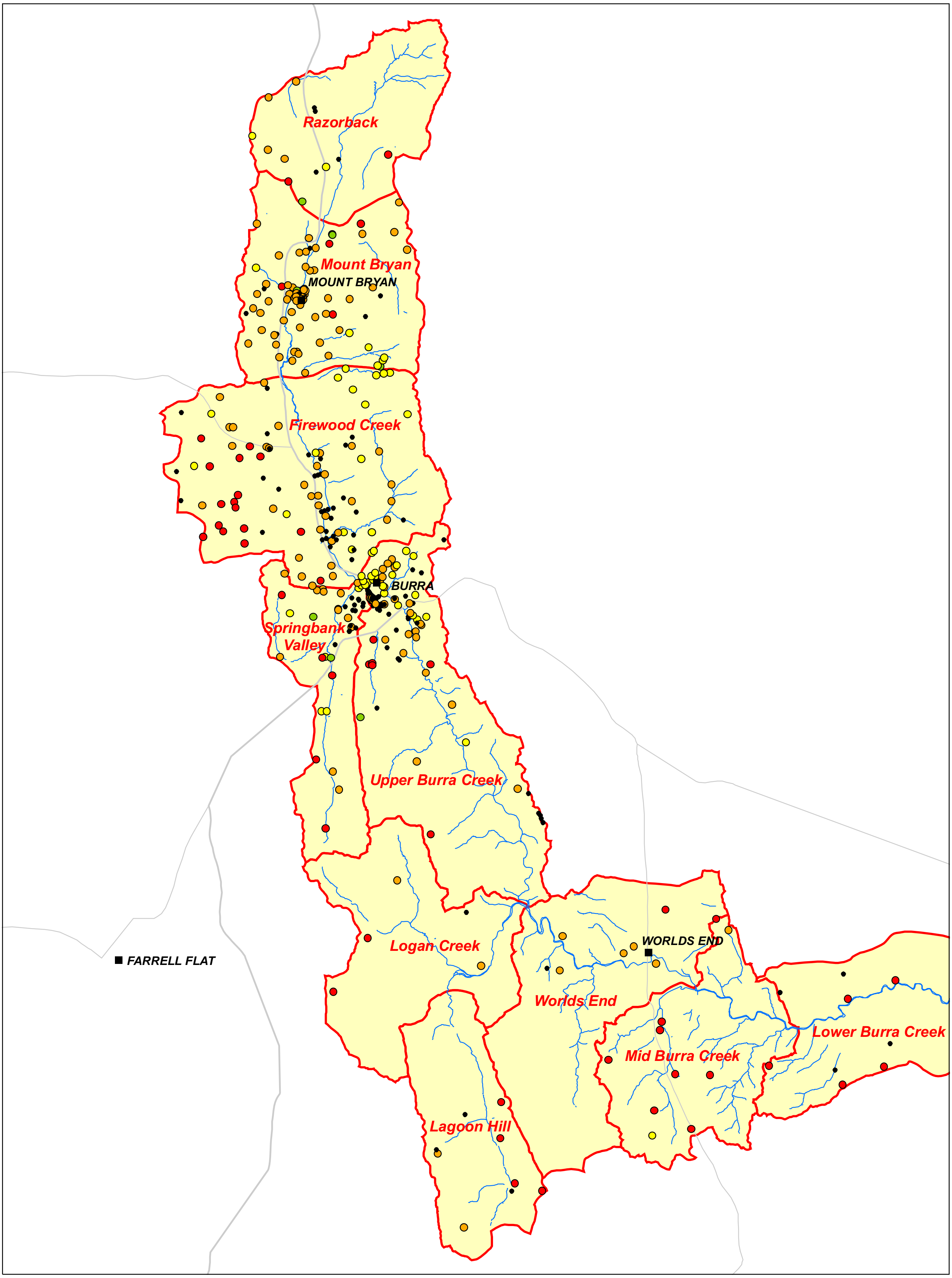
Table 9. Range of selected groundwater parameters, Burra Creek Catchment

Parameter	Lower limit	Upper limit	Median value	25th–75th Percentiles
TDS (mg/L)	175	47 600	2 795	2 073–3 991
Yield (L/s)	0.01	30	1.0	0.5–1.9
Depth to water (m)	0	87	12.8	6–23

Source SA Geodata 2006

2005). Well yield is typically higher at shallower depths in these systems, due to the presence of a more highly weathered, and therefore transmissive, layer nearer to the surface. Of note is the presence of a few higher yielding wells at greater depth. These wells most likely intersect higher yielding larger fracture sets. However, given the moderate quality of available water, the unpredictability of being able to find good supplies combined with the cost of drilling to, and pumping water from, such depths, the usefulness of this resource is somewhat limited.

Figure 32 shows the distribution of groundwater salinity based on well data from SA Geodata, and shows that the majority of wells are in the range of 1500–3000 mg/L. Better quality water tends to be found in the vicinity of faults around Burra township and immediately to the north, near to Mount Cone. Figure 33 shows the same information for well yields. The majority of higher yielding wells also appear to be associated with fault systems, especially those drilled in the immediate vicinity of the township.



Townships
Roads
Watercourses
Model subcatchments

Well salinity (EC units)

- No data
- 1 - 1500
- 1501 - 3000
- 3001 - 6000
- > 6000

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

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

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

N

0 1.25 2.5 5 km

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Figure 32. Groundwater salinity, Burra Creek Catchment

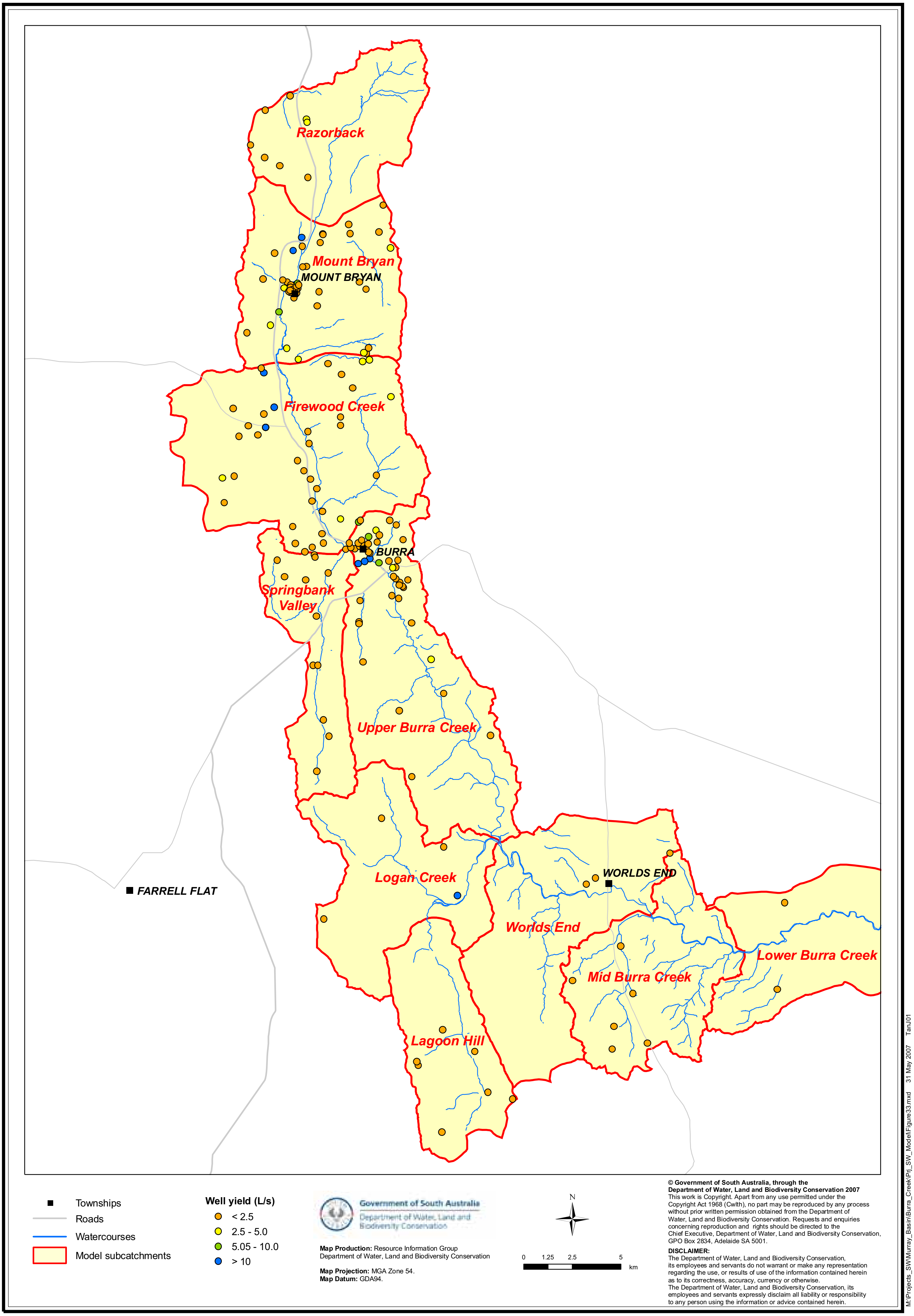

Figure 33. Groundwater yield, Burra Creek Catchment

5.3 SURFACE WATER – GROUNDWATER INTERACTIONS

5.3.1 SIGNIFICANCE OF THE GROUNDWATER CONTRIBUTION TO STREAMFLOW

The area referred to in this report as the central catchment is highly significant due to the presence of a relatively extensive supply of permanently flowing surface water. This perennial flow is entirely due to the year-round surface expression of groundwater, so clearly understanding the interaction of surface and groundwater is an important consideration in protecting the resource and this unique feature.

As discussed elsewhere in this report, the most significant quantities of surface discharge are attributed to the highly faulted and fractured Skillogalee Dolomite. It is important to consider the potential impacts of development on these discharges.

5.3.2 IMPACTS ON WATER BALANCE

In its simplest form, the water balance of an aquifer can be described as consisting of inflows, changes to storage, and outflows. Gravitational or pressure gradients within the system drive the flow of water, which moves from high to low potentials. Changes to any of the components of the water balance will change the driving gradients, producing changes in the direction or magnitude of the other flow components to compensate.

Under pre-development conditions, the groundwater system is presumed to have been in equilibrium conditions. Under such conditions, the amount of water held in storage, averaged over some period of time, is considered to be constant. Effectively, groundwater inflow over the averaging period is equal to groundwater outflow, water moves through the system in response to stable gravitational or pressure gradients, and the entire system is said to be in equilibrium.

Catchment development can alter all three of these components, effectively changing the driving gradients and moving the system from equilibrium. Storage is arguably the component of the water balance most directly affected by human activities, through removal of water via pumping. By removing a proportion of the storage component, changes to the driving gradients will be created, which can affect the direction and magnitude of water movement. The volume of water removed is balanced by a decrease in storage, an increase in recharge, a decrease in discharge, or some combination of all of these.

Recharge (inflows) can be also altered through developments that change streamflow patterns (e.g. farm dam development, channelisation or levee construction) or by altered land use (e.g. clearance of vegetation, contour banking).

Discharge can be affected by changes in the evapotranspiration rate of groundwater (e.g. afforestation, deforestation), or in response to changes in the other components. Changes to the inflow and storage components will likely also manifest in changes to the discharge component, and the effects of these changes should then be evident in the discharge characteristics of the system.

While the individual water-balance components are unknown, the above discussion does form a framework for consideration of potential impacts on the outflows, or discharge from the aquifer. If over the period of streamflow record any change in outflow can be considered only to be a result of changes in streamflow discharge (i.e. evapotranspiration discharges have remained constant and can be largely ignored), the baseflow component of the stream hydrograph represents a direct measure of this change. This is the subject of the following sections. Streamflow hydrograph analysis will not indicate whether perceived changes are due to changes in storage (as a result of pumping) or changes to recharge rates. This is important information, as groundwater that is effectively carry-over storage from a prior higher recharge period (often referred to as fossil water) cannot be withdrawn from storage without degrading the resource.

In assessments of groundwater sustainability, it is necessary to determine current recharge rates and the volumes of groundwater that are required to maintain dependent environmental assets at a low level of risk. Once these values are established, some proportion of the remaining volume can be determined that is available for human needs. The allocated volume will need to take into account the aridity of a catchment, and the irregularity of recharge processes. Hence, it will be necessary to ensure that storage is sufficient to prevent ‘mining’ of the resource (drawing down the aquifer beyond its capacity to recover) during extended drought conditions, preventing degradation or loss of the resource.

It is beyond the scope of this assessment to determine a quantitative water balance and sustainable yield for the Skillogalee Dolomite, but these are among the most urgent requirements for the catchment from an environmental perspective.

5.4 BASEFLOW ANALYSIS

Baseflow is theoretically defined as that part of the surface streamflow attributed to groundwater discharge to streams. In reality it is extremely difficult to exactly apportion the major components of a streamflow hydrograph — quick or overland flow; interflow or unsaturated flow through the soil; and saturated subsurface (groundwater) discharge.

In order to develop a quantitative understanding of the relative contribution of groundwater to streamflow at the gauging station, a baseflow separation was undertaken. This process can be highly subjective (Nathan & McMahon 1990) and numerous methods exist to achieve the separation. These can be divided into graphical and digital approaches.

Graphical techniques may produce more realistic separations for individual storm hydrographs, but are time consuming and not suited to analysis of continuous streamflow data (Chapman 1999). The methods are also relatively subjective compared to digital filters, which are commonly used in the case of continuous data. Two digital filters were applied to the Burra Creek streamflow data, with the output of the Lyne–Hollick filter (α = 0.925, Lyne & Hollick 1979) being preferred. The Chapman–Maxwell filter using recession constant values of 0.975–0.995 derived from streamflow hydrograph analysis (Chapman & Maxwell 1996) appeared to underestimate the baseflow during periods of zero rainfall, and hence surface runoff, and was not utilised in the assessment.

Although not as well founded on theoretical principles as the more recently developed Chapman–Maxwell method (see Grayson et al. 1996), the Lyne–Hollick filter is generally considered to rapidly and objectively produce similar results to graphical analyses (Nathan &

McMahon 1990), and has also been recommended due to its widespread application in other catchments, facilitating inter-basin comparisons (Evans & Neal 2005).

5.4.1.1 Data analysis

Following the baseflow separation filtering, baseflow was analysed for annual and monthly patterns and also for seasonality and trends.

5.4.1.2 Annual baseflow

Figure 34 shows the annual streamflow and estimated baseflow volumes, and the baseflow index (the percentage of total streamflow attributed to baseflow). As can be seen in the figure, the value ranges from ~20% in extreme years such as 1974 and 1992–93 to over 90% during low annual discharge years such as 1994 and 2001–02. When total streamflow and baseflow for the entire period are summed together as single volumes, the baseflow index is 40%, but the average annual baseflow index is 70%. This highlights the reliance of the creek on baseflow to persist in the great majority of years.

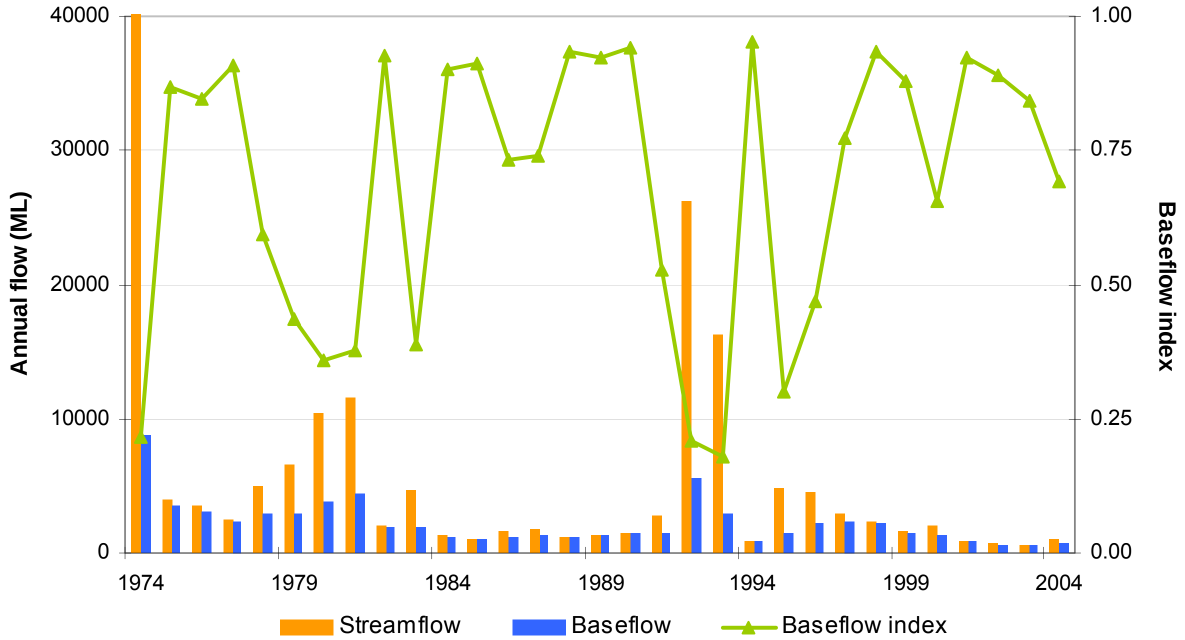

Figure 34. Annual streamflow, baseflow and baseflow indices, Burra Creek Catchment

5.4.1.3 Monthly baseflow

Baseflow was analysed for monthly patterns, and the mean monthly baseflow and standard deviation for the period 1974–2004 is shown in Figure 35. The highest monthly baseflows broadly reflect the highest streamflow months, with August, September and October dominating. This indicates that the apparently reliable streamflow observed during these months is attributable to baseflow rather than surface runoff. This has implications for the management of water resources in the catchment, as care must be taken to determine an appropriate level of streamflow upon which to base a permissible surface water yield. If the majority of streamflow is effectively groundwater, then the potential for double allocation of the same volume of water must be addressed.

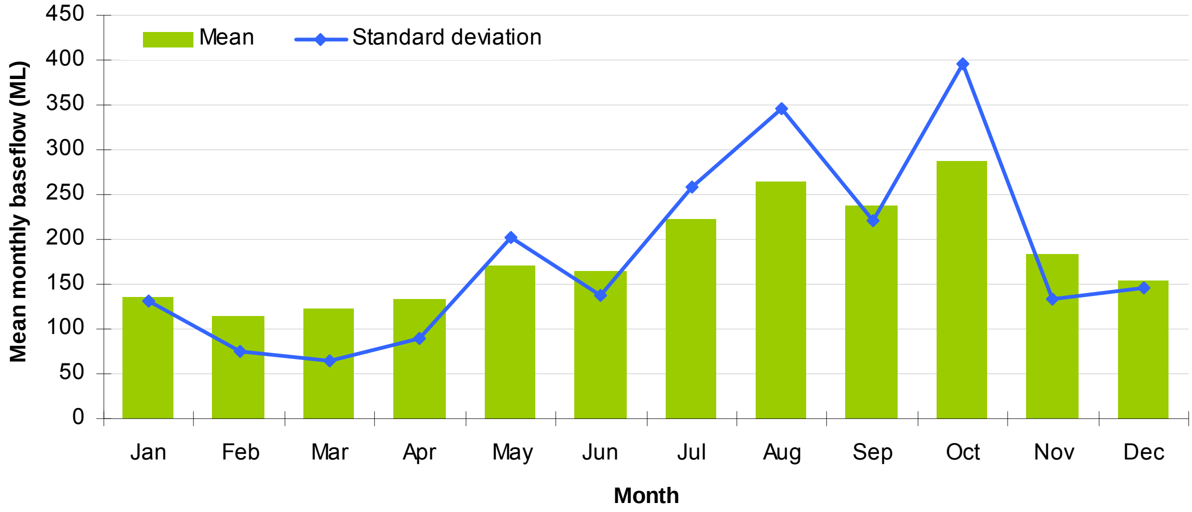

Figure 35. Mean and standard deviation, monthly baseflow, Burra Creek Catchment

5.4.1.4 Seasonality and trends

As was shown in Figure 29 (the daily streamflow record), baseflow exhibits a seasonal signal. Peak baseflow occurs typically during September–October and minimum discharges occur during the months of February–March. Seasonal variations in baseflow are usually attributed to increases in the watertable following the high rainfall winter season and the seasonal changes in evapotranspiration rate.

To examine the effects of evaporation, Figure 36 is a plot of daily baseflow at Worlds End and daily evaporation from Bundaleer Reservoir for the period 1974–92. Evaporation data have been smoothed using a five-day moving average to remove the noise. The figure clearly shows the ‘out of phase’ relationship between baseflow and evaporation where minima in one value coincide with maxima in the other. The precise mechanism of the interaction cannot be determined but it is to be expected that evapotranspiration from riparian vegetation and direct evaporation from the free water surface once spring flow enters the stream would both contribute.

No information is available to ascertain the relationship between watertable elevation and baseflow volume, but Segnit (1937) reported on information collected during the use of the Skillogalee Dolomite as a town supply and clear seasonal responses were evident. The fact that baseflows typically peak during October (two months after peak streamflow) suggest that both watertable elevation and evapotranspiration rate exert significant control over baseflow discharge volumes. The state of recharge of the aquifer is also highly important in this regard and the effects of rainfall and streamflow during the previous year on baseflow is discussed in the following section.

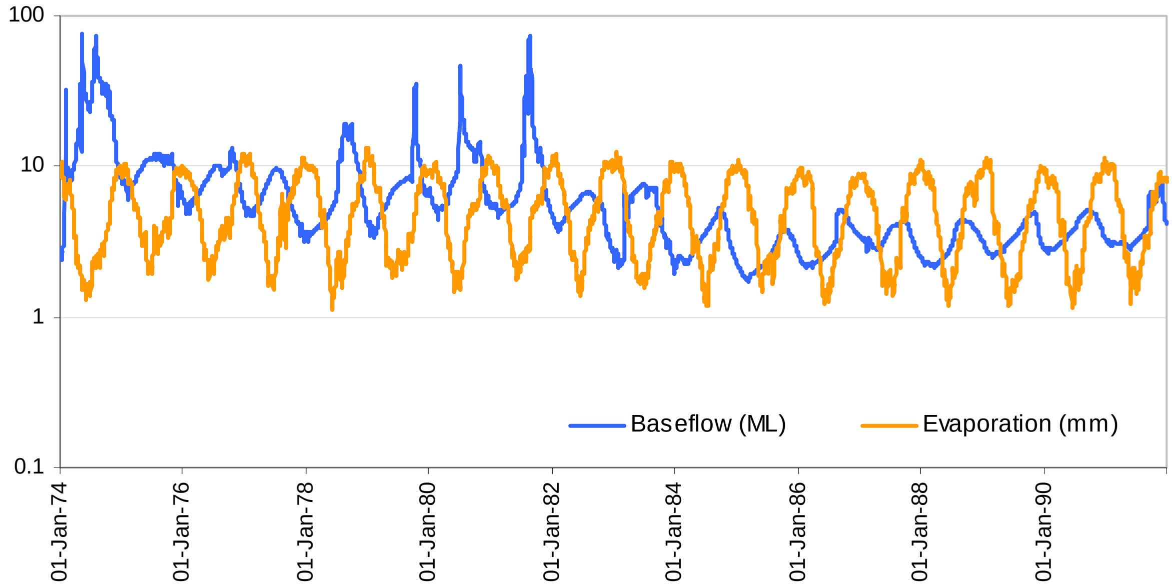

Figure 36. Daily baseflow (Worlds End) and pan evaporation (Bundaleer Reservoir) 1974–91

Figure 37 shows the daily baseflow and streamflow record. In many, if not most, years the baseflow contribution is a very significant proportion of total streamflow. The magnitude of groundwater discharge, and hence baseflow, is a function of the relative water level within the aquifer (and hence the volumes of both precipitation and streamflow received in the preceding period). Possible explanations for the variations in annual baseflow minima in Figure 37 (see also Section 4.3, Fig. 25) are now discussed.

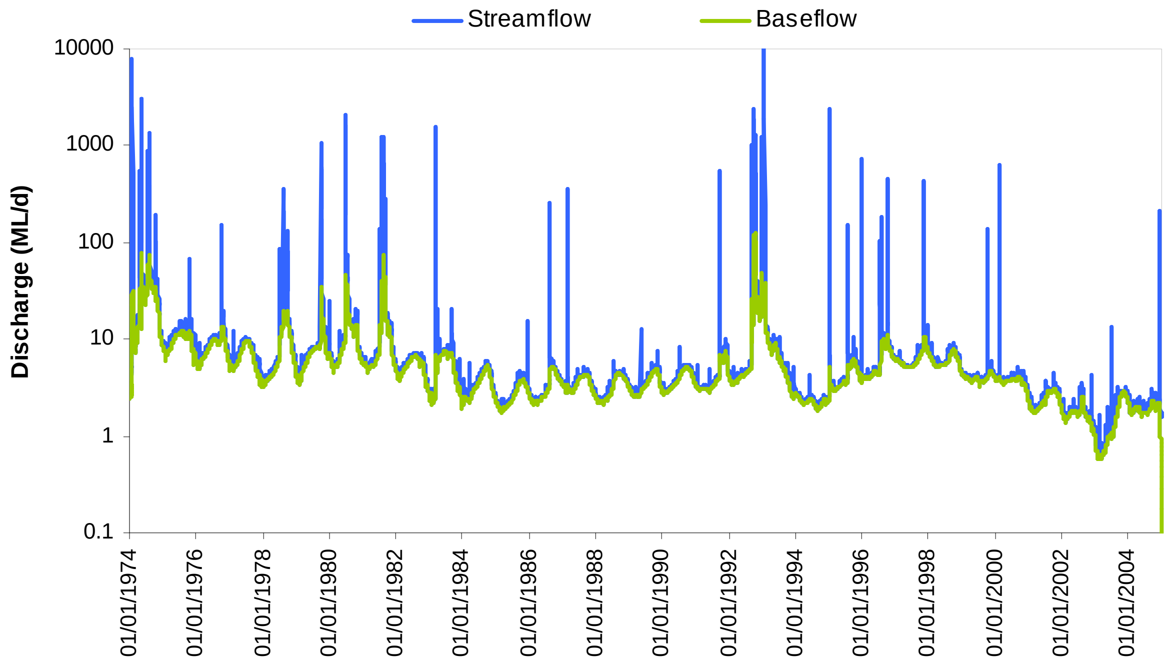

Figure 37. Daily streamflow and derived baseflow, Burra Creek 1974–2004

Following the very high rainfall received during 1974, a gradual decline in the minimum baseflow (and hence streamflow) level can be observed for subsequent years. This suggests that extremely high recharge occurred during 1974, which then gradually discharged over a number of seasons. This is supported by Read (1980) who reported a groundwater mound identified through potentiometric surface analysis in the vicinity of Burra in 1975. This mound subsequently decayed over a period of several years.

Minima continued to decrease up to January 1978. A gradual rise in watertables is suggested up until the early 1980s, corresponding with four consecutive years of above average rainfall during 1978–82.

