Willochra Catchment Hydrological and Ecological Assessment

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

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Cover Photographs

Department of Water, Land and Biodiversity Conservation, Willochra Creek and Tributaries

FOREWORD

Management of South Australia's natural resources requires a collaborative effort between the spheres of government, community based boards and committees and the public. Preparation of this report is an example of this. The Northern and Yorke Agricultural District Integrated Natural Resource Management Committee (NYAD INRM) commissioned the report in partnership with the Department of Water Land and Biodiversity Conservation, using funding from the joint State-Commonwealth National Action Plan for Salinity and Water Quality. The committee itself includes a blend of community, local government and public sector expertise.

Both the committee and the department have taken a keen interest in the study, bringing community, natural resources and specialist hydrological and ecological perspectives to the material in it. Individuals in the community have had input to shape the study in public meetings and have received briefings in its later stages. Following up on invitations to be involved, individuals and various agencies have provided information that has been used in the study.

The material provided in this report is a starting point that brings together what we know of the main water resources and water dependent ecosystems of the Willochra catchment. It will provide guidance to the NYAD INRM in establishing the way forward to better manage the natural resources of the area and it will be a useful information source for scientists and those in the community with an interest in water resources and associated development and ecosystems.

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EXECUTIVE SUMMARY

This report provides a preliminary assessment of the risks to sustainability of water-related development in the Willochra catchment. It focuses on water resources development in the southern part of the catchment and on the condition of water ecosystems in its more significant watercourses.

The study was undertaken by the Northern and Yorke Agricultural District Integrated Natural Resource Management Committee (NYAD INRMC) in collaboration with the Department of Water, Land and Biodiversity Conservation (DWLBC). The purpose of this study is to draw together existing community and scientific information, supplemented by limited ecological field work, to assess what further work needs to be done in the area to manage appropriately the water resources and associated development.

The surface water and groundwater water resources of the area support town water supplies, tourist activity and farming, including production of sheep, cattle, pigs, wool and broad scale cereal cropping. There has been a recent shift toward irrigated horticulture including the establishment of vineyards and olive groves. The region has a number of national and conservation parks of ecological significance that contribute to tourism.

Recent increases in irrigation development have led to stakeholder concerns that water resources may be approaching or exceeding sustainable levels of extraction.

While there is some scientific information on the water resources and fresh-water ecosystems of the area, it has not been drawn together with local knowledge and the data collected by community members to make the best of this information. A series of meetings have taken place to call on local information and data and existing work has been reviewed. In addition, a preliminary hydrological model has been developed to assemble rainfall and flow data according to the present understanding of physical processes. A fish and aquatic habitat survey of remnant pools has been completed to provide insight into the present state of health of water dependant ecosystems.

The objectives of this study are to:

- provide a greater understanding of catchment hydrology and ecology
- identify knowledge gaps and provide recommendations for future monitoring requirements
- make a preliminary assessment of the potential risks to sustainability of present water management.

Surface Water: The Willochra catchment is a semi-arid to arid catchment with low annual rainfall ranging from 650 mm in the south to less than 250 mm in the north, coupled with high potential evaporation of 2400 mm in the south to 2600 mm in the north. Runoff from the catchment is highly variable and dependent on rainfall intensity.

First order estimates of catchment runoff generated within the Southern Willochra catchment average around 7.4 ML/km^2 with an average annual catchment yield of approximately 8000–9000 ML. Based on typical water diversion equivalent to 200–300 mm over 40% of irrigated properties, water diversion is estimated to be approximately 2000–3000 ML. Generally farm dam development in the catchment is low with a density of 1.2 ML/km^2. The farm dam capacity is estimated to be 1400 ML.

A sustainability indicator was developed for the *State Water Plan 2000*, primarily for management of water use from farm dams. If water diversions are near or exceed the sustainability indicator, it triggers action to carefully manage water use from existing development and to limit new development until more reliable and accurate estimates can be made.