The gradual incline in the annual groundwater discharge minima between around 1984 and 1991 corresponds with the period of time following mine de-watering, which ceased in 1981. The de-watering operation is not likely to have removed large volumes of groundwater as it is thought that much of the water discharged into the creek simply re-infiltrated through the bed (see Section 5). The continual pumping is likely to have reversed the gradient in the vicinity of Burra township, which may have had a similar effect on flow rates from springs in the down-gradient direction. It would seem likely that this increase represents a gradual return to a more natural watertable following the cessation of this removal of water as gravitational gradients were restored. It is of note that, if this is the case, it would have occurred despite six out of the eight years concerned receiving below average rainfall.

Data following 1992–93 becomes confused, with no apparent seasonal baseflow pattern. This is likely to be due to issues with the hydraulic response of the gauged reach due to excessive siltation. Although the data since this period for low flows are unreliable over recent years, the declining trend of baseflow minima from 1998 up to and culminating in the lowest flow gauging in 2003 is of concern. The prior year, 2002, received lower rainfall than all but 10 years in the 120 year record, and the very low flow observed may represent a decline in watertables as a result. If this is the case, it is notable that baseflow levels appear to have recovered since this time, but still do not demonstrate the seasonality evident prior to 1992.

Annual baseflow volumes show a statistically significant decreasing trend across the period of record, but again this result has a degree of uncertainty resulting from doubts over the recent gauging record. Future assessments need to firstly confirm whether flow levels have declined to the lowest on record, requiring re-establishment of the low-flow sensitivity at the gauging station. If it is confirmed that baseflow has reduced to record low volumes, the cause will need to be determined and, if due to human activities, it will be necessary to take appropriate action to ameliorate this impact.

5.4.1.5 Recharge processes

Recharge has been conceptually defined (Lerner et al. 1990) as being from one of three sources — direct recharge (from the vertical percolation of rainfall in excess of evapotranspiration); indirect recharge (percolation through watercourse channels during streamflow); and localised recharge (where surface depressions allow ponding of water in the absence of watercourse channels). Localised recharge is not considered further as topography does not appear to favour this in the vicinity of the Skillogalee Dolomite. The major potential recharge sources for the Skillogalee Dolomite are likely to be direct infiltration of some proportion of rainfall or percolation of streamflow through the bed or banks during flow events. It is the intent of this section to utilise the available data to explore whether any indication can be derived of the relative importance of these mechanisms.

Figures 38 and 39 show the five-day minima for baseflow observed during January to March for the period 1974–92 on the y-axis. Figure 38 plots these minima against the previous winter rainfall, and Figure 39 plots baseflow minima against log streamflow observed during the previous winter (here defined as July–October).

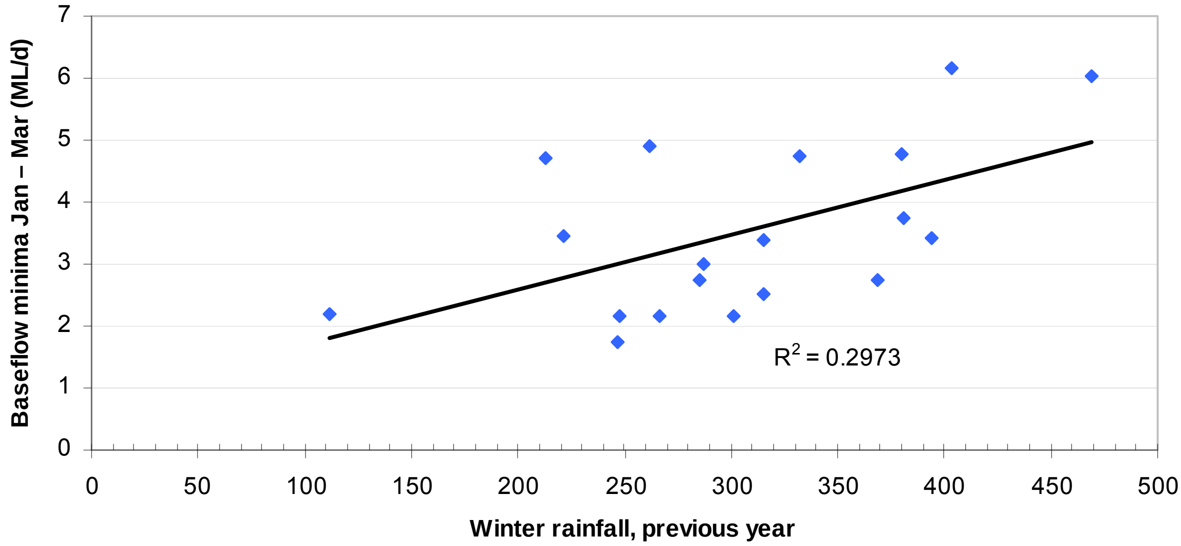

Figure 38. Five-day baseflow minima versus prior winter rainfall, Burra Creek Catchment

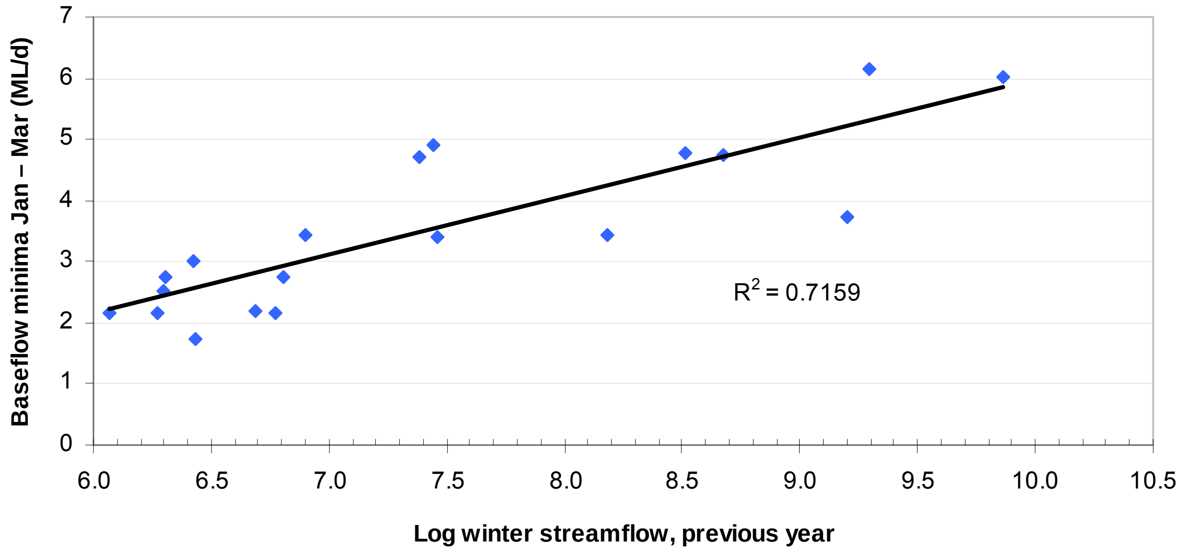

Figure 39. Five-day baseflow minima versus prior log winter streamflow, Burra Creek Catchment

A trend line fitted using least squares regression shows that a positive trend is evident between baseflow minima and both potential recharge processes, suggesting that higher winter rainfall and streamflow are both correlated with elevated baseflow during the following seasonal low. The trend between streamflow and baseflow minima is more clearly evident, implying greater importance. However, it should be borne in mind that some degree of streamflow persistence (i.e. the same process facilitating high streamflows is likely to produce subsequent high baseflows) will exaggerate this relationship, and the absolute contribution cannot be determined in this manner.

The analysis was repeated using the winter quickflow (streamflow minus baseflow) for the same period and produced an R^2 value of 0.63. These correlations also support streamflow as a significant recharge source for the Skillogalee Dolomite. Although this is not conclusive evidence, it is well known that in arid areas the high evapotranspiration rate can greatly reduce the volume of rainfall that will recharge to the aquifer, and increasing aridity tends to favour the indirect recharge mechanism (De Vries & Simmers 2002; Dingman 2002).

The geological setting also suggests that streamflow may provide significant volumes of recharge. For more than 20 km, commencing immediately upstream of the township of Burra, the creek and its many small tributaries flow over a zone of faulting within the highly transmissive Skillogalee Dolomite (Fig. 40). It is likely that the creek and other watercourses in fact follow this zone owing to the relative ease of erosion (T. Wilson, DWLBC, pers. comm., 2005). Where watercourses are spatially associated with faulting zones, relatively high recharge rates can be expected due to increased fracturing and higher loss rates through the stream bed.

Other evidence of the importance of streamflow for recharge can be found in some of the historical and more recent investigative reports reviewed. Durkay (2002) estimated bed losses from a 425 m section of the recreational lake upstream of the weir to be of the order of 368 ML/y, suggesting a high hydraulic conductivity.

Additionally, Read (1980) undertook a potentiometric surface analysis of the watertable in the vicinity of Burra, investigating declines over the five year period from February 1975 to February 1980. A lobe of watertable decline of ~1 m was observed to follow the creek to the north of the township, and was attributed to the creation of a mound of groundwater formed during the high rainfall year of 1974 and its subsequent decay. Declines in other groundwater mounds present near the creek from this extremely high rainfall year were also reflected in the analysis.

The importance of determining the major source of recharge relates to the potential for human impacts on this process. Section 6 on surface water modelling suggests that streamflow may have been reduced by 70–90% during dry years. Clearly, if farm dams and other catchment land-use activities have reduced streamflow by this amount, the indirect recharge that occurs as a result of this streamflow will also be reduced. The volumetric reduction may not necessarily be proportional however, as recharge studies in arid areas have found that extreme events generate large volumes of recharge due to overbank flows (Lange 2005). This further emphasises the need to undertake dedicated surface water – groundwater interaction investigations in order to better understand the water balance of the Skillogalee Dolomite.

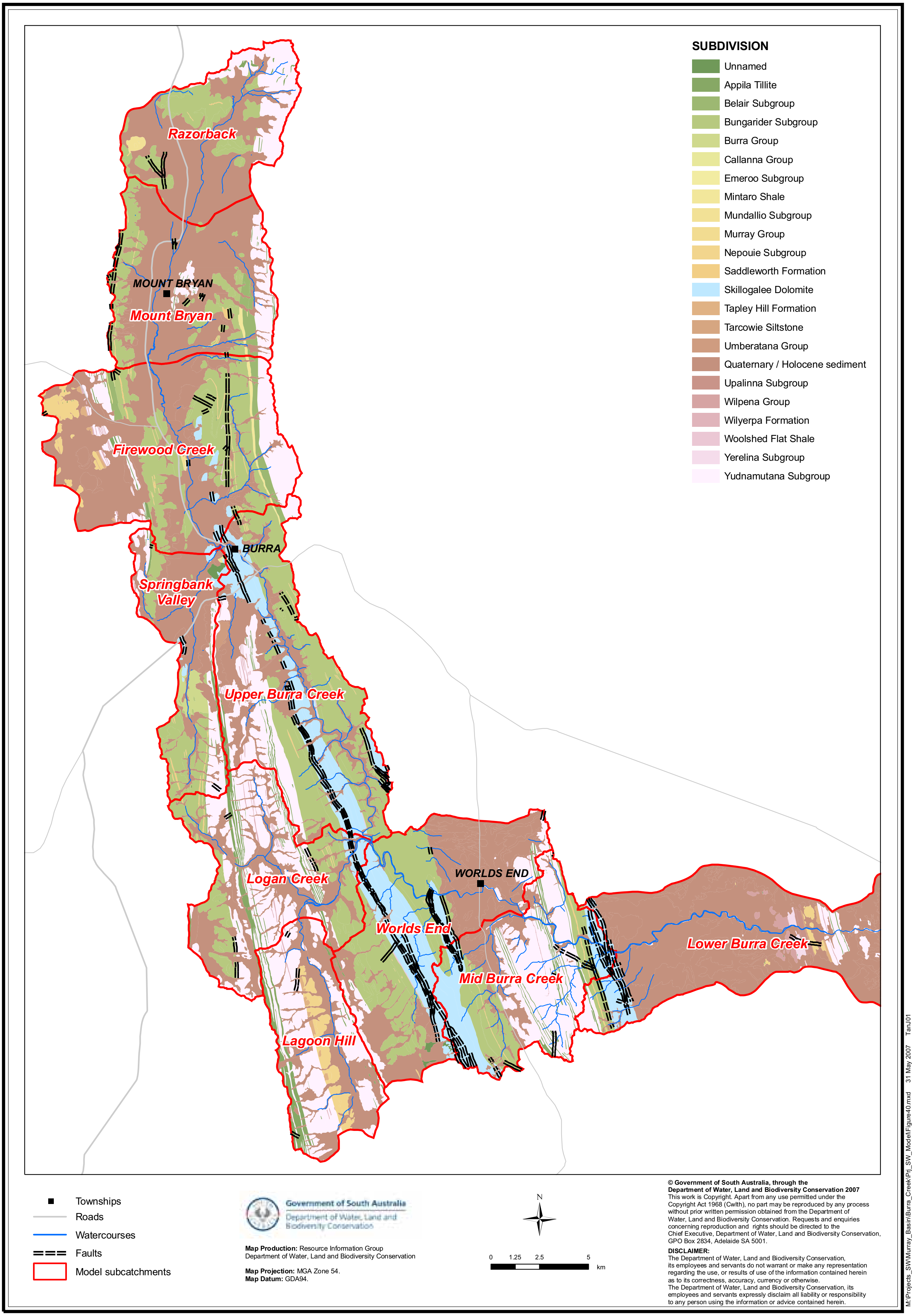

Figure 40. Broad geology and faulting, Burra Creek Catchment

6. SURFACE WATER MODELLING

6.1 OVERVIEW[2]

Hydrological computer models that can adequately describe catchment rainfall-runoff processes and incorporate current development levels provide a flexible means of determining the availability of surface water resources, predicting long-term catchment behaviour and estimating the impact development has on the natural flow regime. Such models also provide a tool with which to conduct environmental flows assessment, analyse the impact of potential future development levels and facilitate the assessment of various water management options.

For this study, long-term daily rainfall and discharge data and monthly evaporation data were used to calibrate a surface water model to simulate runoff data for the Burra Creek Catchment. This involved the following stages:

1. **Model Construction** — The spatial distribution of those physical features that control or influence the volume of runoff and its movement through a catchment were represented as a series of interconnected nodes, each representative of a small area of the catchment. Nodes are characterised by a series of mathematical equations that describe how water (rainfall, evaporation or runoff) moves into, is stored in and moves out of that node. The majority of nodes for a given catchment represent rural areas in which the transformation of rainfall into runoff occurs. This was carried out using a rainfall-runoff or conceptual water-balance model that simulated the physical processes of interception, evaporation, transpiration, infiltration, percolation, recharge and baseflow using a set of mathematical transfer functions linking a number of interconnected water stores.

2. **Model Calibration** — The water balance model parameters are estimated by an iterative process to best reproduce observed catchment behaviour. Input rainfall and evaporation data are transformed into computed runoff hydrographs that are then compared to observed hydrographs from recorded streamflow records. The parameter set that produced computed hydrographs that best represent the observed hydrographs were chosen as the optimal parameter set. The suitability of a particular water balance model and the efficiency of the calibration process is highly dependent on data availability. The less data that are available the less complicated the water balance model should be if reasonable calibration is to be obtained.

3. **Scenario Evaluation** — The calibrated model was used to generate synthetic runoff data under current catchment conditions and also for pre-development conditions. This allowed an evaluation of the effect that current development levels have had on the natural flow regime.

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[2]This section has been modified for use from Heneker (2003).

6.2 MODEL CONSTRUCTION[3]

The WaterCress (Water — Community Resource Evaluation and Simulation System) modelling platform (Clark et al. 2002; Cresswell 2002) was used to construct a catchment model for the Burra Creek Catchment. In recent times, WaterCress has been used for a number of other catchment studies in South Australia (e.g. Savadamuthu 2002; Teoh 2002; Heneker 2003) because it allows flexibility in the description of catchment attributes such as rural and urban areas, diversion weirs, water supply infrastructure, farm dams and reservoirs, aquifers, wetlands, and sewage treatment works. It also contains a number of water-balance models for rainfall–runoff transformation in rural and urban areas.

The methodology for constructing the model in this study involved:

- division of major sub-catchments into minor sub-catchments
- calculation of dam storage, surface area, diversions and water usage within each minor sub-catchment
- representation of the spatial relationship of minor sub-catchments and farm dam storages as a series of interconnecting nodes
- preparation of daily rainfall and evaporation data files, and quantification of rainfall spatial variability
- preparation of daily streamflow data files for model calibration
- selection of water-balance models for rainfall–runoff transformation.

Once the model has been constructed, the calibration of water-balance model parameters is undertaken.

6.2.1 MODEL SUB-CATCHMENTS

The gauged catchment sub-catchments used for modelling are shown in Figure 4. These sub-catchments were based on general topographical divides and, where present, significant on-stream dams. Each sub-catchment is represented by a rural catchment node in the model. Farm dams were collated into a single storage and represented as an off-stream dam node within each sub-catchment, and a proportion of the runoff is diverted into these to simulate their influence on hydrology.

6.2.2 FARM DAM ATTRIBUTES

The streamflow data used to calibrate the catchment model have been influenced by farm dams. This influence changes over the period of observed records, as new dams are constructed. Due to the low catchment yield in dry years relative to current storage, these years will proportionally demonstrate a greater impact than is likely to have occurred. Due to a lack of historical information with which to estimate incremental dam development during this period, it was necessary to use the full storage volume as determined during this study from aerial photographs captured during January 2005.

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[3]This section has been modified for use from Heneker (2003).

The farm dams within each model sub-catchment are represented in the model by off-stream dam nodes. This representation has a number of important characteristics:

1. For each dam node, the capacities of all farm dams within the represented minor sub-catchment were aggregated to form a single storage. A proportion of the runoff occurring from the rural catchment node (rural area within the minor sub-catchment) was then diverted into the dam. This proportion is dependent on the location of the dams(s) and hence the catchment area draining into the dam(s). For example, an on-stream controlling dam will capture 100% of runoff from the upstream catchment and therefore the diversion to this dam would be 1.0 if this dam lies on the downstream catchment boundary. However, if the dam is located partway up a stream branch, then a smaller proportion of runoff from the total minor sub-catchment will enter the dam. Similarly, when the total storage comprised numerous truly off-stream dams spread throughout the model sub-catchment, less than 100% of the total runoff will be captured and the diversion will be less than 1.0. The maximum daily diversion to a dam is assumed to equal the capacity of the dam.

2. The total surface area for the aggregated dam storage is the sum of the surface areas for each individual dam. The surface area and dam capacity were then used to determine an approximate surface area to capacity relationship using the following relationship:

$$V = F_1 A^{F_2} \tag{1}$$

where:

$V =$ volume/capacity (ML);

$A =$ surface area (m^2); and

$F_1, F_2 =$ parameters.

F_2 was left at a constant value of 0.9505 based on the findings of other studies (see Risby et al. 2003). A value of F_1 was then calculated for each dam node. Calculating values of F_1 for each dam node ensured that when the aggregated dam was full, the surface area calculated by this equation was equal to the surface area of the aggregated dam.

The amount of water used annually was estimated at 30% of the total dam capacity, as no significant water-use activity such as irrigation was identified. This use of farm dam water was assumed to occur year round. There is very little recorded information on water use from farm dams, but field surveys and inspection of the aerial photography taken in February 2005 showed the majority of dams to be empty or nearly empty. This is assumed to be due to evaporative losses more than extractive use however, which is incorporated in the model as described above.

6.2.3 RAINFALL SPATIAL VARIABILITY

The WaterCress modelling platform allows a rainfall record to be linked to each rural, urban and dam node and a rainfall factor applied. By applying a different rainfall factor to each node, and hence each modelled sub-catchment, it allows the data from the rainfall stations presented in Section 4 to be adjusted and therefore incorporate rainfall spatial variability.

The relative position and values of the rainfall isohyets shown in Figure 10 were used to determine the appropriate rainfall factor. The factor was defined as the ratio of the isohyet passing through the sub-catchment to the isohyet passing through the rainfall station. For example, if the isohyets passing through the sub-catchment and rainfall station were equal to 400 mm and 350 mm respectively, then a rainfall factor of 1.14 would be applied to the data from the rainfall station.

Appendix B presents information relating to each model sub-catchment including the mean rainfall adopted, BoM station data utilised and resulting rainfall factors.

6.2.4 RAINFALL-RUNOFF MODEL

The water-balance model chosen to transform rainfall into runoff for rural sub-catchments was WC-1. The model schematic and parameter descriptions are provided in Appendix H and I, respectively.

6.3 MODEL CALIBRATION

The completed model was calibrated using a combination of automated and manual techniques to determine the optimum values for the required model parameters. Both procedures are iterative, where different combinations of sets are trialled, and the results compared to produce the best possible fit between observed and modelled data.

Calibration of the WaterCress project with the WC-1 rainfall-runoff model was carried out by using a combination of manual adjustment of parameters initially fitted using the NLFIT optimisation program (Kuczera 1994). NLFIT is a Bayesian non-linear regression program to which specific model algorithms or executable programs can be added and subsequently calibrated. The WaterCress program was linked to NLFIT, and used to calibrate daily, monthly and yearly flow values, and the daily flow duration curve.

The appropriateness of the calibrated parameters was assessed by comparing the values predicted by the model to observed data at annual, monthly and daily time scales in addition to correlation statistics. These statistics are used to determine how well a model is able to reproduce the observed data. Two common statistics for this assessment are the coefficient of determination (R^2) and the coefficient of efficiency (E).

6.3.1 OBSTACLES AND TRADE-OFFS IN MODEL CALIBRATION

A 31 year period of continuous streamflow data was available with which to calibrate the model. Three aspects of the data in particular made actual calibration of the model problematic, and these are discussed along with other less significant limitations below.

The first problem faced was the continuous baseflow present at the site, and more particularly the large proportion of the total streamflow volume that this represents (an average of 70% of annual streamflow; see Section 5). The WC-1 rainfall-runoff model has only a limited capacity to simulate baseflow, as it was not a key requirement for the model, which was developed to simulate rainfall-runoff processes. Although there is a parameter controlling the rate of groundwater discharge, it generates only a simple linear response to the volume held within the groundwater store. It was not possible to maintain groundwater at a sufficient flow volume to reproduce observed streamflows, and also to recharge the groundwater store, without introducing an extremely large initial volume held in groundwater storage. Although in effect this appears to be the physical reality of the catchment (that a large groundwater storage supports the permanent baseflow), any assignment of an initial storage volume would need to be based on purely speculative values rather than those underlying physical realities, which are not fully understood. This approach also has the potential to destabilise the model considerably, and it was clear early in model development that it would not be possible to reproduce the permanent baseflow.

The main aim of the project was to establish the surface runoff response of the catchment to rainfall events in order to determine if farm dam development is significantly impacting on streamflow. It was therefore necessary to remove the influence of the baseflow in order to determine the rainfall-runoff response of the catchment, and this was done using two different approaches. Firstly, the model was calibrated against only flow volumes exceeding a pre-determined threshold to remove the baseflow component, but the problem with this approach was determining a suitable threshold volume above which flow could be attributed purely to quickflow. As illustrated in Section 5.4, baseflow volumes vary considerably throughout the year, and a single threshold could not be determined.

A compromise solution was to calibrate the model against the quickflow component resulting from the baseflow separation initially, and check this calibration against natural flows above the threshold of the median flow of 4.4 ML/d. The calibrated model was capable of reproducing natural flows to an acceptable standard, but it is acknowledged that the outputs of a digital filter separating the quickflow component introduces further uncertainty in the analysis, and any future modelling should allow sufficient development time to reproduce the baseflow component within the modelled environment. With the available data, this was considered the best approach to meet the aims of the exercise — to gain an understanding of catchment yield against which to assess the likely impacts of farm dams on surface runoff processes.

The second major difficulty lies in the uncertainties in the data following the siltation of the site in 1992. Despite a range of approaches such as data filtering and baseflow separation being attempted, it was not possible to produce a calibration that could adequately reproduce streamflow in the catchment since 1992. The final calibration was optimised for the reliable streamflow data from 1974 to 1991, and produced good results for the calibration period and acceptable results across the full period of record. The model was only capable of reproducing the streamflow of recent years to a limited degree. This is thought to be due to a combination of the shifts in rating and the extremely low runoff that has occurred during this period. The loss of sensitivity is extremely unfortunate, as catchment management is thought to have changed over this period, with improved management techniques such as contour banking to increase infiltration into soil profiles. Without reliable data it is not possible to evaluate the changes to catchment runoff response, which may have compounded any reduced streamflow resulting from farm dam developments. A future priority for the management of the catchment must be to return the low-flow sensitivity of the surface water gauging site to enable a detailed analysis of the catchment response.

The third major limitation of this work relates to the lack of knowledge of historical levels of farm dam storages. Current estimates are based on development levels in 2004, but in earlier periods fewer dams were present and these clearly had a lower impact. To simulate the increases in dam development described by landholders over recent years, all dam storage volumes were reduced to 50% of current levels in 1974 as a starting point, and storage capacity was incremented annually by 1.6% of current to simulate increasing development over time. Future studies may be able to access earlier data and estimate the rate of dam development more closely and hence reduce this uncertainty.

A relatively minor but still significant uncertainty observed during calibration of the model was a lack of daily evaporation data, the use of which should in general improve the performance of the model. However, the daily data from Bundaleer Reservoir was found not to perform as well as monthly averages of the same data. There may be several factors contributing to this, notably the influence of rainfall intensity on generating runoff events. It is likely that the conditions at Bundaleer, which is ~30 km west of the Burra Creek Catchment centroid, do not generally reflect those of the catchment itself. Improved estimates of evaporation through measurement of this parameter within the catchment is recommended for future refinement of the model.

Although a natural feature of the catchment, another factor that affected model calibration was the number of extreme summer storm events. The daily time step model is not capable of reproducing the effects of rainfall that generate runoff by exceeding the maximum infiltration rate of unsaturated soil (Hortonian runoff). The mechanism used in the model is the tracking of soil stores, and runoff is only generated once soil stores exceed capacity. The only manner to address this is to collect rainfall intensity data and utilise an hourly time step model.

A final limitation in the model is the very limited stream gauging network for the size and complexity of the catchment. Although the model estimates the runoff in the catchments to the north of Burra township, these estimates are based only on catchment characteristics such as area, rainfall and evaporation. It is unlikely that the upper catchment responds to rainfall in exactly the same manner as the central catchment, but as no data were available to fine tune the model, all sub-catchments were fitted with the same parameter set, reflecting a catchment-wide average response. This can only be addressed in future modelling exercises if monitoring sites gauging streamflows from smaller sub-catchments within central and northern Burra Creek are established.

Despite the limitations of the model, the final calibration statistics and general model performance are considered adequate for the purposes of this preliminary study. Any future work intending on refining the estimates herein will need improved rainfall intensity, evaporation and streamflow gauging data. In addition, it will also require a quantitative understanding of surface–groundwater interactions, particularly those associated with the Skillogalee Dolomite to develop a suitable approach to deal with the permanent baseflow.

6.3.2 CALIBRATION RESULTS

Annual, monthly and daily time series as well as flow durations were used as indicators of the match between values predicted by the model and observed data. Modelled and observed data statistics are shown in Table 10.

The model produces a good correlation between observed and modelled flows at an annual and monthly time step. The relatively low value for the coefficient of efficiency is related to the inability of the model to reproduce the baseflow component, and as a result it also underestimates flow volumes by ~24%. This is not seen as being problematic, since the model reproduces surface runoff processes well. Correlation between daily values is not as good, but this is to be expected given the daily sampling frequency requiring the

Table 10. Correlation statistics for the final parameter set, Burra Creek WaterCress model

Time step	Coefficient of determination	Coefficient of efficiency
Annual	0.97	0.86
Monthly	0.90	0.80
Daily	0.82	0.66

aggregation of rainfall and streamflow data to a single value representing a 24-hour period. The R^2 and E correlation statistics indicate that the model performs adequately for the purposes required.

Figure 41 shows the daily flow duration curve for observed and modelled streamflow data for the Burra Creek gauged catchment over the period 1974–91. This chart highlights the issues associated with the permanent baseflow, which the model was not capable of reproducing. Section 5 demonstrates that up to 95% of streamflow in a dry year is due to baseflow alone, and the average annual groundwater contribution to gauged flow is estimated at 70%. The majority of streamflow events occur within the top 20% of flows, and the model is capable of reproducing a close fit to the observed data within this range of flows. The difference between the modelled and observed data over the remainder of the curve reflects the influence of baseflow on the recorded streamflows.

Figure 42 shows the daily observed and modelled runoff for 1974, indicting that the model is capable of reproducing catchment responses to rainfall reasonably well. In general, years where rainfall was above average resulting in significant surface runoff and streamflow were reasonably well reproduced.

The monthly response of the model is shown in Figure 43. Although the absolute values differ considerably in some months, broad seasonal patterns are reproduced reasonably well. This is an important requirement to be able to assess changes to seasonality of streamflow resulting from farm dam development. Most months have a lower value than the observed, reflecting the importance of baseflow in maintaining streamflow. This is particularly true of November and December, where mean flows are underpredicted by ~80%. The notable exception to the underestimation of flow volumes is June, which is overestimated.

Most months have a correlation of greater than 0.8, the major exceptions being November and December for reasons already discussed. August also has a lower correlation, which is attributed to the latter years of the calibration period where the model predicted a number of large runoff events that were not observed.

Given the limitations of the available data and semi-arid nature of the catchment, the model was considered capable of reproducing observed streamflows to a level warranting its use in quantitative assessments of the impacts of farm dams. The calibrated model was used to evaluate the impacts of current catchment development levels by comparing the observed runoff with that of a catchment with the effects of farm dam storage removed. The following chapter focuses on a comparison of the observed level of farm dam development with sustainability benchmarks in use on other catchments within the South Australian portion of the Murray-Darling Basin. Further use of the model is made in Section 8 (Environmental water requirements) to assess the level of stress that current development levels may be exerting on aquatic ecosystems.

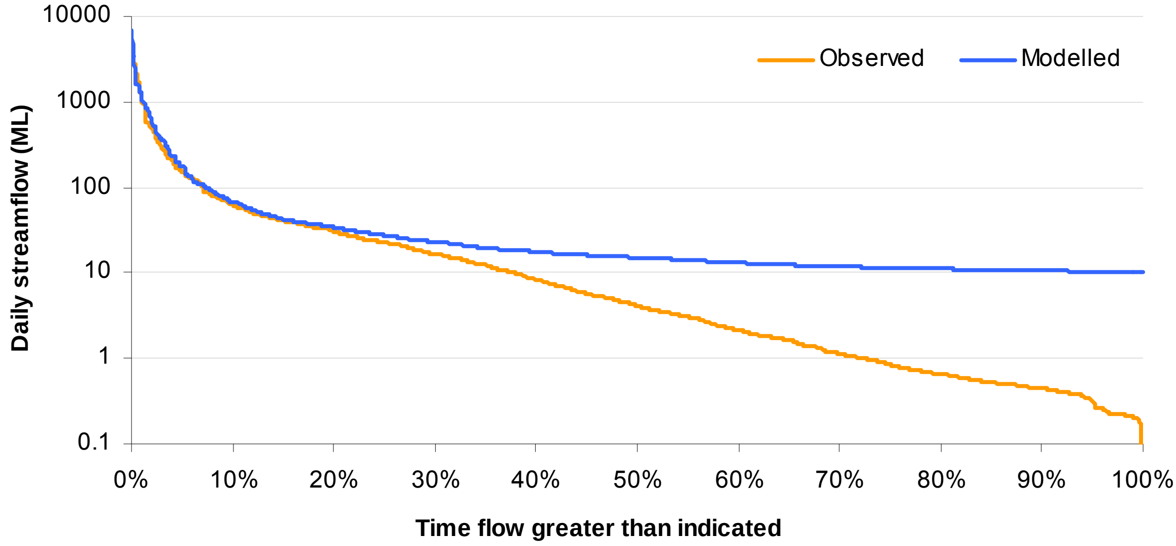


Figure 41. Daily modelled and observed streamflow flow duration curve, Burra Creek Catchment

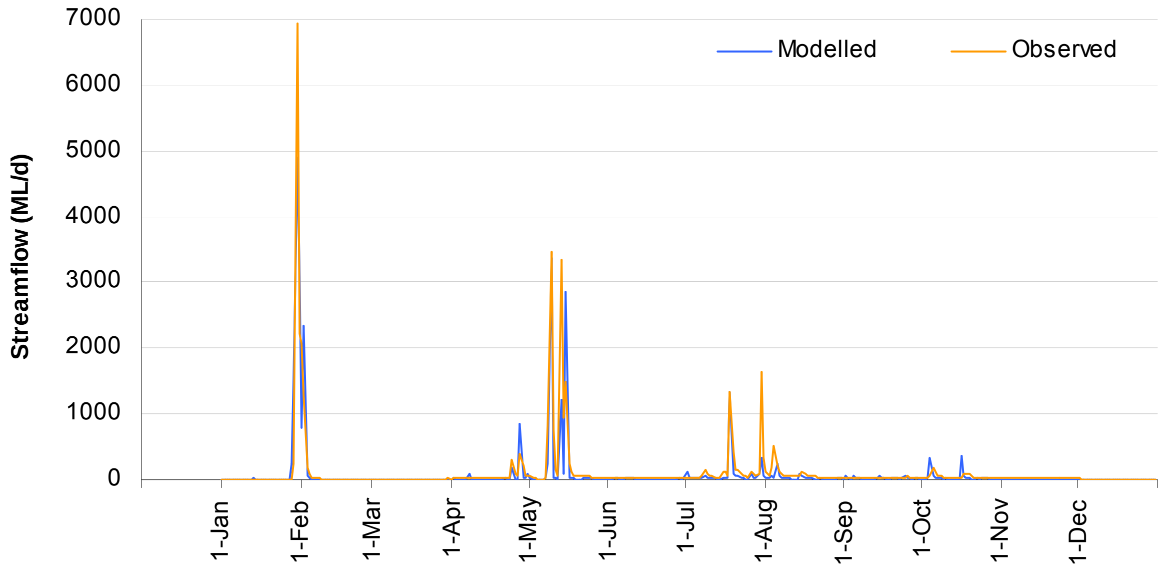


Figure 42. Daily observed and modelled streamflow, Burra Creek, 1974

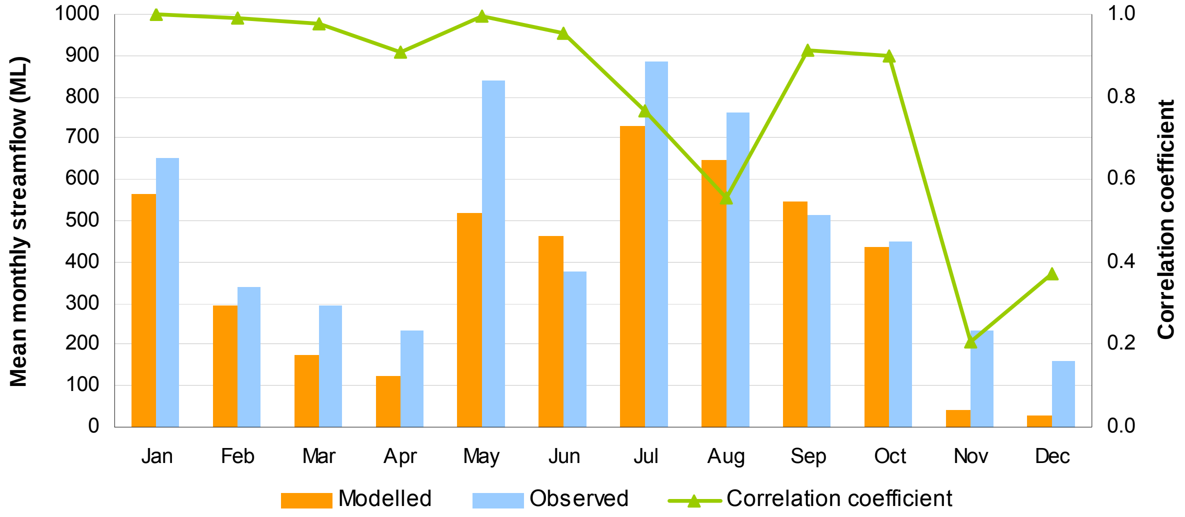


Figure 43. Observed and modelled monthly mean flows and correlation, Burra Creek, 1974–91

7. FARM DAM IMPACT MODELLING

7.1 METHODOLOGY

7.1.1 ADJUSTED RUNOFF

Observed runoff data from the gauging station includes the influence of farm dams to varying degrees. Farm dam data were only available for this study for a single point in time and the growth in farm dams during the period of streamflow records (1974–2004) is not known. As discussed in Section 6.3, this was addressed by a linear increment in annual farm dam volume.

To estimate the runoff from the catchment that would have occurred over the period had no farm dams ever been constructed required the use of two modelled scenarios. The model was firstly run with the incremental volumes discussed above. Dam storages were then removed from the model and it was run again. The difference between the two sets of data is considered to represent the best possible estimate of the capture volumes of the farm dams. This volume was then added to the observed runoff data for the period 1974–2004 to estimate the volume of water that would have flowed through the catchment without the influence of dams. This volume is referred to as the 'adjusted runoff' and is used in the following analyses.

Clearly there are a number of uncertainties in the approach, notably the actual levels of farm dam development and the poor streamflow data quality in the period 1992–2004. Little can be done with regard to the streamflow data, except to return low-flow sensitivity and re-assess the rating shifts to see whether some improvement is possible. With regard to historical farm dam storages, future studies may be able to obtain historical aerial photography and determine an improved pre-2004 volume estimate in order to more accurately evaluate the increase in farm dam capacities. In the absence of any such data, the use of a volume equivalent to 50% of current capacity, although effectively arbitrary, still provides some representation of the increase in dam volumes over time.

The adjusted and observed streamflow data were initially analysed at annual, monthly and daily time steps at the whole-of-catchment scale. In order to analyse the spatial distribution of farm dam impacts on runoff at sub-catchment and reach scales, the adjusted volume for the catchment as a whole was subdivided. To achieve this, the proportion of total adjusted catchment yield attributed to each analysis zone was determined based on the relative area and average rainfall of the zone.

7.2 IMPACTS OF FARM DAMS

7.2.1 IMPACTS ON STREAMFLOW

7.2.1.1 Annual streamflow

The adjusted mean annual catchment yield for the period 1974 - 2004 was 6569 ML. Figure 44 shows the observed and adjusted annual streamflow volumes for the period 1974–2004. The percentage reduction in annual flows is also shown and reveals that dams have relatively little impact during high flow years. The reduction in annual catchment yield varies from 6% to almost 70% of total streamflow. As would be expected intuitively, in dry years the impact of dam storages is much greater than during wet years.

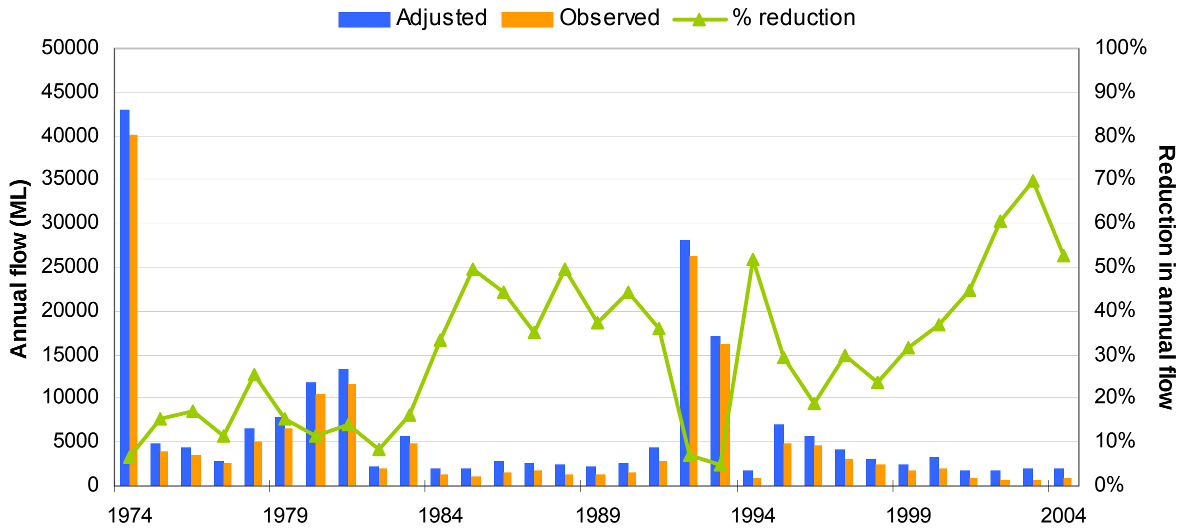


Figure 44. Annual adjusted and observed streamflow and percent reduction, Burra Creek Catchment

7.2.1.2 Monthly streamflow

Figure 45 again shows the adjusted and observed streamflow and percentage reduction, but this time on a monthly time step. The percentage change to streamflow is spread throughout the year rather than being focused in dry months as in generally found. This is likely an indication that farm dams are rarely full to capacity and will capture runoff even during the winter–spring months in the majority of years. The reduction in mean monthly flows varies from ~5% to more than 35%. June is clearly the month that is impacted the most, with a 37% reduction in mean flow predicted by the modelling. The observed mean monthly flow for June (Fig. 26) is the same as for May, and it appears that the reason for this may be related to farm dam interception of early season runoff. This delay in the onset of streamflow is a typical impact of this type of development and is thought to be a significant environmental impact.

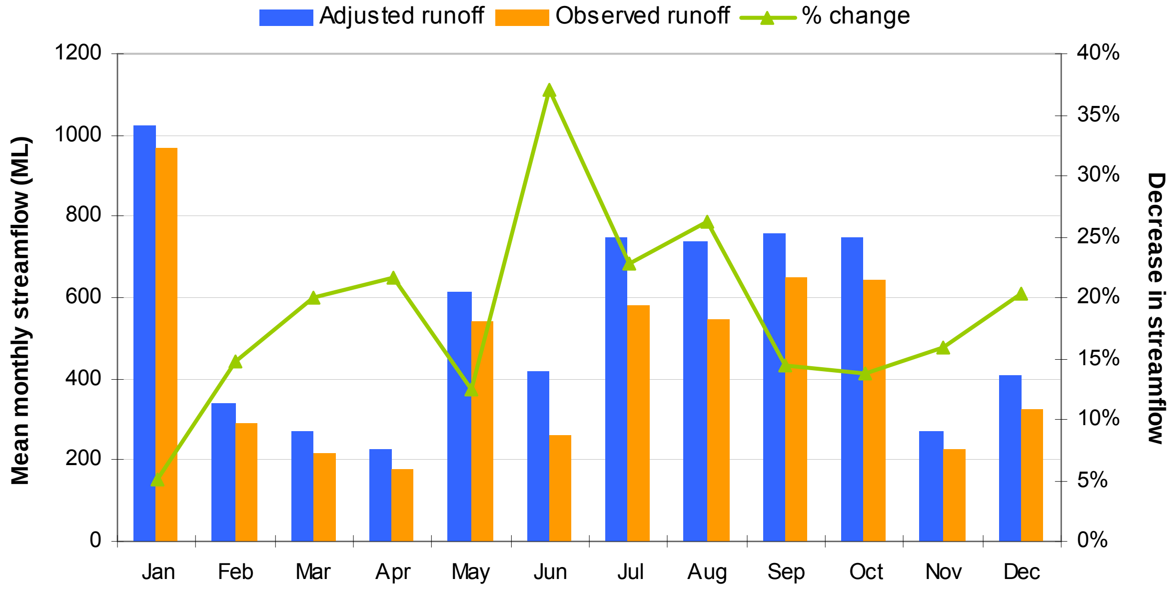


Figure 45. Mean monthly observed and adjusted runoff, Burra Creek Catchment

7.2.1.3 Daily streamflow

Impacts on daily streamflow were assessed through the creation of a daily flow duration curve. Figure 46 shows these data for the adjusted runoff dataset for the period 1974–2004. The adjusted flow (red curve) demonstrates a slight decrease in all but the top few percent of daily flows. Median flow is estimated to have been reduced from 5.8 ML/d under natural conditions to 4.4 ML/d under the actual farm dam development. The most striking feature of this figure however, is the large influence of the underlying baseflow volume on daily flows. As the adjustment volume is simply added to the existing streamflow volume, the overall shape of the flow duration curve still follows the observed shape.

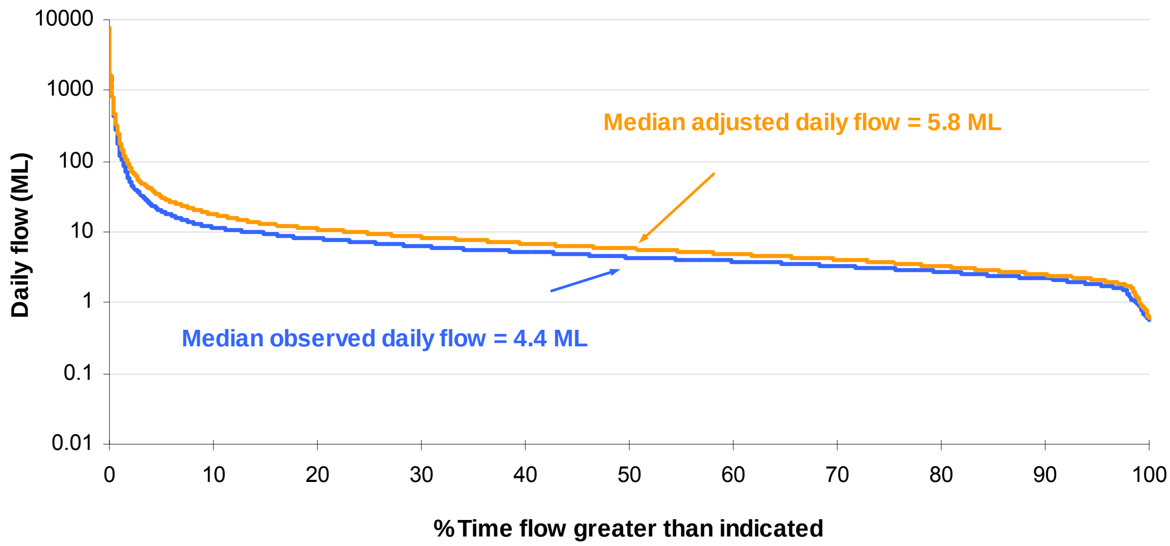


Figure 46. Flow duration curve — adjusted streamflow, Burra Creek, 1974–2004

As a result of this, and in order to gain an appreciation of the actual interception of surface runoff by farm dams, the analysis was repeated using the separated quickflow component (Section 5) as representing the natural conditions. The resulting analysis, shown in Figure 47, probably provides a better indication of the changes to surface runoff processes that have resulted over the period of interest. The figure suggests that the median flow volume has been more than halved from 0.5 to 0.2 ML/d, and that periods of no flow have been increased by around 40 days per year. While impacts on low flows in the catchment are perhaps predictable, of interest is that the impact is apparent on all but the very highest daily flows. This highlights the modest volumes of surface runoff that are generated in the catchment and further demonstrates the contribution that baseflows make to total streamflow.

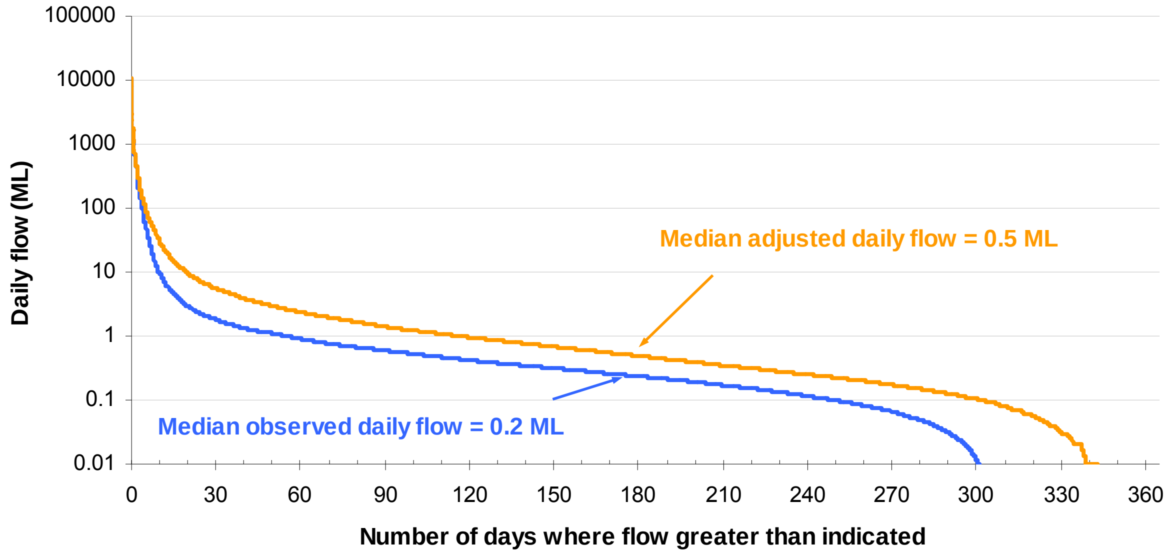


Figure 47. Daily flow duration curve — adjusted and observed quickflow, Burra Creek, 1974–2004

7.2.2 BENCHMARKING DEVELOPMENT LEVELS

For the purposes of comparing the current estimated use with that which might be considered sustainable from the water resource policy perspective, two state benchmarks are available.

The *State Natural Resources Management Plan 2006* sets a guideline for catchment surface water development outside of prescribed areas, generally referred to as the '50% rule'. Where no water allocation plan, applies the rule states that property scale farm dam capture should not exceed 50% of the median adjusted annual runoff for that property. The term 'adjusted' refers to the pre-development volumes of catchment runoff, such as have been estimated in this study through the use of the surface water model.

The former River Murray Catchment Water Management Board, now replaced by the SA MDB NRM Board, has a policy within their catchment plan allowing for permissible farm dam runoff capture levels to be up to 30% of the long-term average winter runoff, with winter being defined for this purpose as being from May to November inclusive (hereafter called the '30% rule').

Prior to presenting the results of a comparison against this criteria, it is important to recognise that the adjusted runoff used to develop the permissible volumes includes the baseflow component of streamflow. This is the usual practice, but in the case of Burra Creek the contribution is very significant; calculated on a yearly basis, the average baseflow component is 70% of the total streamflow volume. Inclusion of this component therefore greatly increases the permissible volume, yet it is unknown what proportion of this volume may have entered groundwater by direct infiltration and in effect never comprised part of the surface water resource. The implication is that this volume may be 'double accounted' if used for the determination of permissible surface and, in future, maximum groundwater extraction volumes. This highlights the need for improved understanding of surface–groundwater interactions and for the conjunctive management of water resources in the catchment.

Adjusted runoff volumes generated by the combination of the model output and the streamflow record were only available for the whole catchment, as only one gauging location was available. At the whole-of-catchment scale, development appears to be within both criteria (Table 11), but this masks over-developed areas within the catchment. In order to allow a more detailed spatial analysis of the extent of dam impacts, this volume was proportionally divided between the model sub-catchments using catchment characteristics such as area and average rainfall.

Table 11. Comparison of farm dam storage and sustainability benchmarks, Burra Creek gauged catchment

Catchment name	**Total dam storage** (ML)	**Total permitted 30% rule** (ML)	% of allowable 30% rule	**Total permitted 50% annual median runoff*** (ML)	% of allowable 50% rule
Burra Creek gauged catchment total	985	1289	76	1536	64
Razorback	102	122	83	146	70
Mt Bryan	174	148	117	177	98
Firewood Creek	120	239	50	284	42
Springbank Valley	95	110	87	131	73
Upper Burra Creek	172	213	81	253	68
Logan Creek	100	161	62	192	52
Worlds End	107	174	62	207	52
Lagoon Hill	113	117	97	140	81

7.2.2.1 Analysis of model sub-catchments

Table 11 provides a comparison between the estimated current dam storage in each modelled sub-catchment and the allowable volumes using the two sustainability criteria discussed above. Mount Bryan is above the 30% rule development levels, and fully developed according to the 50% rule. Lagoon Hill should be considered to be fully developed under the 30% rule, and effectively three further sub-catchments — Springbank Valley; Razorback and Upper Burra Creek — all have development levels that are of concern given the uncertainties in the analysis.

7.2.2.2 Reach-scale sub-catchments

More detailed spatial representation of dam stress levels was undertaken through proportional division of the estimated adjusted runoff volumes for each model sub-catchment into reach-scale areas. These are shown in Figure 48 along with the nomenclature adopted for each sub-catchment.

Reaches are colour coded to indicate the current farm dam storage capacity in comparison to the SA MBD NRMB 30% rule. Areas of highest concern are shown in red, indicating over 100% of the estimated allowable capture volume under the rule, and orange, which indicates a capture volume of 75–100% of the allowable maximum.

Farm dam capture in the upper catchment appears to be of the highest concern. Areas of the central catchment have only low development levels, which is probably indicative of the importance of the permanent water found through this area for stock water, meaning that there is little to be gained by construction of dams for this purpose.

Appendix B shows further comparative statistics relating to the spatial distribution of farm dam density in the catchment. Included in the table is a comparison of the level of farm dam densities in the reach-scale subdivisions of the gauged catchment. The densities range from less than 0.5 to over 7 ML/km^2, with the highest densities found in sub-catchments MTB5 and LOG5. Average storage capacities of dams within each sub-catchment are also shown; the largest average dam size is in LOG5 (6.2 ML) and RAZ1 (4.0 ML).