The combined pressure generated from flood irrigation and farm dam development approximates and probably exceeds the sustainability indicator for surface water. Consequently the need for closer attention to management of the surface water resource is indicated.

Anecdotal information provided by members of the community demonstrates that the surface water resource, under current climatic conditions and current development levels, is under significant stress. Impacts on the resource include:

- Reduced surface water runoff through capture of initial/early season runoff
- Delayed onset of stream flow events
- Shorter duration of seasonal flows
- No flow during drought periods
- Greater frequency of low flow events instead of a range of low, medium and high flow events
- Increased attenuation between the upper and lower reaches to the catchment
- Reduced connectivity between the upper and lower reaches of the catchment.

Land management practices such as the construction of contour banks further reduce runoff and thus impacting on stream flow regimes and the environment. Further to this clearing of vegetation, channel modification and both point source and diffuse pollution are also risks identified to adversely impact the sustainability of the surface water resource and the environment it supports.

The lack of suitable hydrological data impedes the accuracy and confidence of hydrological results necessary for sound management decisions. A hydrological model was constructed as part of this study and shows significant promise however was impeded by a lack of suitable data. A significant risk to the resource is not having the appropriate data to be able to carry out a more detailed and accurate assessment.

Groundwater: O'Driscoll (1957) and Shepherd (1978) estimated the sustainable yield of the basin to be 400 ML/year. Martin et al. (1998) estimated the sustainable yield of the basin to be 4000 ML/year. The Engineering & Water Supply Department (1987) as cited in Martin et al (1998) estimated groundwater use in the area to be 3250 ML/year, indicating that the groundwater basin is also approaching its sustainable limit. With the recent increase in development of irrigated horticulture in the region it is probable that the current level of groundwater extraction is equivalent to the sustainable yield of the basin.

Anecdotal evidence provided by landholders indicates declining potentiometric surface in both Quaternary and Tertiary aquifers in recent years. While declining water levels have been experienced in the region in the past it is particularly concerning given the current climatic conditions are far from the driest conditions experienced in the catchment. This suggests that the current level of development is close to or may exceed the sustainable development limit of the basin.

The impacts of the current level of groundwater use include:

- Declining groundwater levels in wells and dry wells constructed to Quaternary aquifers
- Cessation of flow of artesian flowing wells and increased depth to water in the wells
- Loss of springs within both fractured rock and sedimentary aquifer systems.

Reported practices, such as pumping groundwater to farm dams that suffer large evaporative losses, leaving windmills to continuously pump groundwater to overflowing tanks and not equipping artesian wells to control groundwater flow, further impact on the resource and are clearly not sustainable practices.

Since the cessation of the conjunctive use of surface water and groundwater for township reticulation (in the 1994–1995 season) the demand on the groundwater resources for Wilmington has increased by 86%, this if not carefully managed could impact greatly not only on the groundwater resource itself but also on the ecology of Spring Creek. Currently there are no observation wells within the fractured rock aquifer system of the ranges near Wilmington to monitor groundwater levels and salinity.

Springs and soaks sustained by groundwater discharge have been reported dry in recent years. The loss of springs within the southern reaches of the catchment has serious consequence for the maintenance of species that depend on the refuge areas they provide.

Ecological Systems: There are significant ecological assets in the lower reaches of the Willochra Creek and also in streams draining the southern to mid-western catchment, in the form of permanent pool refugia. These assets exhibit a broad range of physico-chemical and habitat characteristics, and biological components of these systems vary accordingly. The potential range of permanent pools and baseflow reaches, along with broad-scale riparian vegetation, were mapped within surveyed streams using aerial videography and GIS.

The limited field surveys undertaken suggest fish diversity in the catchment is very low, with only two species recorded. This included a distinct sub-population of the Lake Eyre hardyhead, which was found within the lower reaches of the Willochra Creek but was absent from upper catchment. Presence of the hardyhead is a more significant biodiversity asset than previously realised. The introduced species, eastern gambusia, was also found to be present, and had a similar distribution to the Lake Eyre hardyhead.