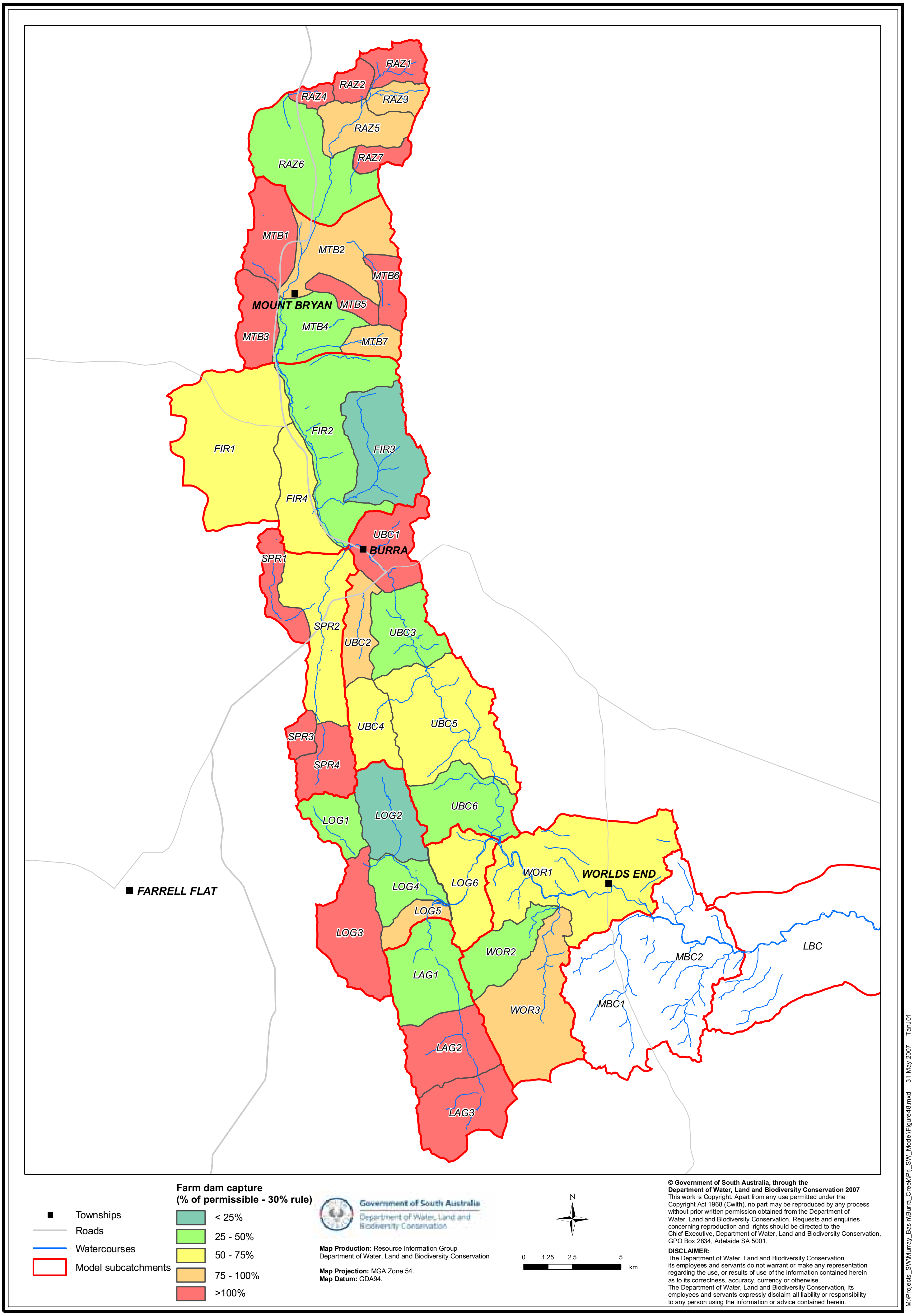


Figure 48. Farm dam development levels, Burra Creek Catchment

8. ENVIRONMENTAL WATER REQUIREMENTS

8.1 APPROACH AND LIMITING FACTORS

This section examines the potential impacts on stream ecosystems that may be occurring as a result of the current levels of farm dam development. The approach employed was to compare the currently observed flow regime with one considered to represent more natural conditions. The difference between the two was then assessed to determine the deviation of current flows from the natural condition, which allows a more informed evaluation of the likely impacts. Assessments of this nature are subject to two common difficulties:

1. The first challenge faced in such studies is establishing a benchmark for the natural hydrology in the absence of human activities. As no pre-development streamflow data are available, the benchmark employed for the 'natural' flow regime is that predicted by the calibrated surface water model with the impacts of farm dams removed. It is unknown to what extent this reflects conditions prior to European settlement, and this is an acknowledged uncertainty of the work.

2. The second, more problematic challenge involves linking the ecological requirements of aquatic biota and their physical environment to streamflow characteristics. The crucial factor is determining whether ecological processes have been compromised by the changes to catchment hydrology resulting from development, and if so to what degree. A common approach is to use a single umbrella species, or iconic species that is thought to have environmental water requirements representative of the system as a whole, but there exists no comprehensive biodiversity data upon which to base an assessment of this nature. This study has therefore relied on previous expert panel assessments made in similar studies in neighbouring catchments as a basis upon which to gain an appreciation of potential impacts.

It is currently not possible to make a definitive statement as to whether existing development is impacting on environmental water requirements due to a lack of historical and scientific information. This assessment, by necessity, proposes the types of impacts that might be expected, based on the findings of a flow deviation analysis. Future assessments will need to assess the potential impacts discussed herein and develop appropriate field methods and monitoring programs to confirm or reject any cause and effect relationship.

8.2 ECOLOGICAL CHARACTER

Streamflow is recognised as a key organisational factor in the ecology of lotic (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). In considering the aquatic ecology of the catchment, it is important to distinguish between the two fundamental influences on the flow regime and hence the available surface water, and to recognise their separate and combined influence on the ecology of the catchment. These two sources are surface water resulting from direct runoff, and groundwater discharge to stream channels (baseflow).

8.2.1 THE ECOLOGICAL SIGNIFICANCE OF GROUNDWATER

The defining ecological feature of the Burra Creek Catchment is undoubtedly the perennial central catchment, which contains numerous large, deep and permanent waterholes, connected by continuous baseflow. Both of these features, but particularly the longitudinal extent of the permanent baseflow, is effectively unique in semi-arid South Australia and is therefore of intrinsic conservation value.

These perennial reaches are best categorised as a groundwater-dependent ecosystem, and fit within the classification scheme proposed in Hatton and Evans (1998) as a river baseflow system. A key to determining the environmental water requirements for all groundwater-dependent ecosystem is to establish their degree of dependence on groundwater. Five levels of dependency have been suggested, ranging from entirely to opportunistically dependent (Hatton & Evans 1998). For the pool-baseflow systems discussed here, the level of groundwater dependence will vary in accordance with the availability of surface runoff. However, it is clear from the findings of this project that for much of the year, in the majority of years, the perennial central reaches are entirely dependent on groundwater to persist. Hence, it is clear that protection of the environmental water requirements of permanent pools throughout the catchment cannot be achieved without adequate management of the groundwater resources.

The ecological significance of permanent habitat in a semi-arid region is self evident, and extends to terrestrial fauna and flora. Permanent surface aquatic habitat has been found to feature a greater abundance and diversity of organisms than temporary habitat (e.g. Brock et al. 2003). Within the setting of ephemeral and intermittent streams, aquatic organisms without a desiccation-resistant life-history phase are able to persist within the system by retreating to these permanent refugia pools as flow ceases (Ward et al. 1998). Refugia pools in intermittent streams have been found to have the highest biodiversity of all habitat types immediately following the cessation of flow, as all organisms retreat to the remaining wetted habitat (Boulton & Lake 1992; Acuña et al. 2005). When suitable flow conditions present, these organisms are then able to re-colonise the entire catchment, ensuring that a higher overall level of biodiversity is maintained at the landscape scale. Owing to this re-colonisation potential, connectivity between permanent pool refugia is a key process in ephemeral systems, allowing for distribution of organisms throughout larger areas of the catchment. Compared to episodic surface runoff, the permanent groundwater baseflows provide the baseline conditions for the survival and seasonal dispersal of organisms.

Other than providing permanent aquatic habitat, groundwater exerts an additional influence through its chemical composition. The salinity of the permanent baseflow reflects the underlying groundwater salinity, being of the order of 2000–3000 mg/L. Plants and animals can only live and reproduce within a specific range of salinities and these levels impose a natural limit on the range of biota that can persist in the catchment. The aquatic organisms observed in the catchment 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.

As they are dependent on groundwater, the permanent surface expressions are also indicative of the strong interaction between surface and groundwater. Where this interaction occurs via sediments below the stream bed, it becomes increasingly significant to stream ecology and is referred to as the hyporheic zone (Brunke & Gonser 1997; Boulton et al. 1998; Hose et al. 2005). By providing a hydraulic link between the surface and subsurface 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.

8.2.2 SURFACE WATER FLOW — RELATED ECOLOGY

In contrast to the relatively stable baseflow discharge, streamflow from surface runoff is highly variable and exerts a major influence on critical ecological variables in the system such as habitat diversity and water chemistry. It is a well-established ecological principle that natural flow regimes are fundamental in shaping the life history of aquatic biota present in the system (e.g. Walker et al. 1995; Bunn & Arthington 2002). More than simply the characteristics of the natural flow regime, the variability found within this is influential in shaping the resident biota on daily to evolutionary time scales. The range and variability of flows to which ephemeral systems are subject is both a source of stress and a defining feature. Changes to any of the flow characteristics potentially limits biodiversity and ecosystem function.

Excluding the extensive permanent reaches, the broad ecological character of the Burra Creek Catchment, including its associated tributaries, is that of a semi-arid ephemeral stream ecosystem. Streamflow patterns in such river systems are generally highly episodic. For the Burra Creek Catchment, little reliable seasonality is evident in the surface runoff flow record, and the relative flow contribution of extreme events is clearly apparent in the monthly mean flows.

Despite its variability when contrasted to baseflow, surface runoff is still highly important for the riverine system. The ecological significance of surface runoff can be considered within the catchment both as the sole source of aquatic habitat in the ephemeral reaches, and by the manner in which it modifies conditions within the perennially flowing reaches. Both of these factors influence the ecology at catchment scale.

Patterns of surface runoff are superimposed on the almost constant underlying baseflow signal. The combination of these sources is what appears as the overall flow regime in perennial reaches. Surface runoff is not sufficiently reliable to create permanent flow, but does greatly increase the area and diversity of wetted habitat, and improves water quality.

At a landscape scale, temporary water bodies that collect and hold surface runoff for periods of weeks to months probably contribute significantly to landscape-scale aquatic diversity. Less salinity tolerant animals that can complete the aquatic phase of their life histories within periods of weeks to months can exploit such temporary habitat. For example, macro-invertebrates with a flight phase to their life histories are capable of rapidly dispersing and colonising ephemeral water bodies. For such animals, stream water quality may be a more important factor than permanence. Farm dams provide a lentic (still water) environment of relatively good water quality, but many animals with low salinity tolerance are adapted to high flow volume features such as riffles, and may rely on streamflow.

Although the low volume, constant perennial baseflow supports permanent aquatic habitat, it is the range and variability of surface runoff flows that support the most diverse ecological processes within the riverine system. Detecting possible changes to natural surface flow patterns, and predicting any resulting ecological impacts, is the aim of this chapter. The following sections deal firstly with the ecological functions of the various flow bands. The findings of the field surveys are then discussed in terms of the ecological assets that are present in the system, before an analysis and interpretation of the flow deviation analysis is presented.

8.2.3 FLOW BANDS

8.2.3.1 Overview

Consideration of environmental water requirements is generally framed around a discussion of important flow bands, or ranges of flow, each of which are linked to ecologically important processes within an aquatic ecosystem. The designation of these flow bands is therefore a critical step in determining and identifying any impacts to ecology.

Although a number of studies in South Australia have developed plausible relationships between riverine ecology and streamflow characteristics through an expert panel consultation process, little work has been done to verify these responses. Lack of empirical support for these conclusions has been identified as a gap in knowledge in South Australia (e.g. Favier et al. 2000; VanLaarhoven et al. 2004) and in Australia generally (Gordon et al. 2004).

The flow bands (and flow-related ecological responses) referred to in this report are a generalised application of information developed through the expert panel process in other studies (notably the Mid-North Rivers Management Planning Project) to the Burra Creek Catchment. Background reports developed by expert technical panels for the adjoining Broughton River Catchment (Lloyd 2000; Cresswell 1999) and Marne River (MREFTP 2003) were used in the main.

Channel cross-sectional area largely determines the unique relationship between flow volume and water depth at each point on a watercourse. Clearly relating flow bands to watercourse stage is a critical element of an assessment of this nature, but is also site specific. Extensive field surveys to develop a detailed understanding of the relationship between watercourse stage and flow volume at key ecologically important sites was, however, beyond the scope of this report.

As the stage-discharge relationship was by necessity already well defined at the site, Worlds End gauging station was chosen as an indicative site upon which to base the designation of flow bands for this study. This also simplifies the assessment of the ecological impacts of flow alteration, as the actual flow data are directly applicable. Stated discharges for each of the flow bands identified are based on gauged data and stream cross-sections from this location. Although they provide an indication of catchment-wide impacts, it should be noted that:

- the volumetric value of the flow bands determined apply only at the gauging station
- even at this site these should be considered to be first-order estimates and require further research and field investigation to be refined and matched to the likely ecological processes.

8.2.3.2 Description

Most South Australian streams feature an annual cease-to-flow period, which provides a clear indicator of change that can be analysed in terms of its timing and duration. Although the observed flows at the gauging station have never ceased, the modelled flows only reproduce the surface runoff component, and hence an annual cease-to-flow period is in evidence in the analysis. The duration of this period is critical to permanent pool refugia within a catchment, as water quality will deteriorate during periods of no streamflow due to evaporative loss.

Baseflows are discussed above as an example of a flow band that has been determined to hold ecological significance by maintaining wetted habitat and bank soil moisture levels. To some extent, baseflow may also reduce seasonal fluctuations in salinity and temperature that would occur in isolated pools. Other flow bands perform equally important ecological functions.

Periods of mid-level flows (freshes) generated by surface runoff provide connectivity to increased areas of the catchment and improve water quality. In addition to re-distribution of organisms, these events may also trigger and sustain other ecological responses such as recruitment in many aquatic species.

Latitudinal connectivity is achieved through higher level flows (bankfull and overbank), which provide access to floodplain habitat where significant additional resources become available. High flows also increase the area and duration of longitudinal continuity. These times of high connectivity and resource availability potentially provide biological boom periods, allowing aquatic species to extend their range and numbers beyond those supported by refugia pools.

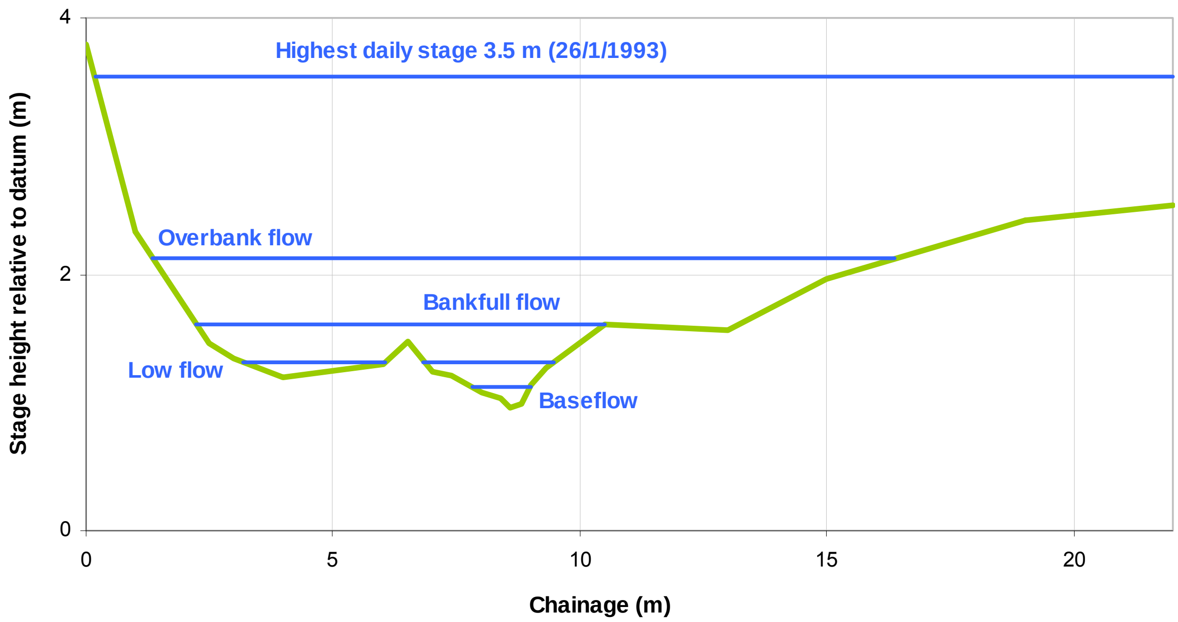
Tables 12 summarises the flow bands adopted for assessment in this study. The ecological processes thought to be supported by these are summarised below and examples appear in the field survey results. A cross-section depicting the effects of the various flows on the channel at the gauging control appears in Figure 49.

Table 12. Flow band description and ranges, Burra Creek at Worlds End

Flow band	Discharge (m^3/s)	Discharge (ML/d)	Stage[1] (depth)	Frequency
Baseflow	0–0.04	0–3.0	0.962–1.1112 (<20 cm)	Annual
Freshes	0.04–0.4	3.0–33	1.12–1.32 (20–40 cm)	1–3 pulses per year
Bankfull flow	0.4–2.5	33–220	1.32–1.614 (40–60 cm)	1–2 years
Overbank flow	2.5–17	220–1500	1.614–2.12 (0.6–1.2 m)	4–6 years
Maximum daily gauged flow[2]	125	10 866	3.544 (3.54 m)	Estimated at 1 in 50–100

1 Stage refers to gauged depth in metres above a datum; depth refers to depth of water above cease to flow.

2 Note that instantaneous peaks would be considerably higher than the daily peak.



Vertical scale exaggerated by approximately a factor of 4.

Figure 49. Cross-section of Worlds End gauging site showing designated flow bands

- Baseflows support the maintenance of wetted habitats with diverse hydraulic character such as still-water pools and riffles as well as providing a more stable chemical and thermal environment for surface water organisms. These flows also exert a strong influence on the ecology of the terrestrial interface, the riparian zone, where they help to maintain macrophyte and other vegetation and also support recruitment. Given the underlying salinity of the baseflow, surface runoff represents a significant source of water quality improvement in permanent reaches, helping to moderate variations due to evaporative loss or excessive nutrient inputs.
- Freshes increase the extent and variety of wetted habitat, bringing increased opportunities and resources for biota; for example, on the cross-section shown in Figure 49, freshes are sufficient to inundate the secondary channel. Additionally, these short duration flows provide periods of longitudinal connectivity that can create migration and movement opportunities for biota between refugia pools. Flows of this volume and above will also assist in habitat maintenance including removal of organic and silt fines from riffles.
- Bankfull flows provide for some degree of channel maintenance, including mobilisation of fine sediments in pools, and may produce isolated cases of lateral inundation as channel morphology varies. They will also ensure connectivity between isolated pools along the entire riverine system.
- Overbank flows (and above) inundate floodplain environments, accomplish major reworking of sediments, and may also uproot reedbeds where these have become obstructive in waterways. These events may also be important to initiate high growth periods where river red gums overlie saline groundwater, and also to provide enhanced recruitment opportunities (Roberts & Marston 2000). Discharge of these larger flows to the lower catchment floodplain will recharge aquifers, improving groundwater quality in shallow sedimentary aquifers.

8.2.4 BIOLOGICAL COMPONENTS

Although detailed biodiversity surveys were beyond the scope of this investigation, existing information on biodiversity has been reviewed and field visits included limited biological surveys. The main aim for field surveys was to identify the main ecological and habitat features at each site in order to better interpret any impacts that may result from any changes to the natural flow regime. The following section summarises the biological diversity identified, and the section on field sites lists both biological and flow-related habitat values.

8.2.4.1 Fish

Due to their dependence on natural hydrology, susceptibility to degrading processes and biodiversity values, fish are often used as indicator species for riverine condition. In recognition of this, native fish were a focus of the field survey work. No native fish were detected in the course of this or other recent surveys undertaken by Native Fish Australia South Australia (NFASA).

Two species of exotic fish were captured during surveys — Plague Minnow (*Gambusia holbrookii*), and Rainbow trout (*Oncorynchus mykiss*). Brown trout (*Salmo trutta*) is also known from the Burra Creek Catchment (App. J). All of these species have the potential to impact on native fish populations and reports of illegal releases of hatchery trout species into the creek are of particular concern for the ecology of the creek and its tributaries.

It is currently not possible to state categorically whether native fish populations were ever present in the catchment (see App. J — the report on fish sampling in the region by NFASA), but given the extent of permanent habitat and occasional connection with the River Murray, it is highly probable that they were, and possibly still are, present. Based on their presence in nearby eastern Mount Lofty Ranges streams, Mountain galaxias, smelt and three species of gudgeon are all considered to at least have the potential to be present within the gauged catchment. In addition, hardyheads could potentially inhabit the saline pools of the lower catchment.

8.2.4.2 Anurans

Due to difficulties associated with their sampling, frogs and toads were not a specific target of field surveys, but calls were heard at most sites. These were identified as being of the Common Froglet (*Crinia signifera*), which was also observed at two sites on The Gap Station.

To gain an appreciation of the level of diversity representative of the region, reviews of the South Australian Museum database, the DEH Biosurvey database and the EPA Frog Census reports (Walker 2003) were undertaken. The review identified records of the following frogs in the region from the period 1998–2004:

- Common Froglet (*Crinia signifera*)
- Brown Tree Frog (*Litoria ewingii*)
- Spotted Grass Frog (*Limnodynastes tasmaniensis*)
- Eastern Banjo Frog (*Limnodynastes dumerili*)
- Painted Frog (*Neobatrachus pictus*)
- Sudell's Frog (*Neobatrachus sudelli*)

- Trilling Frog (*Neobatrachus centralis*).

Additional species that may be present in the catchment (due to the known distribution in adjacent catchments) include:

- Southern Bell Frog (*Litoria raniformis*)
- Bibrons Toadlet (*Pseudophryne bibronii*)
- Eastern Sign Bearing Froglet (*Crinia parinsignifera*).

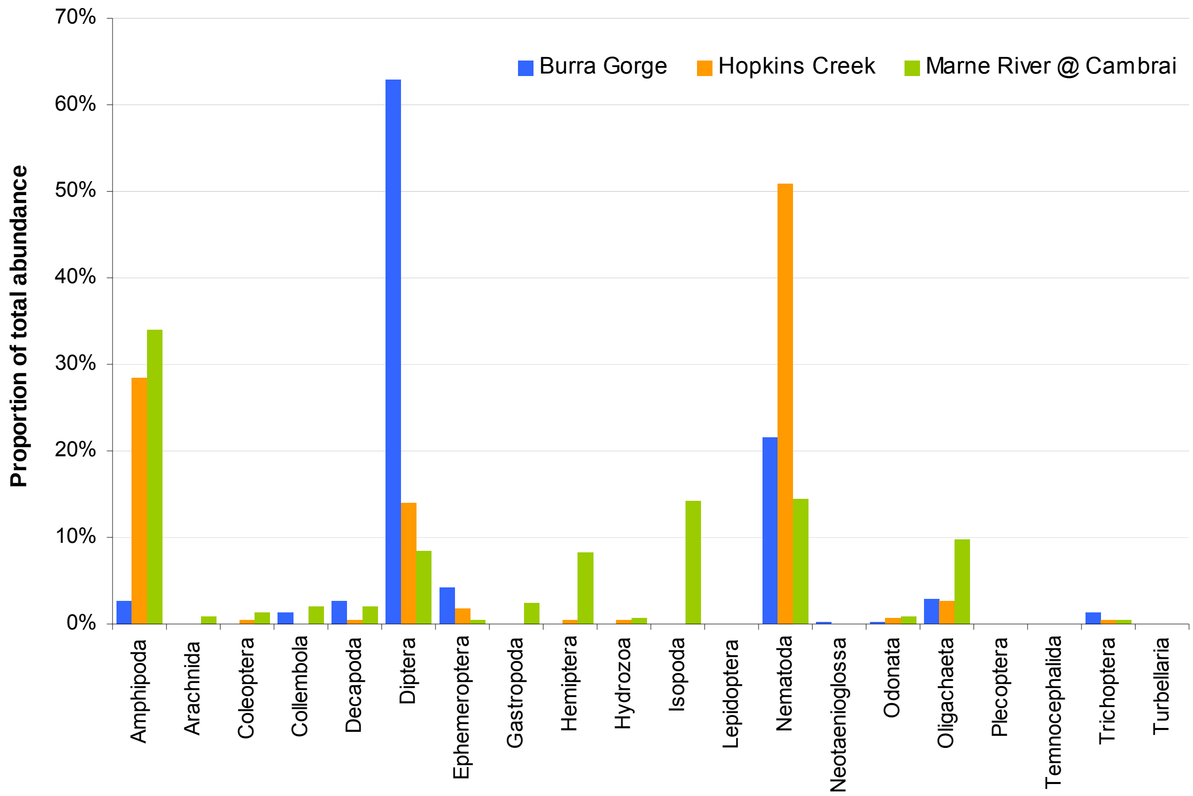
8.2.4.3 Macro-invertebrates

Macro-invertebrates were sampled at two sites as part of the field component for this project to provide an indication of the diversity present. Sites were sampled during June 2005, with samples identified and the data analysed using the 'Autumn Edge' AUSRIVAS model by the Australian Water Quality Centre (AWQC; see report in App. K). The model returned a Band A rating (OE50 of 1.02, indicating reference condition) for the Burra Gorge site, and a Band B rating (OE50 of 0.56, indicating a slightly impaired condition) for the Hopkins Creek site. (This is thought to be due to a sampling error as the dense overhanging riparian vegetation and thick organic layer made sampling from the pool edge physically difficult).

The Burra Gorge site had a slightly higher overall diversity and abundance of animals with 381 animals representing 28 taxa collected, compared to 295 animals from 21 taxa at Hopkins Creek. Figure 50 shows the percentage relative abundance of animals grouped together by order or higher taxonomic level. Amphipods, Dipterans (true flies) and Nematodes were common in the samples from both sites, with Dipterans (63% of total abundance) dominant at Burra Gorge and Nematodes (51% of total abundance) at Hopkins Creek. Animals from the Order Oligachaeta (segmented worms) comprised 3% of the samples collected at each site.

To provide an indication of the sensitivity of macro-invertebrate families to water quality parameters such as salinity and alkalinity, the SIGNAL (Stream Invertebrate Grade Number Average Level) index was developed in the 1990s, and has recently been updated (Chessman 2003). With the maximum rating of 10 indicating a highly sensitive taxa, SIGNAL scores for the majority of animals collected at the Burra Creek Catchment sites range from 1 to 4. This implies that the macro-invertebrate community is comprised of species adapted to moderate water quality. A notable exception is the Order Ephemeroptera (mayflies), which were present at both sites, and have a SIGNAL rating of 9. SIGNAL scores at this level of taxonomic resolution can be misleading however, and the family level score for the two families present — Baetidae and Caenidae — score only 5 and 4, respectively. Of the relatively robust taxa present, Baetid mayflies are arguably the most at risk due to their salinity tolerance, which has recently been determined to be in the range 5500–6200 EC (Kefford et al. 2003).

As single biological samples are not representative of the overall diversity of a site, it was considered useful to assess the samples collected for this study against a more extensive dataset to compare abundances. The most comprehensive, freely available data on macro-invertebrate communities in South Australia are collected by the Environment Protection Authority (EPA) Ambient Water Quality Monitoring Program. Data from another river system in the South Australian part of the Murray-Darling Basin — the Marne River at Cambrai —



Marne River at Cambrai data summarises ‘edge’ data from the EPA Water Quality website collected at the site between 1994 and 2005; Burra Creek and Hopkins Creek data are from Appendix K.

Figure 50. Percentage abundance of macro-invertebrate taxa by order, Burra Creek and Marne River

has a significant record of the macro-invertebrate fauna, with regular samples taken since 1994. The raw data were obtained from the EPA data download website (see http://www.epa.sa.gov.au/nrm_map.html).

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As an ephemeral site, the Marne River taxa would be expected to differ from that at a site of permanent water due to the physical constraints occasional drying imposes, and the resulting changes to community dynamics. However, water quality samples taken at the site indicate a comparable but lower level of salinity to Burra Creek (mean EC of samples from the Marne was of the order of 3400 µS/cm), and over time a similar macro-invertebrate fauna might be expected to be found within the Burra Creek Catchment.

Around 170 taxa have been recorded at the Marne River site, and the relative abundance of all taxa collected is shown for comparison, along with the abundances of the single samples from Burra Gorge and Hopkins Creek, in Figure 50.

There is similarity in many of the abundant orders present in the Marne River and Burra Creek sites, particularly with regard to the more tolerant taxa. Marne River has records for some of the 'missing taxa' (see App. K) predicted by the AUSRIVAS model for the Burra sites, including Acarina (Arachnida).

Overall, the diversity represented at the Marne site may be more indicative of what could be expected within the Burra Creek Catchment with repeated sampling. Although only present in low abundance, the fact that the sensitive taxa stoneflies (Plectoptera) have been recorded from the Marne site is of interest. Families in this order have SIGNAL grades ranging from 6–10, and are not tolerant of salinity or pollution (Gooderham & Tsyrlin 2002). The high baseline salinity of the Burra Creek system suggests that such sensitive taxa are unlikely to be found in the permanent reaches during much of the time. However, in the Marne River site at least, the data suggest that periods may occur where high volumes of surface runoff reduce salinities to acceptable levels for sensitive animals to complete the aquatic phase of their life cycle. This is an example of the need to build long-term datasets in order to fully appreciate the biodiversity values associated with the catchment.

8.2.4.4 Waterbirds

Waterbird species observed during the field visits were recorded opportunistically, but owing to the short duration of time spent in the field only limited species were sighted. Dusky Moorhen (*Gallinula tenebrosa*), Australasian Grebe (*Tachybaptus novaehollandiae*) and White-necked Heron (*Ardea pacifica*) were all species observed directly, and the calls of the Clamorous Reed-Warbler (*Acrocephalus stentoreus*) were heard at two sites.

A review of the South Australian Museum (SAM) and DEH Biosurvey databases indicated that 18 species of waterbird are recorded from the area (Table 13). Both Baillon's Crake and the Painted Snipe are listed as rare under the South Australian *National Parks and Wildlife Act 1972*.

8.2.4.5 Aquatic and riparian plants

Riparian species — much of the catchment has seen the riparian zone completely cleared, and it is difficult in much of the upper catchment to distinguish between watercourses and paddocks.

River red gums are more common in gorges of the central catchment, although typically these were isolated mature individuals. As might be expected for a watercourse where the riparian zone was subject to grazing, even where river red gums were present, the riparian zone in general lacked any understorey. Streamside vegetation was often a combination of reeds, sedges and terrestrial grasses.

A notable exception was the area around the Burra Gorge camping area, where red gums formed a closed canopy for several hundred metres of watercourse. The understorey through this area comprised a mix of riparian and terrestrial species such as *Myoporum montanum* and *Callitris* or *Acacia* spp., as well as exotics such as pepper trees. Red gums were not as dense downstream of the gorge, becoming increasingly sparse with movement towards the floodplain.

Table 13. Waterbirds recorded in SAM and DEH databases for Burra Creek

Scientific name	Common name
Anas gracilis	Grey Teal
Anas superciliosa	Pacific Black Duck
Anhinga melanogaster	Darter
Ardea pacifica	White-necked Heron
Aythya australis	Hardhead
Calidris acuminata	Sharp-tailed Sandpiper
Calidris ruficollis	Red-necked Stint
Chenonetta jubata	Australian Wood Duck
Egretta novaehollandiae	White-faced Heron
Elseyornis melanops	Black-fronted Dotterel
Gallinula tenebrosa	Dusky Moorhen
Malacorhynchus membranaceus	Pink-eared Duck
Porzana fluminea	Australian Spotted Crake
Porzana pusilla	Baillon's Crake
Rostratula benghalensis	Painted Snipe
Tachybaptus novaehollandiae	Australasian Grebe
Tadorna tadornoides	Australian Shelduck
Vanellus tricolor	Banded Lapwing

Emergents, Sedges — were often found to be the only true riparian vegetation and a reasonable diversity was represented with *Juncus krausii* and *Cyperus gymnocaulos* common. Other species observed included *Baumea juncea*, *Schoenoplectus litoralis* and *Isolepsis* spp.

Emergents, Reeds — *Phragmites* and *Typha* spp were both commonly observed through the non-grazed areas of permanent water. Typically these were present in only small stands around pool edges, as pools had steep bank profiles and water depth prevents the species from choking pools in the central catchment.

Submerged species — the dominant submerged plants were unbranched filamentous green algae including the Stoneworts *Chara* spp. and *Nitella* spp. Other known aquatic plants included Water Buttons (*Cotula coronopifolia*) and *Triglochin striatum*. In the hypersaline pools in the lower catchment, stands of *Ruppia maritima* were present.

8.2.5 FIELD SITE DESCRIPTION

As stated in the Methods section, aerial videography was employed to map the locations of key ecological features such as permanent waterholes and baseflow reaches. Figure 51 indicates the locations of these assets, and the sites selected for field survey are described in the following section. Also shown in the figure is the surface extent of the Skillogalee Dolomite and its contained fault lines. The dependence of permanent water on these features is clearly apparent, particularly at the Burra Gorge where a surface lobe of the formation occurs. In areas where the formation is not shown to be at the surface, it expresses in the form of springs in locations along Burra Creek itself (Segnit 1937).

8.2.6 FIELD SURVEYS

A number of field visits were undertaken to provide an indication as to the current ecological character of the catchment. These visits were largely qualitative in nature and intended to identify key ecological features represented at each site. Major vegetation associations and habitat categories were noted, and limited biological sampling was undertaken as discussed below. The main aim of the field visits was to enable some conclusions to be drawn regarding the role that key flow bands might play in maintaining ecological processes. Additionally, the hydrological alterations resulting from human activities in the catchment could also then be better interpreted in terms of their potential impacts.

Survey site selection was based on inspection of the aerial videography imagery and intended to give a good understanding of the range of habitat types represented. Due to the timing of surveys and the importance of permanent waterhole refugia, surveys were only undertaken in sites where significant permanent waterholes were located. Future work should look to also sample ephemeral habitat to assess the biodiversity values supported within these environments. Table 14 lists the site locations and key features of interest leading to their selection.

Table 14. Burra Creek Catchment site survey locations and key features

Site name	Key features
The Gap Station	Continuous baseflow – deep pool sequence. Major surface water reach on the creek. Presents a diverse range of hydraulic–geomorphic habitat types in a small area. Representative of grazing land use.
Burra Gorge	Similar hydrology to the above, but has continuous canopy cover contrasting with largely cleared riparian zones immediately upstream on The Gap Station. Iconic recreational site not subject to grazing pressure, but is impacted through the presence of camping grounds on the riparian zone.
Hopkins Creek	Tributary to Burra Creek; small catchment presenting a relatively small pool – baseflow reach. Full canopy and natural riparian vegetation. Site is within a conservation park.
Worlds End gauging station	Isolated rock pool and baseflow sequence; site of gauging station and therefore used for cross-sectional flow analysis.
Moseys	Last permanent waterholes on the creek. Highly saline environment in contrast to less saline upstream habitat.

The sites of all of the field visits are shown in Figure 51. A brief description of the ecological and hydrological character at each site appears below.

8.2.6.1 The Gap

Baseflow–pool reach with cleared and grazed riparian zone — central catchment

The largest continuously flowing section of the creek commences ~10 km south of Burra township and continues to just downstream of Burra Gorge (Fig. 51). The majority of this permanent water is located on The Gap Station, which includes the confluence of Logan Creek (also permanent in its lower reach). Land use is cattle grazing, and there is no restriction on stock access to waterways. At the time of site visit (October 2005), both Logan and Burra Creeks were flowing, maintained by baseflow close to its seasonal high (Fig. 52).

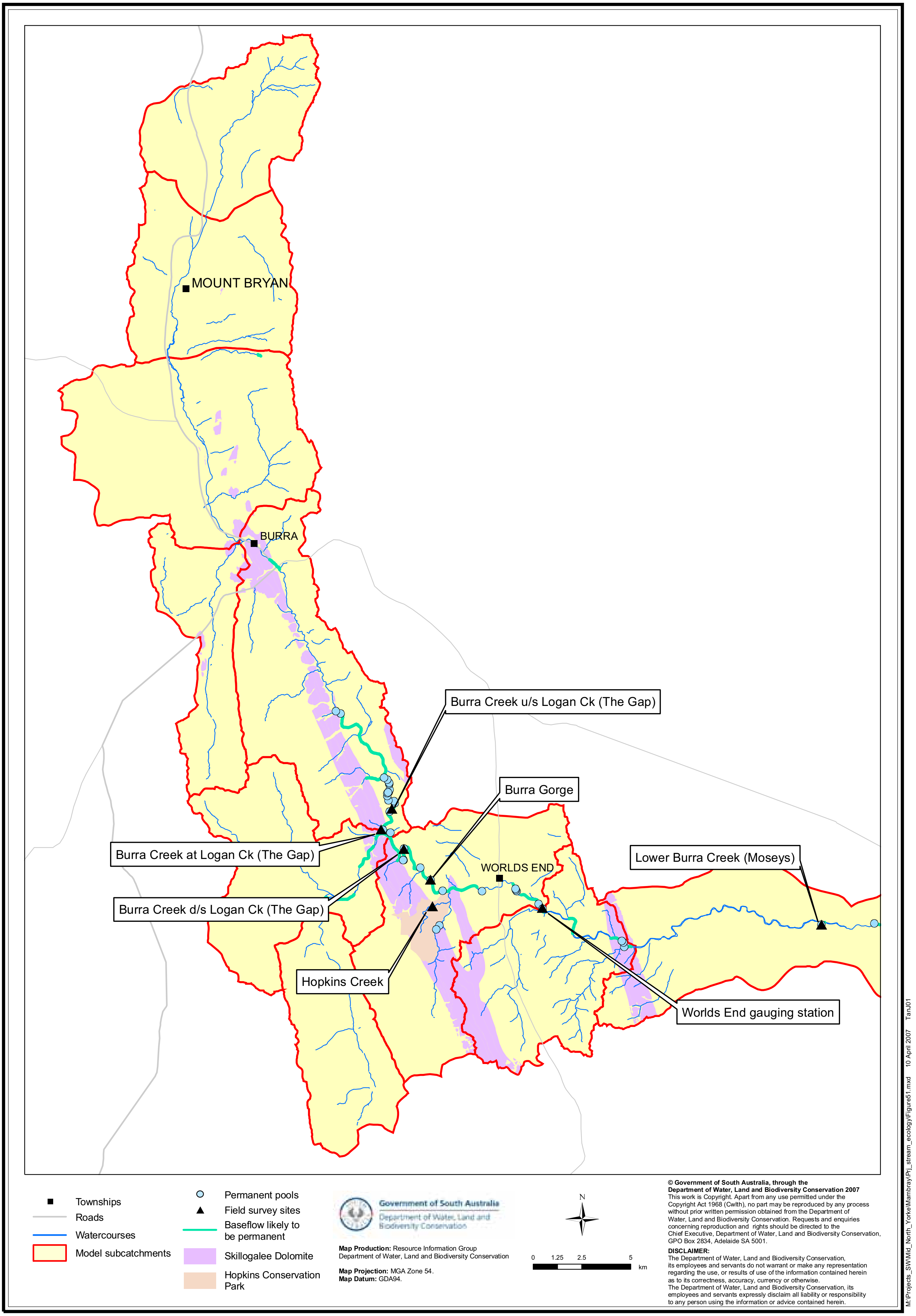


Figure 51. Location of permanent pools and baseflow, Burra Creek Catchment

Figure 52. Burra Creek on The Gap Station, showing baseflow riffle, October 2005

Burra Creek in this region flows within a partly confined to confined river valley of varying width, meandering through rocky ranges of modest elevation. The riverine corridor between the confluence of Logan Creek and Burra Gorge has lateral terraces that sit above the current channel zone to a maximum height of ~10 m. There is diversity of vegetative and hydraulic habitats within the corridor, which varies in width between ~50–150 m.

Typically, vegetation within the riverine corridor is comprised entirely of sedgelands with *Juncus krausii*, *Cyperus gymnocaulos* and *Isolepsis* species forming extensive stands immediately surrounding the narrow, shallow channel. In places where the alluvial form allows, riparian sedgelands were present to ~50 m in width (Fig. 53). These provide complex hydraulic and vegetative habitat, often including small backwater pools and secondary channels. This is likely to be good habitat for frog species such as the Spotted Grass Frog, which tends to favour marshy habitat where ponds are grass lined (Tyler 1994). In shallower sections and riffles, *Cotula coronopifolia* and filamentous green algae were the major submerged species.

Riparian canopy vegetation varies considerably in complexity and density, although diversity is not high. In many areas no overstorey exists at all but, where present, the river red gum canopy can provide up to 70% shading of the stream. The shrub layer is largely restricted to *Myoporum montanum*, which is not palatable to stock (cattle will not graze the species although sheep will) and, although sparse, is regenerating at a high rate. A consequence of the cleared riparian zone upstream and at the site was the low incidence of woody debris within the stream and in pools, particularly when compared to Burra Gorge. This has the ecological effect of decreasing habitat complexity and resource availability.

Deep pools (greater than 3 m) were found at irregular intervals in Burra Creek, typically, but not always, on meander bends. Some of these pools stretched for over 100 m (Fig. 54), providing extensive habitat, but more typical dimensions were of the order of tens of metres. Pools often featured fringing reed beds of *Phragmites*, *Typha*, *Schoenoplectus litoralis*, or *S. pungens.*

Figure 53. Sedge meadows, Burra Creek on The Gap Station

Figure 54. Large permanent waterhole, Burra Creek on The Gap Station

Submerged vegetation was rare within the pools due to the turbid nature of the water and steep bank profile, and was limited to filamentous green algae present on suitable substrates around pool edges. All pools had a thick (~30–50 cm) anoxic layer of fine organic sediment present. In shallower sections and riffles, Watercress, Water Buttons (*Cotula coronopifolia*) and filamentous green algae were common.

The surrounding ranges have very limited vegetative cover and feature significant outcropping bedrock. The slopes of the ranges are very steep and the area is likely to have a high runoff coefficient, generating high runoff volumes and velocities during storms. Flow events have been observed to remove reed beds (J. Gebhardt, landholder, pers. comm., 2005), which is an indication of the flow velocities through the reach.

As a grazed property there are some associated issues with the ecology of the reach, including weeds in the riparian zone and stock access, with consequential nutrient inputs direct to the creek. No major bank erosion was evident from stock access, presumably due to the topography providing easy access and low stocking density. Elevated nutrient levels within the creek, pugging of pool fringes from trampling disturbance (contributing to increased turbidity) and control of riparian vegetation are probably the greatest ecological impact of the stock. Given the working nature of the river, a diverse range of relatively intact ecological features were apparent. Table 15 presents a summary of the main identified flow-related features of the ecology of the site and the relationship of each to the various flow bands.

8.2.6.2 Burra Gorge

Baseflow – pool reach with full canopy cover — central catchment

Burra Gorge is immediately downstream, and permanently linked through baseflow to the above site. As the name implies, channel form is dictated by the prevailing geology in this reach as the creek winds through the northern Mount Lofty Ranges from the west. The creek becomes confined between rocky and grazed hillslopes. Read Creek joins Burra Creek within the gorge, and extensive gravel and sand bars have been deposited at the site of confluence. These may have developed as the combined sediment load from the two streams cannot be entrained as flood waves recede. These deposits may currently be restricting the progress of lower flow bands through the gorge. It is not known how recently the current deposits were made, but this would presumably have been during 1992–93 when significant flooding occurred.

Observations from local landholders are that the extent of the permanent water downstream of the gorge has contracted considerably over the last few years (G. Philips, landholder, pers. comm., 2006). The presence of the old footbridge across the creek (adjacent to the current Burra–Robertstown road) ~1.5 km further downstream than the last permanent water found today also supports a decrease in flow extent (Fig. 55).

Table 15. Flow-related ecological features and watercourse issues, The Gap Station

	Ecological features	Relationship to flow regime
Biodiversity values	Reed beds	Maintained by the presence of pools and baseflow.
		Provide habitat and resources for organisms such as macro-invertebrates during higher flows.
	Sedges	For maintenance — require high soil moisture from permanent water.
		Occasional inundation to further increase soil moisture and allow for recruitment (ideally during early spring).
	Riparian trees and shrubs (sparse to absent)	Survival — probably access bank soil moisture.
		Recruitment — will be prevented as a grazed area.
	Anuran species	Sedge meadows, with multiple channels, small backwater pools and swampy zones provide diverse habitat year round to support breeding and habitat requirements.
		Persistence of low flows required to support the above.
	Potential long-necked tortoise habitat	Persistence of deep waterholes for winter aestivation.
		Overbank and higher flows required occasionally to scour and maintain pool depths.
	Potential native fish habitat — Mountain galaxias, smelt, gudgeons	Persistence of pools and riffles to provide habitat.
		Seasonal increases in baseflow to stimulate breeding during spring.
		Low-flow season freshes required to improve water quality and provide suitable sites for egg laying by clearing fines from riffles (Mountain galaxias).
Habitat values	Deep pools	Continuous baseflow to support wetted habitat and ameliorate water quality.
		Occasional freshes up to bankfull flows to maintain water quality.
		Irregular large overbank flows required to scour organic matter and sediment, maintaining depth and substrate (timing less important — end of high flow season optimal).
	Permanent baseflow	Continuous baseflow to support wetted habitat and ameliorate water quality.
	Riffles	Seasonal to continuous baseflow to support hydraulic habitat.
		Occasional mid-bankfull flows to flush sediment (ideally during the high flow season to coincide with spring recruitment).
	Ecological issues	**Comments**
Issue	Stock access	Impact on water quality — turbidity, nutrients.
		Impose grazing pressure on riparian zone and aquatic vegetation.
		Damage to riparian zone through trampling.
	Baseline salinity	Seasonal periods of diluting flows from surface runoff may enable persistence of salt-intolerant macro-invertebrates through aquatic life-cycle phase provided that duration is adequate.
	Cleared riparian zone	Low woody debris and leaf litter input to aquatic system.
		Poor riparian habitat for birds and terrestrial fauna.
		Increased water temperature and light environment.
	Riparian weeds	Prevents establishment of native riparian species.
		Propagules are spread via the watercourse.

Photo: Courtesy Burra Community Library.

Figure 55. The footbridge at Worlds End, ~1900

The footbridge (Fig. 55) was erected around 1892 by Apoinga Council to provide access to the Worlds End School (Auhl 1975). It seems reasonable to assume that water flowed through this reach during the majority of the time to warrant its construction. Clearly the extent of permanent water has considerably decreased through the gorge area, as this reach now only flows during surface runoff events (Fig. 56). It is not known how long ago the regular flow of water through this reach ceased, or the cause of decreased flow. The reasons for the decrease in permanent water are also unclear, but may be due to sedimentation from major events obstructing the flow of water. Decreased baseflow volumes are also a possible factor, but this might have been expected to have also decreased the extent of wetted habitat upstream, which if it has occurred is not as evident based on the extent of flows.

A series of pools up to at least 3 m in depth, 2–5 m in width and 10–20 m in length are found through the reach (Fig. 57). In the narrowest area of the gorge, a small cascade pool has been created in the bedrock. Other pools feature a sedimentary substrate with a thick layer of anoxic organic sediment deposited on the bed of the pool.

As the gorge environment itself is not grazed, riparian vegetation is relatively thick, but the riparian zone is narrow as steep hills of exposed bedrock or grazing lands surround on each bank and both up and downstream. The canopy and shrub layer is a mixture of native and introduced species. The canopy is predominantly river red gum and is effectively continuous, providing almost complete shade in many places. The understorey is diverse in structure and relatively species rich compared to all sites except Hopkins Creek, with *Myoporum montanum* the most common. The shrub layer includes such species as Old Man saltbush.

In some areas, small clearings are found beside the pools, but in the main they are almost completely surrounded by fringing reed beds of *Typha* and *Phragmites*. Reed beds are in places up to several metres thick and provide excellent habitat for bird species including reed warblers, grebes and swamp hens. Most pools also have considerable overhanging

Figure 56. Remains of the Worlds End footbridge; water no longer reaches this point

Figure 57. A large pool in Burra Gorge

branches from riparian canopies, creating potential nesting sites for woodland and waterbirds alike (although due to human access these are unlikely to be used by larger waterbirds). As a result of the complex canopy, large woody debris is found within and surrounding pools, further increasing habitat complexity.

Sedge populations are considerably reduced compared to the extensive meadows found on The Gap Station, as the channel form does not allow for extensive deposition of alluvial sediments and the light environment is much lower. Some isolated clumps of *Cyperus gymnocaulos* and *Isolepsis* occur, typically observed back from the waters edge.

Macro-invertebrates and fish were sampled at the site and one long-necked tortoise (*Chelodina longicollis*) was observed at the road crossing. *Gambusia* was the only fish species recorded, along with freshwater shrimp (*Paratya australiensis*) and yabbies (*Cherax destructor*). The AUSRIVAS ranking of the site was Band A (Reference Condition). Detailed results of fish and macro-invertebrate surveys are presented in the relevant reports in Appendices J and K. The dense bank and emergent vegetation and diverse habitats provided excellent environment for frogs and toads, in particular the Brown Tree Frog and Eastern Banjo Frog.

Table 16 lists the main identified flow-related features of the ecology of the site, and the relationship of each feature to the various flow bands.

Table 16. Flow-related ecological features and issues, Burra Gorge

	Ecological feature	Relationship to flow regime
Biodiversity values	Reed beds	Maintained by the presence of pools and baseflow.
		Provide habitat for birds, substrate for native fish eggs, and flow refuge for organisms such as macro-invertebrates during higher flows.
	Sedges (limited)	Require high soil moisture from permanent water.
		Occasional inundation to further increase soil moisture and allow for recruitment (ideally during early spring).
	Riparian canopy	Survival — accesses bank soil moisture.
		Recruitment — requires suitable inundation frequency and duration.
	Anuran species	Permanent water with adjacent low bank vegetation for cover, and emergent or submerged vegetation to attach and conceal eggs.
		Persistence of baseflow required to support pools.
	Potential native fish habitat — Mountain galaxias, smelt, gudgeons	Persistence of pools and riffles to provide habitat.
		Seasonal increases in baseflow to stimulate breeding.
		Low-flow season freshes required to improve water quality and provide suitable sites for egg laying by clearing fines from riffles (Mountain galaxias).
	Long-necked tortoise	Persistence of deep waterholes for winter aestivation.
		Overbank and higher flows required occasionally to scour and maintain pool depths.
	Macro-invertebrates	Freshes during the low flow season to maintain pool water quality.
Habitat values	Deep pools	Continuous baseflow to support and ameliorate water quality.
		Occasional flushing high to bankfull flows to scour organic matter and sediment, maintaining depth and substrate.
	Permanent baseflow	Continuous baseflow to support and ameliorate water quality.
	Riffles	Seasonal to continuous baseflow to support hydraulic habitat.
		Occasional mid-flows to flush sediment from gravel.

	Ecological issues	Comment
Issue	Organic sediment build-up	Requires extreme events to move through the reach. Built up bars of sand and gravel at the confluence of Hopkins Creek may be limiting flow through the reach.
	Weed species	Weeds are present within all layers of the riparian vegetation, from pepper trees within the canopy to onion weed.
	Build up of organic matter	The gorge has a dense canopy and riparian shrub zone. Large quantities of rich and anoxic organic sediment cover the bed of all pools. Limited variety of substrates influences biodiversity potential. Requires occasional high flows to scour and flush pools out to maintain biodiversity.

8.2.6.3 Hopkins Creek Conservation Park

Shallow pool – baseflow reach with natural riparian zone — central catchment

Hopkins Creek is a small tributary meeting Read Creek immediately upstream of its confluence with Burra Creek at the gorge. Hopkins Creek has only a relatively small catchment, much of which is conservation park. The land use within the site was formerly grazing but this activity ceased a number of years ago and the native vegetation has regenerated, changing the character of the area considerably.

Although largely ephemeral, there is a short reach (Fig. 58) with several small pools situated a few hundred metres upstream of the Read Creek confluence within a narrow confined valley. The site was visited in June 2005. Pool dimensions were only of the order of 2–10 m^2, but water was relatively deep at around a metre and, although not observable using aerial videography due to the dense canopy, pools are known to be permanent (I. Falkenberg, DEH, pers. comm., 2005). At the time of the visit there was connectivity between the pools from baseflow, also believed to be permanent, but no connectivity with downstream habitat in the gorge. Presumably the site is only connected to the main stem of Burra Creek during significant surface flow events.

Reeds (*Typha*) were present fringing pool edges, and sedges including *Juncus kraussii* and *Cyperus gymnocaulos* were also present. Generally, the surrounding vegetation was dense, and not limited to typical riparian species. A dense and continuous canopy comprising river red gum, *Callitris* and other taller species provided a shaded and relatively moist environment.

The landscape setting was effectively natural bushland and a diverse mixture of vegetation was seen, with species not found at other sites including *Acacia calamifolia* and the sedge *Baumea juncea*. This provided excellent habitat for a range of frogs known to inhabit vegetation near to permanent water including the Brown Tree Frog and Eastern Banjo Frog.

Figure 58. Hopkins Creek permanent reach

Table 17 lists the main identified flow-related features of the ecology of the site, and summarises the relationship of each feature to the various flow bands.