Aquatic biota have life histories that have evolved in response to natural flow regimes. Any major alteration has the potential to selectively disadvantage native flora and fauna, both aquatic and terrestrial. Ephemeral stream ecosystems rely on periodic flow and flood events to provide connection between drought refuges and in-stream and floodplain habitats. This allows for significant recruitment and dispersal, re-building populations in order for these to survive the next drying phase of the cycle.

The distribution of fish in the catchment suggests a possible loss of connection between up-stream reaches and the lower Willochra Creek has occurred due to changes to stream flow patterns. This may be preventing broad dispersal of biota increasing the potential for localised species loss. The changes to duration, magnitude and seasonality of flow events may also be impacting on the condition or distribution of riparian vegetation in some areas. Further research is required to improve understanding of the current ecological condition.

Permanent pool systems in the catchment appear to be highly groundwater dependent for persistence during dry periods, highlighting the importance of conjunctive management of surface and groundwater resources.

There is potential to improve the ecological condition of the system without necessarily impinging on productive water use. This would require an adaptive management approach, which should be underpinned by community involvement and a targeted ecological monitoring and evaluation program.

Recommendations

That the NYAD INRMC:

- Establish a committee of Willochra catchment irrigators to coordinate flood irrigation practices, reduce identified inefficiency, and develop an equitable share arrangement between downstream water users and the environment.
- Raise public awareness of the impacts of farm dams, flood irrigation, dumping of waste in-stream, channel modification, and other identified inefficient practices such as allowing artesian wells to flow and, where practical, remediate
- Develop an adaptive management framework for water resources, informed by appropriate consultation, and ecological monitoring and evaluation programs that adequately assess the health of water-dependent ecosystems and evaluate the impact of water resource management measures and development
- Review and revise existing estimates of sustainable groundwater yield through hydrogeological investigations and determine current extraction rates
- Develop arrangements to monitor fractured rock aquifer systems particularly within the vicinity of the Spring Creek production well
- Improve the current level of surface water and rainfall monitoring within the catchment to refine the initial hydrological estimates.

These recommendations will enable future hydrological and ecological assessment with a higher level of confidence and meet the objectives of the National Action Plan for Salinity and Water Quality by providing the information necessary to address issues associated with increasing salinity and sustainable environmental water flow regimes.

The report is divided into two sections:

- Section 1: Hydrological assessment of the Willochra catchment
- Section 2: Preliminary ecological assessment of significant water dependent ecosystems in the Willochra catchment

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[1] *** Denotes sections of this report that were adapted from *Surface Water Assessment of the Upper Finniss Catchment* (Savadamuthu 2003) and modified to suit the Willochra Catchment.**

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Department of Water, Land and Biodiversity Conservation

September 2003

Report DWLBC 2003/20

INTRODUCTION

Purpose

This technical report describes the methodology and outcomes of a hydrological study of the Willochra catchment. The study was undertaken on behalf of the Northern & Yorke Agricultural District Integrated Natural Resource Management Committee by the Department of Water, Land and Biodiversity Conservation (DWLBC). The scope of the project was to provide baseline information necessary to address issues relating to sustainable development and to identify potential risks to the sustainability of the water resource and the environment it supports.

Background and study objectives

The Willochra river system, situated in the Southern Flinders Ranges, is an ephemeral semi-arid to arid river that flows from the base of Mt Remarkable northward through the Willochra Plain and discharges to the saline lake, Lake Torrens (Figure 1). There is limited information available on the water resources and water dependent ecosystems of the Willochra catchment. This is a major limitation for planning development in the region that ensures environmental water requirements are met, along with providing adequate water supply for future generations.

The region supports a range of agricultural and horticultural activities (Figure 2) that include production of sheep, cattle, pigs, wool, broad scale cereal cropping, and a recent shift toward irrigated horticulture including the establishment of vineyards and olive groves. Further to this the region has a number of national and conservation parks including Mt Remarkable National Park and Mt Brown and The Dutchmans Stern Conservation Parks. These renowned landmarks make the area one of the state’s prime tourist regions. The surface water and groundwater resources are used in the region for a variety of primary industry pursuits as well as tourism. While these activities are of significant economic and social benefit to the region and local communities they also place significant demand on the limited water resource.