Table 17. Flow-related ecological features and issues, Hopkins Creek

	Ecological feature	Relationship to flow regime
Biodiversity values	Reed beds	Maintained by the presence of pools and baseflow.
		Provide habitat for birds and substrate for organisms such as macro-invertebrates during higher flows.
	Sedges	Require high soil moisture from permanent water.
		Occasional inundation to further increase soil moisture and allow for recruitment (ideally during early spring).
	Anuran species	Permanent water with adjacent low bank vegetation for cover, and emergent or submerged vegetation to attach and conceal eggs.
		Persistence of baseflow required to support pools.
	Riparian canopy	Access soil moisture and groundwater.
		Recruitment requires suitable inundation frequency and duration.
	Macro-invertebrates	Freshes during the low-flow season to maintain pool water quality.
Habitat values	Deep pools	Continuous baseflow to support and ameliorate water quality.
		Occasional flushing high to bankfull flows to scour organic matter and sediment, maintaining depth and substrate.
	Permanent baseflow	Continuous baseflow to support and ameliorate water quality.
	Riffles	Seasonal to continuous baseflow to support hydraulic habitat.
		Occasional mid-flows to flush.

	Ecological issues	Comment
Issue	Upstream land use	Only around half the Hopkins Creek sub-catchment is contained within proposed conservation park. Land use in the upper catchment will need to be considered within park management (e.g. excessive farm dam development may impact on flow regimes within the park).
	Build up of sediment	Large volumes of organic-rich anoxic sediment were present in all pools. Flows need to have sufficient velocity and duration to remove this periodically (further potential impact of stream diversions in the upstream catchment).

8.2.6.4 Worlds End gauging station

Rock pool – baseflow reach — central to lower catchment

After leaving the gorge, the creek flows through several kilometres of alluvial–fluvial sediment. The site of Worlds End gauging station is ~6 km downstream of the gorge, and is located on a rocky outcrop of sandstone and siltstone forming a number of deep rock pools maintained by continuous baseflow (Fig. 59).

Historical photographs show that at one stage flows were continuous enough to warrant the construction of a footbridge adjacent to the current Burra–Robertstown road (see Section 8.2.6.2 'The Gorge'). It is notable that baseflow does not persist between the gorge and Worlds End, but reappears ~2 km upstream of the gauging station.

Photo: DWLBC surface water archive

Figure 59. The gauging station at Worlds End

Land use at the site is grazing and the riparian zone is largely cleared, although a few remnant river red gums still remain upstream (Fig. 60). A narrow and discontinuous riparian understorey largely comprising *Myoporum montanum* occurs along the reach. Macrophytes associated with aquatic environments found at the site included Watercress (*Rorippa* spp.), Streaked Arrowgrass (*Triglochin striatum*), Water Buttons (*Cotula coronopifolia*) and Creeping Brookweed (*Mimulus repens*).

Figure 60. Rock pools at Worlds End showing the cleared riparian zone

The reach upstream of the rock pools has lateral terraces ~5 m above the present stream channel. Channel width is ~20 m but narrows at the site of the gauging station. As mentioned in Section 4.3, major sediment deposition has occurred both up and downstream of the gauging control, and reeds have now choked this well-lit shallow water environment. The channel formed in the creek bed through these sections is shallow at ~20 cm, indicating only low flows over recent years. Any increase in flows through this reach would create multiple flow paths, increasing the moisture of the alluvial sediment and probably supporting reed maintenance and recruitment.

Fish were sampled at the site using a seine net, with rainbow trout and *Gambusia* being present. Trout gut contents indicated that the fish had been feeding on *Paratya*, *Cherax* and macro-invertebrates including amphipods, trichopterans and hemipterans. Appendix J presents information on the findings of the fish sampling.

Table 18 lists the main identified flow-related features of the ecology of the site, and summarises the relationship of each feature to the various flow bands.

Table 18. Flow-related ecological features and issues, Worlds End

	Ecological feature	Relationship to flow regime
Biodiversity values	Reed beds	Maintained by the presence of pools and baseflow.
		Provide substrates for organisms such as macro-invertebrates during higher flows.
	Sedges	Require high soil moisture from permanent water.
		Occasional inundation to further increase soil moisture and allow for recruitment (ideally during early spring).
	Riparian canopy	Survival — probably accesses bank and bed moisture directly.
		Recruitment — unlikely due to grazing.
	Potential native fish habitat — Mountain galaxias, smelt, gudgeons	Persistence of pools and riffles to provide habitat.
		Seasonal increases in baseflow to stimulate breeding.
		Low-flow season freshes required to improve water quality and provide suitable sites for egg laying by clearing fines from riffles (Mountain galaxias).
	Macro-invertebrates	Freshes during the low-flow season to maintain pool water quality.
Habitat values	Deep pools	Continuous baseflow to support and ameliorate water quality.
		Occasional flushing high to bankfull flows to scour organic matter and sediment, maintaining depth and substrate.
	Permanent baseflow	Continuous baseflow to support and ameliorate water quality.
	Riffles	Seasonal to continuous baseflow to support hydraulic habitat.
		Occasional freshes to flush sediment.
	Ecological issues	**Relationship to flow regime**
Issues	Introduced species	Rainbow trout may be breeding in the pools and predating on native fish populations.
	Cleared riparian zone	Leads to a reduced habitat value for riparian zone; high light and temperature environment facilitates reed overgrowth.
	Stock grazing	Nutrient inputs; grazing of riparian and emergent species.
	Build up of sediment	Low flows cannot shift sediment but contribute to maintenance of reed beds which in turn exacerbate sedimentation. This cycle can only be broken by intervention or extreme events.

8.2.6.5 Mosey's

Highly saline rock pool – baseflow reach — lower catchment

Downstream of the Worlds End site the baseflow–pool reaches are located increasingly further apart. Around 30 km downstream of Worlds End, the final sequence of permanent water is found. These pools are situated within a partly confined valley at their western extent, and in places the riverine corridor is up to 100 m wide. The most downstream pool is located within a bedrock outcrop and confined between a 10 m sheer cliff and the outcrop (Fig. 61).

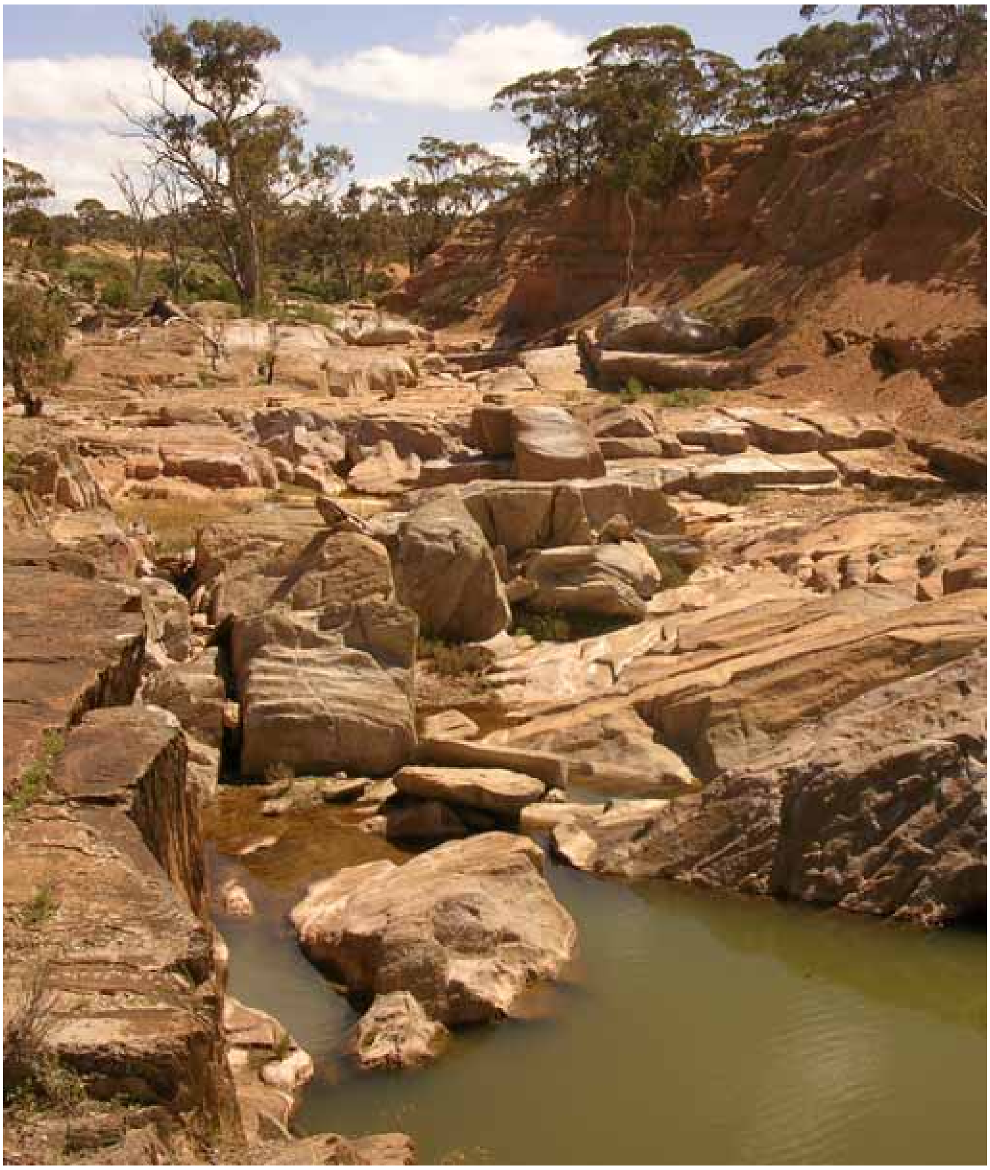


Figure 61. Last downstream permanent pool on Burra Creek, Mosey's property

The pools are an expression of regional groundwater and water quality is much poorer than in the upstream sites visited, with a minimum value exceeding 10 000 mg/L. The pools stretch for several kilometres along the creek and steadily increase in salinity with distance to the east (C. Mosey, landholder, pers. com., 2005) increasing to ~20 000 mg/L at the most easterly of the pools. The high salinities suggest a long residence time underground, and the increases observed along this reach may be due to evapotranspiration losses and hence increasing concentrations down the flow path of the shallow groundwater. The source of recharge for the groundwater is unknown but presumably this would be an intermediate to regional flow system recharged from local rainfall and outflows from the fractured rock aquifer in the much wetter areas to the west.

Riparian vegetation was largely salt-tolerant species including beaded glasswort, pigface and saltbush. *Juncus kraussii* formed extensive sedgelands where riverine sediments were present, and *Triglochin striatum* was also common alongside pools in saturated sediment.

A number of river red gum skeletons were observed within the riverine corridor, and the mature individuals remaining appeared in poor condition. Some regeneration within a single cohort (presumably from 1992–93, the last major flood event) was evident with young trees appearing to be in varying condition, thought to be due to salt stress.

River red gums have been found to overlie shallow saline groundwater up to 20 000 mg/L or more (Roberts & Marston 2000), but in such cases may well be dependent upon regular flushing flows to ameliorate salinity levels. Trials in River Murray anabranches have shown trees to rapidly respond to diluting flows and the observed salinities are almost certainly contributing to the poor condition and death of the individuals observed. The presence of the skeletons suggests that prior conditions were more suited to the species. This may indicate decreased regional groundwater flow, reduced incidence or volume of surface runoff diluting flows from upstream over recent years, or some combination of these.

A feature of several larger pools was extensive growth of *Ruppia maritima*, which formed dense stands and despite being covered in algal epiphytes appeared to be thriving in the high light environment (Fig. 62). These plants are a known source of food for water birds, which consume the turions (reproductive structures). Other aquatic plants observed included Water Buttons (*Cotula coronopofolia*) and Creeping Brookweed (*Mimulus repens*).

Figure 62. Permanent water chenopod shrubland and sedgeland on Burra Creek, Mosey's property

Although open to grazing, the water is too saline for stock consumption and no stock were observed in the riverine corridor. The main threat to the ecology of the area is probably increased salinisation due to decreased diluting flows from upstream.

Table 19 lists the main identified flow-related features of the ecology of the site, and the relationship of each feature to the various flow bands.

Table 19. Flow-related ecological features and issues — saline pools on Mosey's property

	Ecological feature	Relationship to flow regime
Biodiversity values	Sedges	Require high soil moisture from permanent water.
		Occasional inundation to further increase soil moisture and allow for recruitment (ideally during early spring).
	Submerged plants (*Ruppia*)	Require the presence of permanent water. May provide resources for some waterbirds which consume turions.
	Riparian canopy	Survival — probably rely on occasional runoff flows and rainfall as surface water salinity is too high for optimum condition. Presence of red gum skeletons may indicate decline due to increased salinities.
		Recruitment — would require flows of sufficient volume to ameliorate salinities and suitable inundation duration and follow-up inundations during summer to allow establishment. This appears to be unlikely given the current climate. Grazing pressure would be likely if freshwater was present in the creek.
Habitat values	Potential native fish habitat (Artherinidae)	Persistence of pools to provide habitat.
	Macro-invertebrates	Freshes during the low-flow season to maintain pool water quality.
	Deep pools	Continuous baseflow to support and ameliorate water quality.
		Occasional flushing high to bankfull flows to scour organic matter and sediment, maintaining depth and substrate.
	Permanent baseflow	Continuous baseflow to support and ameliorate water quality.
	Riffles	Seasonal to continuous baseflow to support hydraulic habitat.
		Occasional mid-flows to flush.
	Ecological issues	**Relationship to flow regime**
Issues	Increased salinity	Decreased groundwater discharge or surface flows would lead to an increase in the salinity of surface water and in the extreme case to a loss in surface water habitat.
	Build up of sediment	Although the riparian canopy was sparse to absent, high organic and silt sediment loads were present in pools. This would only rarely receive surface flows, and flushing of pools would be very irregular.

8.3 ENVIRONMENTAL FLOW MODELLING

The calibrated WaterCress model for Burra Creek as described in Section 6 was run for current dam development levels and a no dams scenario over a 31 year period coinciding with the gauging record. The question of whether simple removal of existing dams represents an authentic modelled 'natural' flow regime is worth considering at this point. However, in the absence of other benchmarks or pre-European streamflow data, there was no reasonable alternative point for comparison.

The synthetic streamflow data from the above analysis were assessed to determine the degree of change to the flow bands discussed in Section 8.1.1. Note that the model calibration was not optimised to attempt to reproduce permanent baseflow at the site, and therefore produced periods of no flow not present in the observed streamflow record. This is appropriate for use in this assessment, as the process of interest is surface runoff and resulting streamflows. As a result of this, however, streamflow statistics from this modelling scenario are not directly comparable to the adjusted or observed volumes, but can be compared to the volumes in Table 7, which shows the observed streamflow and separate quickflow volumes. At the site of the gauging station where the analysis is based, it can be thought of as representative of the impacts on streamflow with the influence of the baseflow component removed.

A stress index developed by environmental flows researcher Tim Doeg based on work by Heron, Doeg and Sovitslis (2002) and Heron, Doeg, Crook et al. (2002) was employed for this analysis using the modelled data representing natural and current streamflows. This approach has been employed in developing flow rehabilitation plans for ephemeral streams in Victoria. As this method has also recently been applied in the nearby Marne River Catchment (MREFTP 2003), it was considered useful to frame reporting in a consistent manner with that reference to allow for direct comparison of the findings.

The method firstly requires identification of natural 'flow seasons' based on observed streamflow data. Key aspects of the seasonal flows are tested for impacts using the modelled flow data for natural and impacted conditions. Indices representing the degree of impact are then derived from the magnitude of deviations. This analysis determines deviations in the surface runoff signal, which is superimposed on the underlying baseflow at the site of the gauging station. The impacts resulting from the deviations detected can be expected to apply to streams throughout the catchment, although the volumes will of course be different.

8.3.1 ASSESSING CHANGES TO FLOW SEASONALITY

8.3.1.1 Defining seasonality

Flow events or characteristics are linked to ecological processes not only through their magnitude and duration, but also through the relative timing of the events within broader seasonal cycles. Organisms have adapted not only to the size of events but also their timing within the year (Bunn & Arthington 2002). Flows likely to trigger biological events can often be tied to particular flow seasons when the probability of such a flow is greatest. These seasons should be distinguished from climatic seasons, although it should also be recognised that flow seasons, like climatic seasons, are long-term generalisations, and flows of any magnitude can occur during any period. Table 20 presents the flow seasons determined for Burra Creek using the MREFTP (2003) method.

Table 20. Flow seasons adopted for the Burra Creek assessment

Flow season	Months
Low flow season	November–May (inclusive)
Low to high transition	June
High flow season	July–September
High to low transition	October

8.3.1.2 Indicators of change

As mentioned above, each flow season has a range of indicators identified for assessment that have ecological significance. These are described for each flow season in Tables 21–23.

Table 21. Selected indicators to assess deviation from natural for the low-flow season, Burra Creek at Worlds End

Indicator	Comment
Mean daily flow	Measure of changes to total low-flow seasonal volumes.
Median daily flow	A resistant indication of ambient flow volume change in the low-flow season.
Coefficient of Variation (Cv)	A measure of flow variability.
Cease-to-flow periods	A measure of the isolation of pools.
Duration of cease-to-flow periods	Highlights any change in isolation periods. Is therefore a surrogate indicator of decreases in wetted habitat extent and declining water quality of pools.
Freshes per 100 years	Measure of any changes in the number of freshening flows resulting from low-flow season storms. (Median low-flow volume used as the threshold of a fresh.)
Freshes — duration	Measure of changes to flows from storages or catchment land use.

Table 22. Selected indicators to assess deviation from natural for transitional seasons, Burra Creek at Worlds End

Indicator	Comment
Mean daily flow	Measure of total seasonal volume; may indicate changes in seasonality of baseflow.
Median daily flow	A resistant indication of ambient flow volume change.
Coefficient of Variation (Cv)	A measure of flow variability.
Freshes per 100 years	Measure of any changes to the number of freshening flows resulting from early or late season storms. Median transition flow volumes used as the threshold of a fresh.
Freshes — duration	Measure of stress induced by reduced duration of specified flow band.

Table 23. Selected indicators to assess deviation from natural for high flow seasons, Burra Creek at Worlds End

Indicator	Comment
Mean daily flow	Measure of total seasonal volume.
Median daily flow	A resistant indication of ambient flow volume change.
Coefficient of Variation (C_v)	A measure of flow variability.
Freshes per 100 years	Indicator of extent of frequency of longitudinal connectivity. Threshold for onset of a fresh is 33 ML/d.
Freshes — mean duration	Measure of time available for ecological processes to be supported during the above pulse flows.
High flows — number of spells per 100 years	Measures for lateral connectivity with floodplain environments and channel resetting flows. Threshold of a high flow spell is defined as 75% of bankfull flow (165 ML/d).
Duration of high flows	Measure of the impact on processes requiring extended periods of high flow.

Assessing flow deviation

In order to test for impacts from development, it is necessary to determine some of the key features in each flow season, assess whether these have altered and determine the magnitude of any deviation. To achieve this, the above series of indicators were developed for each flow season, and comparative statistics are calculated for each indicator based on the modelled natural and current flows. Where possible, indicators developed for MREFTP (2003) have been retained but modified to suit identified flow bands in the Burra Creek catchment.

To further assist in interpretation and allow comparison across catchments, the same score weighting and classification system used in MREFTP (2003) has also been adopted. This allows for single score indices to be reported, simplifying comparison within and between catchments. This should also help to indicate the key flow band impacts potentially requiring management intervention. The ratings are shown in Table 24.

Table 24. Indices used to rate flow stress magnitude for reporting, Burra Creek

% deviation from natural flow		**Rating**
Decrease	*Increase*	
90–100	100–149	0
70–89	150–199	1
50–69	200–399	2
<50	>400	3

8.3.2 FLOW DEVIATION ANALYSIS

The results of the flow deviation analysis are shown in Table 25. Scores indicate that the degree of likely impact is the highest in low-flow season, but impacts to the median flow are apparent across all flow seasons. The median daily flow has been more than halved across all flow seasons, resulting in an impact rating of three for each.

The low-flow season has suffered the greatest impact on flows, which is a typical finding for a catchment with excessive farm dam development. The most severe impact on median daily flow was observed during this season, with the 'natural' modelled flow (influence of farm dams removed) of 0.7 ML/d, reduced with the inclusion of farm dams to 0.2 ML/d. The 20th percentile flow and duration of freshes above 3 ML/d have also been more than halved, leading to further stress during this season. Flow variability has also been affected, as shown by the increase in the coefficient of variation. The mean duration of no-flow spells has been slightly decreased, owing to the increase in the frequency of no-flow events, which have more than tripled.

The deviation is less apparent during the transitional flow seasons, but these both score moderate impacts for low-flow indices. In particular, median daily low-flow volume has been decreased by over 60%.

Outside the reduction in the median, relatively little impact can be seen in the indicators of deviation for the high flow season. This supports the findings of other studies where farm dam impacts have been assessed in other catchments in South Australia (e.g. Savadamuthu 2003; Heneker 2003; Champion et al. 1999), which have shown greater impact on low flows.

Table 25. Results of flow deviation analysis, Burra Creek Catchment

Low flow season (Nov–May)	No dams	Current	% of natural	Score
Mean daily low season flow	9.9	7.7	78	1
Median daily low season flow	0.5	0.2	41	3
20th percentile flow	0.2	0.1	47	3
Coefficient of variation	14.8	18.3	124	0
Cease-to-flow events	61.4	222.9	363	2
Mean duration of above	34.1	28.5	84	1
Spells per 100 y >3 ML/d	442.5	381.1	86	1
Mean duration of above	6.1	2.9	48	3
Low to high transition season (Jun)	**No dams**	**Current**	**% of natural**	**Score**
Mean daily low season flow	19.1	13.4	70	1
Median daily low season flow	1.8	0.7	36	3
Coefficient of variation	7.5	10.1	134	0
Spells per 100 y >median flow	148.6	106.6	72	1
Mean duration of above	2.3	1.9	82	1
High flow season (Jul–Sep)	**No dams**	**Current**	**% of natural**	**Score**
Mean daily low season flow	23.8	18.2	77	1
Median daily low season flow	3.2	1.2	39	3
Coefficient of variation	5.2	6.0	117	0
Spells per 100 y 33 ML/d	510.3	445.7	87	1
Mean duration of above	2.2	2.2	100	0
Spells per 100 y 220 ML/d	129.2	110	85	1
Mean duration of above	1.2	1.2	98	0
High to low transition season (Oct)	**No dams**	**Current**	**% of natural**	**Score**
Mean daily low season flow	18.5	14.3	77	1
Median daily low season flow	0.8	0.3	36	3
Coefficient of variation	5.9	6.7	113	0
Spells per 100 y >median flow	138.9	161.5	116	1
Mean duration of above	11.1	6.2	55	1

The ecological impacts of the predicted flow deviation due to farm dams would be related to decreases in wetted habitat and potentially to water quality changes. Table 26 presents a summary of the major flow deviations and the likely ecological impacts that can be expected to result.

As with other aspects of the use of the modelled data in this catchment, uncertainties exist around the significant influence of permanent groundwater expression on catchment hydrology and the associated difficulties in predicting catchment response using a rainfall-runoff model alone. Further studies focused on this surface–groundwater interaction are essential to provide improved clarity as to the quantitative nature of this relationship in order to further improve understanding of flow deviation impacts in the low-flow range.

Table 26. Likely ecological impacts of flow deviations, Burra Creek Catchment

Flow band	Ecological values	Deviations and resulting impact
Permanent baseflow and low flows (0–3 ML/d)	Maintains permanent aquatic habitat. Maintains bank moisture supporting emergent and riparian plants. Maintains water quality.	Reduced availability of aquatic habitat and decreased water quality due to reduced frequency and volumes of surface runoff. This is particularly apparent during the low-flow season but also found across all flow seasons. Will result in a reduction in the available aquatic habitat and hence the abundance of biota. Over time, aquatic biodiversity may be reduced through exclusion of biota that is already close to its water quality tolerance, e.g. Baetid mayflies.
Freshes (3–33 ML/d)	Increases wetted habitat diversity and quality. Provides longitudinal connectivity between refugia. Improves water quality generally across all hydraulic habitat types (pools, riffles, runs). Increases bank moisture, providing for germination and survival of recruits and improving the vigour of riparian plants.	Reductions observed in number, but more particularly the duration of freshes. This will decrease all of the stated benefits for the aquatic environment, especially the water quality improvements. This will increase the pressure on less-tolerant biota as stated above.
Bankfull flow (33 ML/d)	Increase the area of aquatic habitat. Provide periods of longitudinal connectivity allowing migration and re-distribution of aquatic species. Improvements in habitat quality through some fine sediment removal.	No significant deviation detected and hence impacts on this flow band unlikely.
Overbank flow (>165 ML/d)	Latitudinal connectivity with floodplain habitat provides benefit to riverine and terrestrial ecosystems. Re-setting of habitat through major scouring of pools, maintaining depth.	No deviation detectable through this analysis and hence impacts on this flow band unlikely.

8.4 DISCUSSION

Despite the presence of perennial flow in the central catchment, runoff events are relatively rare, lacking the strong seasonal winter flow signal found in higher rainfall catchments to the west and south. Flow events can occur at any time of the year and, due to the low catchment yield, even small events can be a significant proportion of total flow for a given year. This unpredictable hydrology is likely to favour opportunistic biota capable of responding rapidly to runoff events whenever they occur.

The permanent water in the catchment is groundwater dependent and moderately saline. Salinity within permanent waters of the central catchment is of the order of 2000–3000 mg/L (~3000–5000 EC), and this exerts a strong influence on the ecology, limiting the range of possible species that can persist in the catchment. For example, Kefford et al. (2003) found a salinity tolerance of 5500–6200 EC for Baetid (mayfly) nymphs. Kimberley et al. (2003) suggested that salinities of ~3000 mg/L become limiting for a range of freshwater macro-invertebrates, and also stonewarts such as *Chara* spp. All plants and animals have an optimal salinity range within which they are able to survive and recruit successfully. While the catchment biota is likely to be adapted to current background salinities, if baseflow concentrations increase markedly aquatic plants and animals currently present may be unable to persist.

The lower catchment features much higher salinities ranging up to 20 000 mg/L. These salinities are extremely limiting and exert additional pressures on most plants and animals. Only extremely tolerant biota can persist in these areas and hence the risk of increased salinity affecting ecology is reduced.

A further influence on the ecological integrity of the catchment as a whole is the land use, and the ecology of the riverine corridor must be considered within this context. Stock graze freely from the permanent reaches in the central catchment, with largely cleared riparian zones. In addition to altering the light and temperature environment, the clearance of native riparian vegetation allows invasive weed species to proliferate, further altering the ecological character of terrestrial and aquatic systems. Effects of this nature include changes to the carbon input cycles, both in terms of timing and nutritive value of terrestrial inputs.

The exception to this land-use pressure is the Hopkins Creek Conservation Park, which has not been grazed for many years and shows considerable regeneration. Riparian vegetation in the area has recovered to some extent from grazing and this is probably the best approximation of what would have been found naturally through the central catchment.

Although only relatively small pools are located within the proposed park, the water is permanent and provides an opportunity for more natural processes to be studied. Clearly the significantly reduced volumes of water compared to Burra Creek will foster some different ecological values, and in particular the absence of the large pools found along the main channel of the creek is a point of difference. Nonetheless, in future this site could be used as a relative reference site for the central catchment in monitoring or research programs. It could also potentially provide a good source of propagules and a relatively natural example of structural composition for riparian restoration work. If a suitable site can be located within the catchment, it would also provide a small and relatively natural catchment for a stream gauging station to provide an indication of the runoff volumes generated under comparatively natural landscapes.

Although in general different levels of flow and their duration are known to be key drivers of ecological processes, the ranges employed in this study are based on arbitrary estimates. The need to improve this body of knowledge emerges as a key issue currently hindering improved management of ecosystems dependent on natural flow patterns. An increased monitoring and research effort in South Australia is critical to addressing this barrier, particularly if catchment water users are to be expected to make tradeoffs to achieve environmental benefits through restoring flow bands.

9. CONCLUSIONS AND RECOMMENDATIONS

The major motivation in undertaking this work was to ascertain whether current water resource development levels, particularly surface water, were unsustainable and potentially impacting on the environment. The information is intended to direct future NRM decisions that will ensure the on-going protection of these resources. The following section considers the findings of this report within this context.

There is uncertainty in relation to the quantitative results of the actual modelling undertaken, and this needs to be recognised when considering the implications of the findings. Perhaps the most important limitation results from the lack of accuracy in the streamflow monitoring record since 1992, which has prevented the use of the most recent data to calibrate the rainfall-runoff model. Owing to the likely increased uptake of improved land management practice over the period (e.g. contour banking, reduced grazing density, and low or no till), the model calibrated to pre-1992 conditions may produce more runoff than should currently be expected from the catchment. This effect would produce an overestimation of catchment yield during this study and therefore in the permissible dam storage volumes developed.

Despite uncertainties, there is strong evidence from the modelling undertaken in this project that surface water storages are having a considerable impact on the streamflow regime that would occur in their absence. Burra Creek Catchment generates on average only limited surface water runoff and existing farm dams appear capable of capturing the majority of this during many, if not most, years. This perhaps says more about the climate and resulting runoff than the levels of development.

Although some larger storages were identified, the vast majority of current use appears to be limited to small capacity stock dams. Current development levels represent in the main opportunistic use of runoff to provide distributed stock water supplies across the landscape. Although some large storages were identified, no evidence was found of these dams supporting high demand activities. Runoff is too unpredictable to be the sole supply for such land uses, so there is reduced motivation for constructing storages of this size. As a result, unlike higher rainfall areas such as the Marne River or Clare Valley, future farm dam management will not be focused on high-volume irrigation dams. Management of farm dam storage volumes in Burra Creek will mean establishing policies to exert control over the size, number and placement of small stock and domestic dams.

Dams of this nature have not previously been subject to regulation similar to those in higher rainfall areas where prescription has occurred, as these capture only modest volumes of water. In more arid areas, runoff is so limited that issues of equitable resource sharing, resource sustainability and environmental needs will inevitably impose limits on the total storage capacity permissible for dams of all sizes. Significant questions must be addressed as the need to manage stock dam development in semi-arid regions is explored. Foremost among these is the development of policy around what is a sustainable level of surface water development in a low rainfall region.

South Australian policies on acceptable farm dam development levels are based on the premise that capture of some proportion of annual or seasonal totals will be sustainable (e.g. the 30% rule employed in this study) yet the application of these principles has so far been restricted to higher rainfall areas where reliable seasonal streamflow due to surface runoff can be expected. Moreover, even where they are being applied, there is currently no evidence that existing policies achieve the aims of sustainability and protection of environmental water requirements.

In Burra Creek, the impact of climatic variability complicates water resource management considerably. The modelling of surface runoff processes is extremely difficult where annual rainfall is below ~600 mm. In areas where annual rainfall is less than ~450 mm (the usual demarcation of a semi-arid climate), predicting runoff becomes extremely difficult. Burra Creek, with an estimated regional annual rainfall of 417 mm, is in this category. The difficulties experienced relate to the unpredictable nature of surface runoff events, which are to a large degree driven by the intensity of rainfall.

Analysis of the observed quickflow data (Section 4.3) demonstrates how unpredictable direct surface runoff in the catchment is; although there is higher probability of surface runoff during winter–spring months, this is by no means guaranteed. Although underlying baseflow introduces the appearance of modest, but reliable, seasonal runoff in the streamflow record, there is effectively no meaningful definition of a ‘typical’ surface runoff year. Deciding on an amount of water that can sustainably be removed in dam storages becomes complex in this situation. The applicability of policies developed in higher rainfall areas under these circumstances warrants further consideration.

In a sense, the main finding of this study has been to highlight the critical importance of the interaction between surface and groundwater. It is currently only possible to provide a basic conceptual understanding of these processes within the catchment. The challenge now is to put numerical values on all of the water-balance components, as the allocation of defensible sustainable levels of surface water capture requires this context. Until such quantitative understanding exists, the results of this study are of limited value.

As an example of the difficulties faced with existing information, it is quite probable given the climate, lithology and the path of Burra Creek, that streamflow is an important source of recharge. The creek crosses a highly faulted zone in the vicinity of the township, and the catchment contributing flow upstream of this point will potentially provide a significant source of recharge. However, some of the highest farm dam development levels are found in northern sub-catchments and the resulting reductions in flow may be impacting on these indirect recharge processes. Whether limiting farm dams to existing benchmarks will ensure sufficient recharge to maintain the permanent baseflow is currently impossible to determine.

Establishing and protecting environmental needs for water also requires an improved understanding of the catchment water balance. The perennial central catchment constitutes a groundwater-dependent ecosystem, the extent of which is effectively unique in semi-arid South Australia and hence is of intrinsic ecological (and commercial) value. As the permanent baseflow appears to be part of the natural water balance of the Skillogalee Dolomite, in many ways this perhaps should be considered as a discrete groundwater management unit. The most important question to be addressed for the future management of catchment environmental values is arguably determining the level of threat to this highly transmissive zone of the regional aquifer.

Protection of groundwater discharges alone however will not ensure that the ecological integrity of the catchment is maintained. Indications from modelling are that key surface runoff driven flow bands are already compromised to a very significant degree. The variability of runoff across the full range of flows plays a key role in maintaining the ecological integrity of the riverine system as a whole. Substantial additional work will be necessary to confirm the potential impacts indicated by this study and, where necessary, identify methods to ameliorate these.

The following section proposes some steps that could be taken to improve the current understanding of hydrology and ecology within the catchment. This will then allow for the development of meaningful limits on the sustainable use of both surface and groundwater in the catchment.

9.1 TECHNICAL RECOMMENDATIONS

Clearly, a lack of information has hampered the level of certainty and number of conclusions that can be drawn from this investigation. In particular, the lack of monitoring of surface water, groundwater and biological components of ecosystems presents a major challenge to distinguishing impacts due to human activity. The following recommendations are divided into surface and groundwater monitoring, with the monitoring of flow-related ecological processes addressed under the section on further investigations. Recommendations within each section are made in perceived priority order.

9.1.1 SURFACE WATER MONITORING

The catchment area of 541 km^2 is currently only serviced by a single gauging station. Provided that the low-flow response can be restored, the site of this station is probably ideal for continued use as a regional base station. Given the distinct differences between the northern and central catchment, it is unrealistic to expect a single site to provide an accurate representation of catchment hydrology at scales necessary to direct management efforts.

Adding to the difficulties are the complex surface water and groundwater interactions. Whereas the station was initially capable of providing information that would help to monitor the discharge volumes from the aquifer, siltation during the 1992–93 floods removed this capability, which now limits the conclusions that can be drawn from the data.

The following recommendations are listed in roughly the order of priority of appropriate steps to improve the future position to better understand catchment hydrology:

1. ***Maintain and improve the existing streamflow gauging site:*** The gauging station at Worlds End provides a rare long-term, continuous record of streamflow of intrinsic value. The value of this data increases the longer that the site is operational. Although low-flow resolution has been compromised since 1992, much good quality data have been recorded and are of use in determining, for example, return periods of a surface flow event of interest. It is suggested that:

    - The existing site is maintained and the low-flow monitoring capability of the site be restored. Ideally this would involve the installation of a new rated low-flow control structure. Depending on how this was achieved, it may be possible to collect concurrent streamflow records with the existing control for a sufficient period of time to enable a relationship between the two controls to be developed. This will then allow extension of the new station record to include the existing data.
    - At a minimum, the site should be regularly cleared of weeds and silt to guarantee the sensitivity of the low-flow response. This is particularly important following significant flow events.
    - The site be equipped for continuous salinity and temperature monitoring.

2. ***Commission a new site or sites to quantify streamflow from the catchment upstream of Burra township and the interactions between Burra Creek and the Skillogalee Dolomite (including any influence exerted by the maintenance of the recreational lake):*** The upper Burra Creek Catchment is important not only because of the surface runoff it may generate, but also because it is likely that streamflow leaving the catchment is a significant source of recharge to groundwater where the creek flows over zones of faulting and jointing. Given the proximity of the fault and the leakage rate from the lake, this reach may have a disproportionate influence on volumes that recharge to the aquifer when surface runoff occurs. The operation of the lake is the source of significant uncertainties with regard to recharge of the Skillogalee Dolomite and also complicates the measurement of streamflow. At least two flow gauging sites are required to improve understanding of the rainfall–runoff relationship in the upper Burra Creek Catchment and the influence of the lake. Ideally, both would be implemented:
   - Provided that an existing structure proved suitable, the lowest installation and maintenance costs may be for the installation of a continuous water level and EC–temperature probe and data recorder in the recreation lake in the township. The site should be located at the most appropriate control structure to establish a suitably sensitive stage-discharge relationship.
   - If no suitable site can be found in the lake itself, a new flow gauging site will need to be installed upstream of Burra township to allow for the streamflow input to the lake to be determined. Irrespective of the above sites, the volume of water flowing out of the lake will need to be monitored continuously.
   - In addition to the surface water flow gauging sites, information required to address uncertainties relating to the water balance of the creek and underlying aquifer in the vicinity of Burra township include:
     - metering of pumped volumes to the recreational lake,
     - monitoring of lake water levels using a continuous data recorder,
     - collection of continuous rainfall and evaporation data near to the township.
3. ***Poor understanding of rainfall distribution and intensity:*** Install three new pluviometers, one in the northern catchment (possibly near Burra township as suggested above) and two at sites in the central catchment to determine the effects of elevation on rainfall. One site should be on top of a suitable high peak and the other located in the adjacent valley floor. A useful additional parameter would be the concentration of chloride in rainfall to enable future salt balance studies to be undertaken.
4. ***Lack of daily evaporation data within the catchment:*** Install at least one, and preferably two, continuous evaporation monitoring stations within the catchment, possibly co-located with pluviometers or other monitoring infrastructure at locations described above.

9.1.2 GROUNDWATER MONITORING

No current groundwater monitoring has been identified within the catchment. Significant monitoring data were collected during the second period of mine operations commencing in 1975 and continuing until at least 1981. If possible, these data should be located and monitoring of the same wells resumed.

Analysis of the current groundwater levels compared to 1975–81 may provide some insight into the behaviour of groundwater in this aquifer since that time. Additionally, ongoing monitoring, possibly with a small number of wells on continuous recording, if undertaken in conjunction with surface water flow monitoring in the creek immediately north of the fault zone in the township, may help provide an indication of surface water – groundwater interactions and recharge processes.

A catchment-wide groundwater level and salinity monitoring network is also suggested and this could be based largely on community participation, provided that training and equipment were available to support landholders.

9.1.3 ECOLOGICAL MONITORING

As the level of available data is extremely limited, any biological or ecological monitoring program would need to be established through a dedicated research project. The scope of a suitable project is discussed in the following section.

9.1.4 FURTHER INVESTIGATIONS

9.1.4.1 Surface water and groundwater interactions

The priority investigation for the catchment should be seen as investigating the surface water – groundwater interactions in the catchment, focusing on the determination of a full water balance for the Skillogalee Dolomite, to address the following specific issues:

- Confirming whether the Skillogalee Dolomite is the major, if not sole, source of the significant permanent baseflow in the central Burra Creek Catchment.
- The groundwater flow processes between surrounding lithologies and within the Skillogalee Dolomite itself, including the location of discharge sites and rates of flow.
- Recharge processes to the Skillogalee Dolomite, especially the relative contribution of rainfall and streamflow, and whether decreased streamflow from the northern catchment is impacting on aquifer storage and discharge.
- Impacts, if any exist, of pumping from the Skillogalee Dolomite to maintain the recreational lake and, if so, how to minimise these (including any possible impacts of lining the lake).
- Development of guidelines for the future use of the groundwater resource such as minimum buffer distances for new wells to avoid drawdown of permanent surface water features.
- Assist in determining trends in salinity for the catchment.

9.1.4.2 Flow ecology relationships

Flow bands used in this report, although based on well-established principles, are effectively arbitrary. This applies in particular to the threshold values adopted to define these flow bands. The work is intended only to provide the basis for a first-order indication of potential hydrological stress. Future work should more accurately define critical flow stages, their durations and the ecological response through detailed survey work and research.

Application of a similar approach to that employed in this report across some of the other sites of ecological significance by relating flows back to the gauging station will provide a baseline framework to test hypotheses of flow-related ecological response. This may be of particular value in the Hopkins Creek Conservation Park site where riparian condition is the best found within the catchment. Hopkins could also form a control site for future ongoing monitoring program that could be developed out of the research.

An investigation of this nature might take the following broad form.

Stage 1 (6–12 months):

- Select suitable sites for inclusion in the study (a sufficient number to represent the range of broad geomorphic and hydraulic conditions present in the catchment) and install a continuous water level and EC–temperature data recorder. Ideally, sites would have a suitable substrate and morphology to enable a stage-discharge relationship to be developed.
- Clearly articulate hypotheses of level or flow-related ecological responses and identify stage heights that delineate the boundary between these potentially ecologically important processes, and then relate this to estimates of their expected frequencies based on comparisons with the gauging station or modelling.
- Undertake biological and physical surveys to quantify factors such as the current distribution, diversity and abundance of biota at each site; cross-sectional morphology; substrate composition; and recruitment or other expected processes within the zone of influence of each level or flow band.

Stage 2 (2–5 years):

- Continue to conduct quarterly biological surveys and analyse biological and continuous streamflow data to look for trends supporting the hypotheses.
- Refinement of hypotheses, monitoring protocols and sampling frequency.
- Supplementary opportunistic sampling could take place where possible following immediately after key events of interest, for example large floods.
- Identify the minimum data required to assess the ecological integrity of any site in the catchment; this would effectively form a monitoring program.

Stage 3 (on-going):

- Based on the findings of the above stages, ongoing work would focus on more widespread monitoring focusing on establishing the extent of the key ecological processes identified in the pilot study, and linking these to any flow restoration or catchment improvement on ground works.
- Ideally the control site (e.g. Hopkins Creek) would be operated indefinitely to provide insight into processes occurring over a longer period of time and to provide examples over a fuller range of climatic conditions. Ongoing operation of the site would also allow for improvements to the monitoring protocols to be incorporated as understanding of ecological processes improved.

Implementation of the necessary research and monitoring programs that measure responses based on flow patterns will improve the certainty of the flow–ecology relationships and determine any management actions required to recreate critical aspects of natural flow regimes.

9.2 MANAGEMENT RECOMMENDATIONS

For the sound future management of the Burra Creek surface and groundwater resources, it is essential that more baseline information be collected on water use and resource behaviour. The following suggestions could be considered under this heading:

- Conduct a well audit and determine the status of all wells listed in the state drillhole database and their current pumping usage. Rehabilitate any unused wells to prevent the potential for inter-aquifer leakage or surface contamination.
- Implement a catchment-wide groundwater monitoring program focusing on regional watertable levels and salinity monitoring to determine likely groundwater flow paths. A biannual sampling program is recommended for the well network, with levels and salinity taken at the end of the winter rainfall season (i.e. during October–November) and following the high evaporation summer period (i.e. during March–April).
- Raise awareness of the impacts of farm dams and the need to allow 'free-to-flow' areas within all catchments.
- Prevent any further dam development in stressed catchments identified in Figure 48, and consider options to reduce the existing impact through strategies such as the installation of low-flow by-passes.
- Limit the size of all stock dams to a volume that reflects the stock-holding capacity of the proponent.
- Consider the offering of incentives for dam retirement in highly stressed areas such as those identified in Section 7.
- Where possible, encourage the fencing of permanent watercourses and retirement of the riverine corridor from grazing. Where water is pumped from permanent pools within watercourses to support this activity, no impact on water level or water quality in the watercourse should result. In other situations, pumping directly from permanent pools should be avoided.
- Avoid high-volume extractions of groundwater where the pumping zone of influence will impact on a permanent pool or baseflow reach as shown in Figure 51. Potential developments should be required to demonstrate that no impact will occur as a result of the development, and approval should be made contingent upon provision of monitoring data consisting of pumped volumes, regular water levels and rainfall at the site. Continued operation of the proposed development should be contingent upon no detrimental impacts being indicated by the analysis of monitoring data.
- Develop policies for future water resource development that avoid high consumption activities without proper consideration of total resource capacity. If doubt exists over potential high water use proposals, where possible a staged implementation, with appropriate monitoring and evaluation prior to approval for further expansion, should be adopted.
- Raise community awareness regarding the sustainable capacity for use of the water resources of the region.
- Encourage optimal water conservation strategies in all water resource use and future developments.

APPENDICES

A. FARM DAM VOLUME CALCULATIONS

Farm dam volume calculations followed the methods established in McMurray (2004). This involves digitising the surface area of the farm dam from aerial photography and applying the formulae below.

For farm dams of area less than 15 000 m^2:

$$\text{Dam volume (ML)} = 0.0002 \times (\text{surface area})^{1.25}$$

For farm dams of area 15 000 m^2 or greater:

$$\text{Dam volume (ML)} = 0.0022 \times (\text{surface area})$$

B. MODEL SUB-CATCHMENT SUMMARY DATA

Sub-catchment name	Area (km^2)	Farm dam capacity (ML)	Farm dam density (ML/km^2)	Mean annual rainfall (mm)	Allowable dam volume[2]	Free to flow area[3]	Factor 1[2]	Rainfall station	Rainfall factor
Razorback	52.97	101.6	1.92	400	122	0.25	0.09744	021034	0.923
Mt Bryan	63.51	173.9	2.74	407	148	0.25	0.09675	021034	0.941
Firewood Creek	99.04	120.2	1.21	420	239	0.45	0.10030	021077	0.962
Upper Burra Creek	89.99	172.3	1.91	398	213	0.6	0.07196	021077	0.914
Springbank Valley	39.97	95.0	2.37	433	110	0.35	0.09724	021077	0.993
Logan Creek	65.59	100.2	1.53	398	161	0.55	0.08639	021077	0.912
Lagoon Hill	47.77	114.4	2.40	392	117	0.1	0.10614	021077	0.900
Worlds End	82.56	107.5	1.3	346	174	0.5	0.10031	021086	1.088
Middle Burra Creek[1]	61.0	56.8	0.93	318	–	–	–	–	–
Lower Burra Creek[1]	335.3	370.2	1.10	236	–	–	–	–	–

1 Sub-catchment not within modelled catchment.

2 Based on 30% of mean adjusted May–November runoff of 4298 ML.

3 Used in modelling to estimate how dam surface area changes in response to water level.

4 Estimate only, based on visual inspection of digital catchment farm dams, drainage and contour coverage.

C. REACH-SCALE SUB-CATCHMENT SUMMARY DATA

Sub-catchment code	Area (km^2)	Average rainfall (mm/y)	Number of dams	Total dam volume (ML)	Dam density (ML/km^2)	Allowable 30% rule (ML)	Proportion of allowable
FIR1	38.6	436.4	39	58.7	1.5	83.8	0.7
FIR2	28.2	411.1	24	31.7	1.1	61.2	0.5
FIR3	19.8	393.8	5	9.6	0.5	42.9	0.2
FIR4	12.4	425.6	16	20.2	1.6	27.0	0.7
LAG1	17.1	390.6	23	19.7	1.2	36.8	0.5
LAG2	15.1	391.5	38	39.9	2.6	32.6	1.2
LAG3	15.6	394.9	44	54.8	3.5	33.7	1.6
LBC*	335.3	235.5	122	370.2	1.1	–	–
LOG1	7.3	416.6	9	15.9	2.2	16.1	1.0
LOG2	13.6	400.2	8	9.5	0.7	29.9	0.3
LOG3	17.4	408.2	16	25.8	1.5	38.2	0.7
LOG4	8.8	394.7	3	3.7	0.4	19.4	0.2
LOG5	4.2	392.6	5	31.2	7.4	9.3	3.4
LOG6	14.2	375.4	11	14.0	1.0	31.2	0.5
MBC1*	27.2	332.2	23	50.8	1.9	–	–
MBC2*	33.8	307.4	6	5.9	0.2	–	–
MTB1	11.2	420.0	18	42.4	3.8	23.4	1.8
MTB2	18.2	420.0	24	36.0	2.0	37.9	1.0
MTB3	8.9	423.9	16	36.6	4.1	18.5	2.0
MTB4	11.8	423.9	10	12.8	1.1	24.5	0.5
MTB5	4.0	420.0	11	26.1	6.5	8.4	3.1
MTB6	5.1	420.0	7	12.6	2.5	10.5	1.2
MTB7	4.3	423.9	4	7.4	1.7	8.9	0.8
RAZ1	5.6	383.0	5	20.1	3.6	11.5	1.7
RAZ2	3.3	400.0	5	17.3	5.2	6.8	2.5
RAZ3	4.3	400.0	8	9.0	2.1	8.9	1.0
RAZ4	2.0	395.8	6	6.8	3.3	4.2	1.6
RAZ5	9.7	400.0	10	18.6	1.9	19.7	0.9
RAZ6	24.7	395.8	31	22.4	0.9	50.5	0.4
RAZ7	3.2	395.8	6	7.4	2.3	6.5	1.1
SPR1	6.7	440.0	10	20.7	3.1	16.0	1.3
SPR2	21.2	436.6	25	38.6	1.8	50.9	0.8
SPR3	2.9	432.0	7	10.2	3.5	6.9	1.5
SPR4	9.3	420.0	13	25.5	2.8	22.2	1.1
UBC1	12.6	409.6	20	74.2	5.9	26.8	2.8
UBC2	7.8	420.0	13	14.6	1.9	16.6	0.9
UBC3	13.4	413.8	8	12.5	0.9	28.5	0.4
UBC4	9.6	416.2	12	13.5	1.4	20.6	0.7
UBC5	31.0	388.2	16	41.2	1.3	66.0	0.6
UBC6	15.7	374.6	8	16.2	1.0	33.5	0.5
WOR1	44.6	333.0	33	52.3	1.2	84.3	0.6
WOR2	10.6	365.2	12	8.8	0.8	20.1	0.4
WOR3	27.3	359.6	30	46.4	1.7	51.7	0.9

*Sub-catchments located outside of the gauged catchment — no attempt made to evaluate the runoff.

D. RAINFALL DISAGGREGATION AND INFILLING

Rainfall data are collected at 0900 on a daily basis in the BoM stations. Rainfall collected during weekends and public holidays is recorded at 0900 on the next working day. This necessitated disaggregation of the accumulated rainfall for those days when rainfall was not recorded. The methodology used by SKM for disaggregation is based on the method outlined by Porter and Ladson (1993). This method was utilised by SKM on data throughout South Australia up until the end of 1998. The same methods were applied in this study to disaggregate and infill daily data collected since that time.

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

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

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

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

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

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

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

For infilling the missing rainfall records, the correlation method was used. The annual rainfall of a station **S** of interest was correlated with that of other nearby stations. The station with the highest correlation factor with **S** that had data concurrent with the missing period was used for infilling the records using the long-term relative proportional relationship between the means as a correction factor.

E. RAINFALL HOMOGENEITY CORRECTION

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

A monthly double mass curve analysis was used to check the homogeneity of the rainfall records of each station analysed against a regional average. For a homogeneous dataset this should be a straight line. Sections of the line indicating alterations of slope greater than 5% are considered non-homogeneous and require adjustment of the raw data. Homogeneity checks were performed for the long-term rainfall records of the following stations, which were all examined for potential use in modelling — 21019 Farrell Flat; 021077 Burra; 021086 Worlds End; and 021034 Mount Bryan.

For each of these stations, a monthly double mass curve versus the average of all other stations was constructed; an example of these is shown in Figure 63.

The double mass curve was plotted between the monthly rainfall at Station 21019 and the average monthly rainfall of the other three stations listed above. Slope changes were observed in the plot leading to two sections (S1, S2) with varying slopes being identified.

A change in slope of 5% or more is generally considered to be a non-homogenous dataset. Sections that are non-homogenous are then adjusted by using the average slope of the sections on either side of the curve. In this case, all sections were considered to be non-homogenous (as change in slope is >5%) and hence these were adjusted by appropriate correction factors to ensure a consistent slope of the record against long-term regional average.

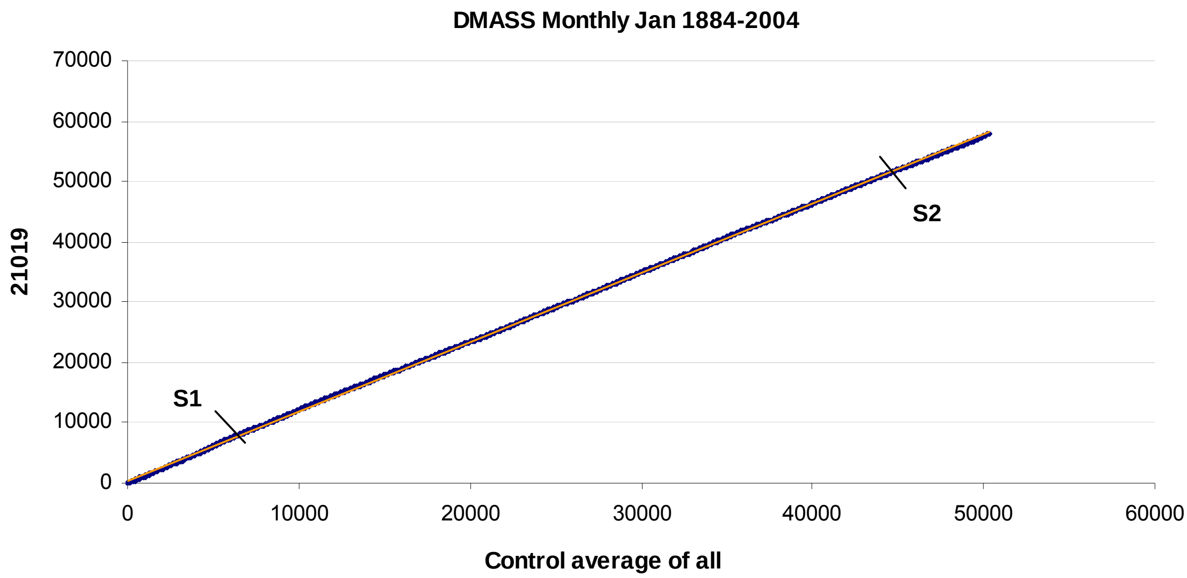


Figure 63. Monthly double mass curve for station 21019 versus regional average, Burra Creek region

F. STREAMFLOW HOMOGENEITY

Streamflow records can also be analysed in the same manner in which consistency of records between rainfall stations can be assessed through a double mass comparison. Figure 64 shows a double mass analysis of the relationship between Burra Creek and the average for two catchments in the adjacent Broughton River (Hutt River and Hill River). As both of these stations are located in reaches that feature a seasonal cease-to-flow period, the monthly data have been filtered to only include months of continuous flow.

The graph shows a linear section within the record corresponding to the period in time immediately following installation of the low-flow control in June 1983 and the major flooding in 1992–93. This relatively consistent relationship suggests that streamflow records from the period are most reliable, and that records are less representative of true flow values since the siltation. This period is shown in more detail in Figure 65.

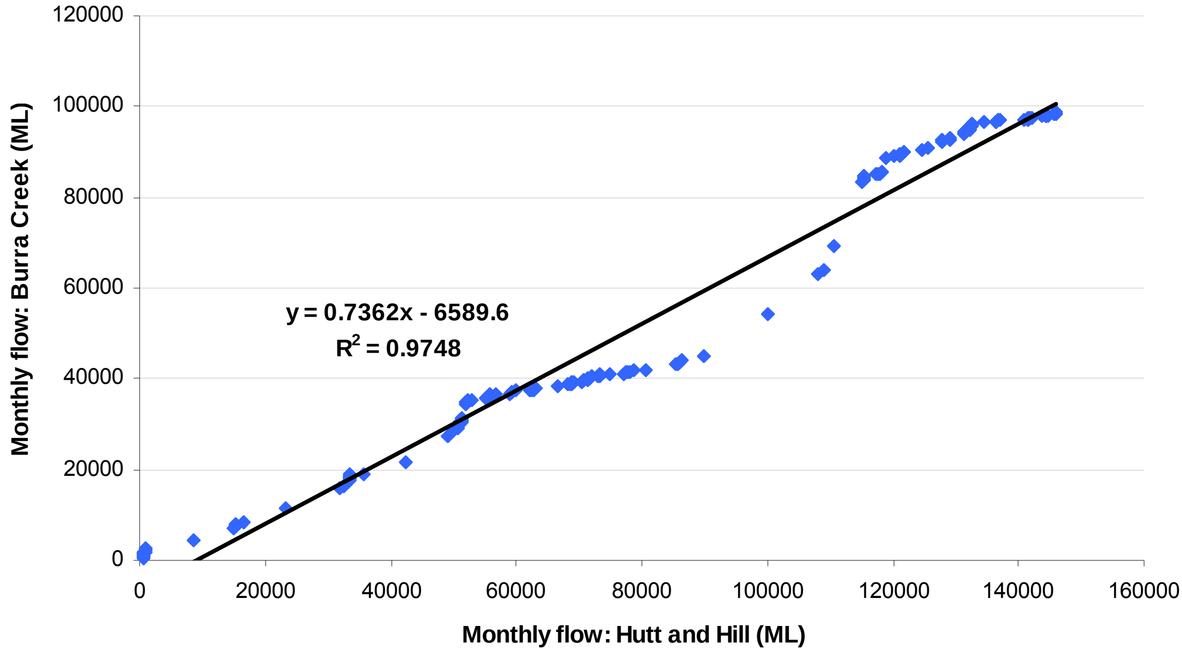


Figure 64. Monthly streamflow double mass, Burra Creek versus Hutt and Hill Rivers, 1974–2004

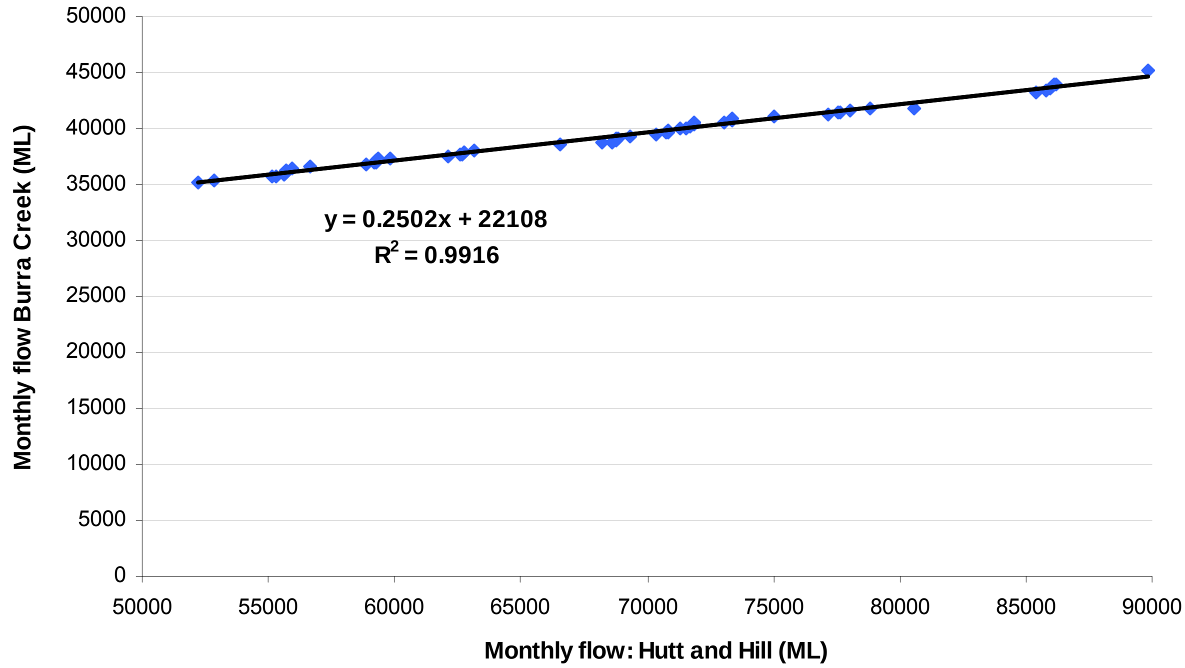


Figure 65. Monthly streamflow double mass, Burra Creek versus Hutt and Hill Rivers, 1983–92

G. DISTRIBUTION OF ANNUAL STREAMFLOW

Statistics derived from annual streamflow data are often used as a basis from which to determine an appropriate amount of development within a catchment of interest. The mean streamflow is often used as a measure of centrality of the dataset and therefore a possible indication of the amount of flow that can be expected in a typical year. The usefulness of the mean, or average, as an indication of the centrality of a dataset is highly dependent on the shape of the distribution itself. In a highly skewed dataset such as that observed for the Burra Creek Catchment, extreme values can elevate the mean to a large degree.

For example, in the Burra Creek Catchment only six years in the period between 1974 and 2004 received the mean annual streamflow of 5248 ML, suggesting that the mean is not an adequate measure of centrality. Log transformations of streamflow data are often observed to make the distribution more closely fit a normal distribution. Log values of streamflow were plotted against a theoretical normal distribution with the same mean and standard deviation, and this appears in Figure 66. The data fit the theoretical distribution relatively well, although the positive skewness is still apparent in the slight concavity.

It was not possible to detect any difference between the distribution of the log-transformed streamflow data and the theoretical distribution using the non-parametric Kolmogorov-Smirnov test (Press et al. 1992), supporting its usefulness as a more appropriate distribution to describe the streamflow data than the normal distribution.

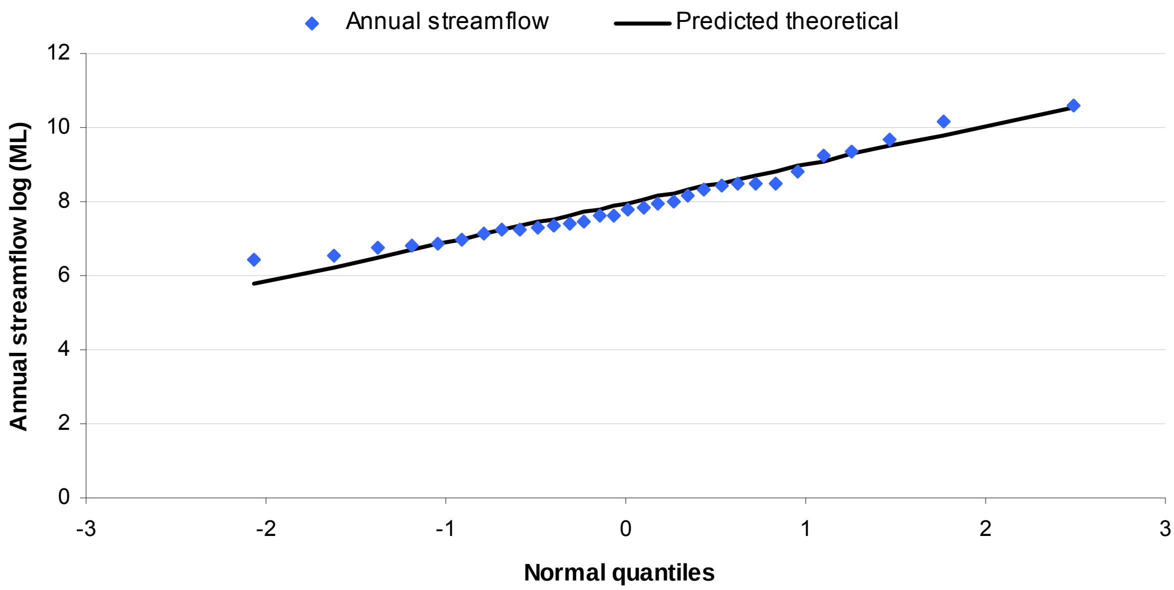
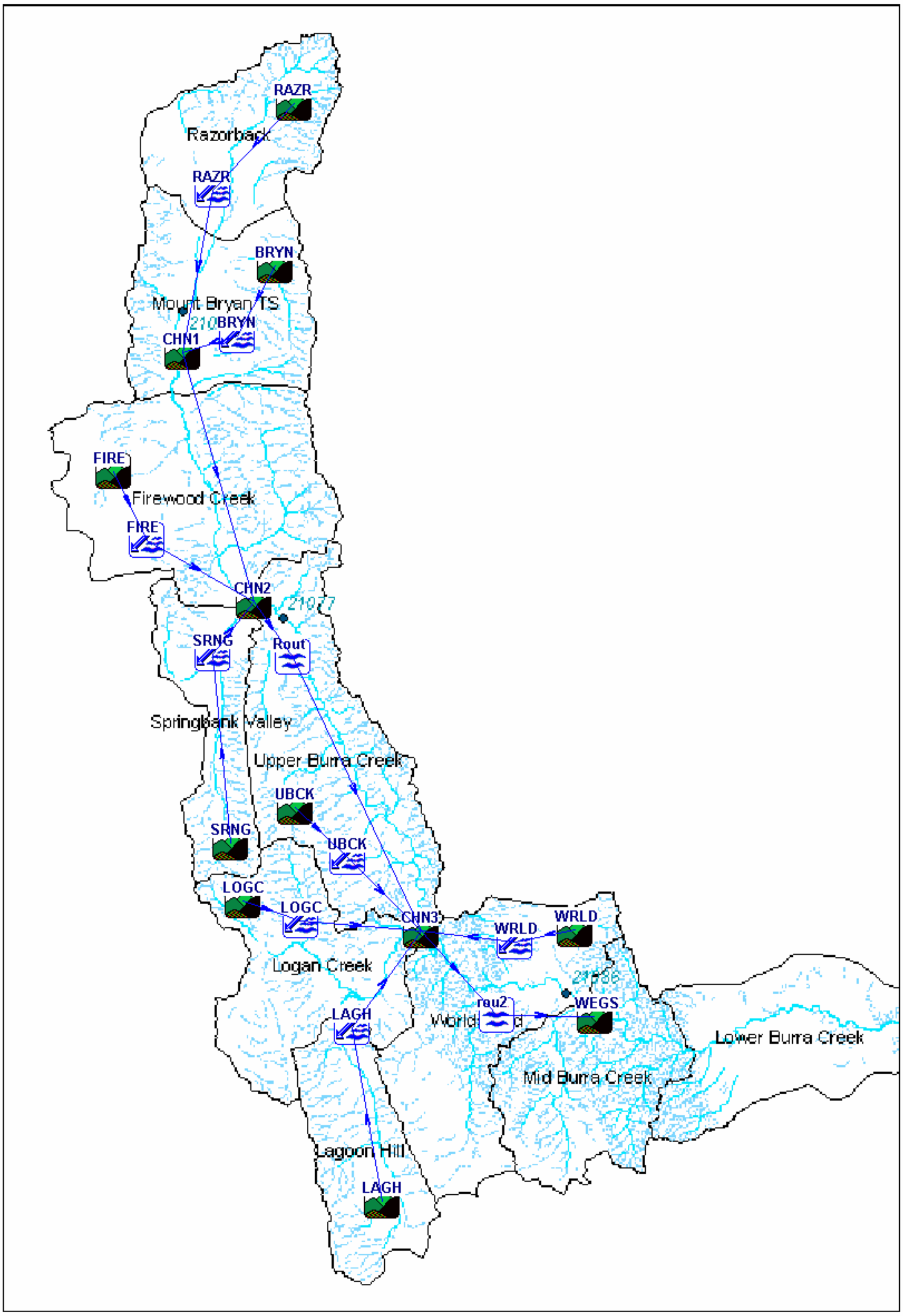


Figure 66. Log transformed annual streamflow data, Burra Creek, 1974–2004

H. MODEL LAYOUT



I. WATERCRESS MODEL PARAMETERS

Abbreviation	Parameter	Value
MSM	Medium soil moisture	101.85
IS	Interception store	14.441
CD	Catchment distribution	48.693
GWD	Groundwater discharge	0.13061E-01
SMD	Soil moisture deficit	0.51691E-03
PF	Pan factor	0.67399
FGL	Fraction groundwater loss	0.10930E-02
SRC	Soil reduction coefficient	0.56182
GWR	Groundwater recharge	0.14936
CL	Creek loss	0.81699E-04

J. NATIVE FISH SURVEY REPORT

Appendix J: Freshwater fish Sampling in Burra Creek:
Summary Report to Department of Water, Land and Biodiversity Conservation

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December 2005

Introduction

Native Fish Australia (SA) provided field assistance and expertise to the Department of Water Land and Biodiversity Conservation as part of a program to assess ecological assets and health of the Burra Creek system, an occasional tributary to the River Murray in South Australia north-east of Adelaide. The below summarises sampling activity for fish including an interpretation of results.

Survey Methods

Two separate trips to Burra Creek occurred on 20th-22nd of June and 26th-28th of October, 2005. A number of types of equipment were used to sample for freshwater fish opportunistically at pre-determined health sites on the waterway. Techniques employed depended upon the nature of habitat taking into consideration, flow, depth and dimensions of pools, also the amount of in-stream cover. Equipment and methods included:

- 6 single winged fyke-nets (6m wing, 3 compartments and 5mm mesh, usually set for 12 hours overnight) – see Fig. 1.
- 7m by 2m seine net (6mm mesh) – standard 10m hauls
- 20m seine net (12mm mesh)
- Baited box traps –set for 1-2 hours
- Sweeping of potential habitat with dip-net (0.5m diameter)
- Observations using polarized sunglasses

Survey Results

Ten sites were sampled on the Burra Creek system (Table 1). There were two exotic species sampled from Burra Creek during this survey: rainbow trout (*Oncorhynchus mykiss*) and eastern gambusia (*Gambusia holbrooki*). Brown trout (*Salmo trutta*) are also known to occur in the Burra Gorge section as identified by concurrent sampling by another Native Fish Australia (SA) team (unpublished data, 2005).

Table 1: Site Details from June and October field sampling, 2005

Site code	Date	Location	Zone	Easting	Northing
B05(t1) 01	20/06/05	Burra Ck @ Gorge	54H	318150	6254715
B05(t1)-02	20/06/05	Burra Ck @ Gorge	54H	317937	6254582
B05(t1)-03	20/06/05	Hopkins Ck	54H	317052	6253728
B05(t2)-01	27/10/05	Burra Ck, d/s Worlds End gauging station	54H	322710	6253645
B05(t2)-02	27/10/05	Burra Ck, Mosey property, most d/s pool	54H	339656	6252789
B05(t2)-03	28/10/05	Burra Ck, Mosey property, u/s pool	54H	336997	6252802
B05(t2)-04	28/10/05	Burra Ck, d/s Thirty Pound pool	54H	316583	6255470
B05(t2)-05	28/10/05	Burra Ck, u/s Logan Ck confluence	54H	314452	6257668
B05(t2)-06	28/10/05	Burra Ck, 2nd site u/s Logan Ck confluence	54H	314452	6257668
B05(t2)-07	28/10/05	Burra Ck, Spring Ck	54H	315382	6256198

Table 2: Site results indicating presence (1) of fish and some larger invertebrates from June and October, 2005, species codes used; GAMH-*Gambusia holbrooki*, ONCM- *Oncorhynchus mykiss*, SALT-*Salmo trutta*, Cherax-*Cherax destructor*, Paratya - *Paratya australiensis*. (*) - known to occur in the area from recent sampling.

site code	GAMH	ONCM	SALT	Cherax	Paratya
B05(t1)-01	1			1	1
B05(t1)-02					
B05(t1)-03				1	
B05(t2)-01	1	1		1	1
B05(t2)-02					
B05(t2)-03					
B05(t2)-04	1			1	1
B05(t2)-05	1		*	1	1
B05(t2)-06	1			1	1
B05(t2)-07				1	

In the Burra Creek, examination of gut contents in October revealed trout were consuming *Paratya*, *Cherax*, Amphipods, caddis (Trichoptera), smaller unidentified hemipterans, and other unidentified smaller invertebrates (e.g. see Fig. 2). Female rainbow trout were found to be ripe with large quantity of eggs observed in specimens captured in October.

Figure 1: Mid-Gorge stream type habitat with fyke observable in fore-ground

Figure 2: Inspecting gut contents of a rainbow trout
(numerous Paratya *and other larger macroinvertebrates)* Photos SW

Discussion

The first sampling trip conducted in June was perhaps not the most ideal time to be sampling, and even in October water levels were up with reasonable flows. Sampling in late summer or autumn would have been more preferable as winter flows and cool temperatures mean that fish numbers are thinned and fish activity low at this time of year. Hence although the survey seemed a reasonably accurate representative of fish fauna in the Creek, some species may not have been detected (e.g. brown trout records).

Although no native fish were found their presence in the area cannot be ruled out. Many smaller native species have been found elsewhere to the south in the Eastern Mount Lofty Ranges, surviving within very restricted ranges (Hammer 2004). Hence it is still quite possible for a population of native fish to be present at some location in the Burra Creek Catchment. It is difficult to establish whether native fish were present prior to European settlement in the catchment due to a lack of historic information or records (see Hammer *et al.* 2005). But given the large size, occasional connectivity to the Murray and reasonable representation of surface waters it is highly probable that native fish have been or are present (species such as smelt *Retropinna semoni*, mountain galaxias *Galaxias olidus*, flathead and dwarf-flathead gudgeon *Philypnodon* spp. and carp gudgeons *Hypseleotris* spp. are some of the most likely candidate species: refer to Hammer and Butler 2001a for details on these species). Specifically there were three main habitat types observed in the catchment. Firstly, the lowland flood-out habitat at the lower end of Burra Creek was quiet saline, containing Chara and *Ruppia*. This would seem to be the type of habitat quiet often populated by saline adaptable species such as those of the family Artherinidae (hardyheads). Higher in the catchment, around the gorge area, there is other potential habitat where salinities are lower, with more consistent flows. Here two other forms of habitat occur: stream and deeper pools. These habitat types in many ways seem analogous to those in other parts of the eastern flowing waterways of the SA Murray-Darling Basin which do contain fish (Eastern Mount Lofty Ranges: Hammer 2004).

Current isolation from other permanent water sources or fish populations would certainly expose species to local extinction due to natural or anthropogenic influences with recolonisation being quite difficult. Hence a range of threats evident in the catchment (e.g. mining, water resource development) may explain the lack of native fishes detected. As the catchment is naturally highly variable with regard to flow, aquatic biota would be especially vulnerable to local or broader threats in times of low flow and pool contraction (dry seasons or extended periods).

A further threat to native species would be posed by introduced fish. Rainbow trout and eastern gambusia found in the waterway are species evolved to environments elsewhere. Both can potentially alter the ecology of aquatic ecosystems. Rainbow trout are a large predatory species native to the western coast of North America (McDowall 1996). They grow much larger than the majority of native species and where trout exist with native species they are likely to not only compete for food and habitat resources but also directly predate upon the native species. Large, active predators like trout can also consume larger sized prey and larger amounts of prey (e.g. see Fig 1 from Burra George). As such they can greatly alter the trophic balance within small pools. It is not known if these individuals are successfully reproducing, or probably the more likely option, are being stocked (see recent report of illegal stocking for nearby Baldina Creek: Hammer *et al.* 2005). Gambusia is native to rivers of the Gulf of Mexico (McDowall 1996). Introduced to Australia in the 1920's, they are now widespread in South Australia. Although only small (max. size around 60mm) they can almost totally dominate under favorable conditions, perhaps a consequence of their live-bearing reproduction. Gambusia will compete for food resources and are known to be aggressive towards fish species (Hammer and Butler 2001b). They may also present a direct predatory threat to larval and small native species.

Importantly other exotic species that commonly present a problem in local waterways, and that might have been expected, so far do not appear to have become established (i.e. goldfish *Carassius auratus*, common carp *Cyprinus carpio* and redfin perch *Perca fluviatilis*). Increasing community awareness about the threats these organisms place on ecosystems may assist in keeping exotic species out of the system into the future.

Future research could focus on autumn snapshots of better conditioned sections of the catchment, especially where springs occur as there is still a possibility that refuge populations of smaller native species occur. Documenting oral history of fish reports would be extremely valuable to help establish the historic species list for the Burra Creek Catchment and to focus future sampling efforts.

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K. MACRO-INVERTEBRATE REPORT

Report: Mid-North Macroinvertebrate Sample Analysis (AusRivAS) and Results

Compiled by: Sally Maxwell

Submission date: 15th August 2005

For: Department of Land Water and Biodiversity

Australian Water Quality Centre

CERTIFIED QUALITY MANAGEMENT SYSTEM ISO 9001

SA Water

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.

Burra Gorge was determined as A Band by the Autumn Edge AusRivAS model indicating that it was equivalent to reference condition.

Hopkins 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 sample in June 2005

Site	OE50	BAND
BUR01	1.02	A
BUR02	0.56	B

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 sites having the highest number of missing taxa record B ratings.

Table 2: Missing taxa in sites sampled June 2005

Site	BUR01	BUR02
Nematoda		×
Hydrobiidae	×	
Acarina	×	×
Ceinidae		
Atyidae		
Collembola		×
Ceratopogonidae		×
Orthocladiinae	×	×
Corixidae	×	×
Hydroptilidae		
Leptoceridae		×
Total no. missing	**4**	**7**

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Appendix 1: Macroinvertebrate Identification Sheet

Sample Alphanumeric		**BURO1**	**BURO2**
Date		20-Jun-05	21-Jun-05
Site Name		Burra Gorge	Hopkins Creek
Habitat		Edge	Edge
# of Taxa		28	21
Total Abundance		381	295
number of vials sorted		13	13
processing time		9.75	8.25
operator name		SM	SM
Family			
Nematoda	Nematoda spp.	82	150
Hydrobiidae	Hydrobiidae spp.	1	
) Naididae	Nais sp.	1	
) Enchytraeidae	Enchytraeidae spp.	1	1
) Oligochaeta	Oligochaeta spp.	9	6
Ceinidae	Austrochiltonia australis	10	84
Aytidae	Paratya australiensis	9	
Parastacidae	Cherax destructor	1	1
) Hypogastruridae	Hypogastruridae spp.	5	
Ceratopogonidae	Culicoides sp.	56	
Tanypodinae	Procladius sp.	66	6
Tanypodinae	Paramerina sp.	17	4
Tanypodinae	Larsia sp.	6	2
Chironominae	Riethia sp.	1	
Chironominae	Cladotanytarsus sp.	6	1
Chironominae	Tanytarsus sp.	1	15
Chironominae	Paratanytarsus sp.	79	
Tanytarsini	Tanytarsini sp.	1	
Chironominae	Polypedilum sp.	1	
Chironominae	Cryptochironomus sp.	1	
Chironomini	Chironomini sp.	5	
Baetidae	Cloeon sp.	3	3
Baetidae	Baetidae spp.	12	1
Caenidae	Tasmanocoenis tillyardi	1	
Aeshnidae	Aeshna brevistyla	1	2
Hydroptilidae	Hellyethira simplex	2	
Ecnomidae	Ecnomus cygnitus	1	
Leptoceridae	Triplectides volda	2	

Appendix 2: 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
BUR01	20-Jun-05	345	421	4470	2500
BUR02	20-Jun-05	429	524	3560	2000

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

~	approximately equal to
EC	electrical conductivity (µS/cm)
pH	acidity
ppm	parts per million
TDS	total dissolved solids (mg/L)

GLOSSARY

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

Anabranch — A branch of a river that leaves the main channel.

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

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

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

Aquifer, 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.

Artesian — Under pressure such that when wells penetrate the aquifer water will rise to the ground surface without the need for pumping.

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

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

Benchmark condition — Points of reference from which change can be measured.

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.

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

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

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

CWMB — Catchment Water Management Board.

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

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

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

DEH — Department for Environment and Heritage.

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.

Dry Sheep Equivalent (DSE) — One DSE represents the amount of feed required by a 50 kg wether to maintain its body weight.

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

EC — Electrical conductivity. 1 EC unit = 1 micro-Siemen per centimetre (µS/cm) measured at 25°C. Commonly used to indicate the salinity of water.

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

Ecological values — The habitats, natural ecological processes and 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.

Ecosystem services — All biological, physical or chemical processes that maintain ecosystems and biodiversity and provide inputs and waste treatment services that support human activities.

Effluent — Domestic and industrial wastewater.

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

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

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

EPA — Environment Protection Authority.

Ephemeral streams or 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.

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

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

Floodout — An area where channelised flow ceases and floodwaters spill across adjacent alluvial plains (adapted from Tooth 1999).

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

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

Fresh — A short duration, small volume pulse of streamflow generated by a rainfall event which temporarily, but noticeably, increases stream discharge above ambient levels.

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

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

GL — *See gigalitre.*

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

Groundwater — *See 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.)*

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

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

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.

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

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

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

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

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

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

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

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

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.*

MLR — Mount Lofty Ranges.

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

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

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

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

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

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

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

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

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

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

PWA — Prescribed Wells Area.

PWCA — Prescribed Watercourse Area.

PWRA — Prescribed Water Resources Area.

Quickflow — (also known as direct runoff or event flow) refers to that portion of streamflow generated during a storm event which enters the watercourse via direct runoff. For the purposes of this report, quickflow is defined as that volume of total observed streamflow for a given day that remains following subtraction of the volume identified as baseflow by the digital baseflow filter.

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.)*

Restoration (of water bodies) — Actions that reinstate the pre-European condition of a water body.

Reticulated water — Water supplied through a piped distribution system.

Riffles — Shallow stream section with fast and turbulent flow.

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

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

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

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

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

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

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.

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

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

Water body — Includes 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; a lake through which water flows; a channel (but not a channel declared by regulation to be excluded from the this definition) into which the water of a watercourse has been diverted; and part of a watercourse.

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

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

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

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