Recent increases in development of irrigated horticulture in the region, and subsequent increases in the demand on the water resource have raised community, and stakeholder concerns for the sustainability of current and future development on the water resources and the ecosystems it supports. This report thus investigates the sustainability of the water resource at current development levels.

The objectives of this study are to:

- provide a better understanding of catchment hydrology by:
  - compiling and analysing existing hydrological information
  - constructing a computer based mathematical model to simulate the catchments rainfall runoff processes
- consequently identify
  - potential risks to the water resources
  - knowledge gaps
  - provide recommendations for future monitoring requirements.

The key outcome of the project is to meet the objectives of the State–Commonwealth National Action Plan for Salinity and Water Quality by providing baseline information necessary to address issues associated with sustainable development.

Methodology

Numerous methods have been used to gather the required information for water resource risk assessment. The methodology used in this report includes examination of existing data from the DWLBC database Hydstra, collection of information from community members and landholders and spatial data and aerial videography data analysis.

The information collectively enabled the construction of a hydrological model that represents the Southern Willochra catchment using WaterCress (Cresswell 2000). This report focuses on the Southern Willochra catchment (Figure 3) primarily because it is the area subjected to the greatest level of development.

The methodology is essentially in three parts: general information gathering, model construction and model calibration. Each procedure is detailed below.

Information gathering methodology included:

1. Collection of hydrological information from members of the community and landholders regarding stream flow regimes, flood events, current and future water use practices, irrigation methods, rainfall events and records, groundwater fluctuations and environmental information.
2. Review of existing literature and hydrological data including rainfall, evaporation and stream flow.
3. Verification of community and landholder information with existing data.
4. Identifying possible risks to the sustainability of the water resources based on anecdotal information provided by community members and landholders and existing information.

Model construction methodology involved:

1. Identifying development levels through spatial data analysis using geographic information system (GIS) ArcMap
2. Determining the location and volume of farm dams through spatial data analysis using GIS ArcMap.
3. Identifying the location of water diversion structures and estimating the volume of water diverted for flood irrigation through aerial videography. The data collected is coded and exported from media mapper to GIS ArcMap for further spatial data analysis.
4. Sub-division of the catchments through digitisation using GIS ArcMap.
5. Representing catchments, farm dams and water diversions using specific icon nodes with in the WaterCress hydrological modelling program.

Model calibration methodology involved:

1. Attributing input data to each catchment and farm dam node including rainfall, evaporation, and farm dam holding capacities and flood irrigation volumes.
2. Refining calibration using existing stream gauging data and varying the catchment parameter set until the modelled data has a good correlation with the observed data.

CATCHMENT DESCRIPTION

Overview

The Willochra catchment (Figure 1) is located approximately 250 kilometres (km) north of Adelaide in the Southern Flinders Ranges. The catchment is bound to the west by the ranges incorporating Mt Remarkable, Mt Brown, Dutchman's Stern and Mt Arden that lies within the Wyacca Range. The catchment is bound to the east by the Pekina Ranges, Oladdie Hills and the Druid Range located to the northeast. Northern bounds of the catchment include Yourambulla and Yappala ranges and Mt Eyre. The catchment area, of approximately 6425 km^2, includes the townships of Murray Town, Booleroo Centre, Melrose and Wilmington in the south, Quorn centrally and Simmonston in the north.

The main stream within the catchment is the Willochra Creek, which originates at the base of the eastern slopes of Mt Remarkable, near the township of Melrose. Willochra Creek is approximately 205 km long and flows in a northerly direction from Melrose, through the Willochra Plain to Partacoona Station. The flow direction then trends northwesterly and the stream discharges to Lake Torrens.

Major tributaries to the Willochra from the south of the catchment include Yellowman Creek, Wild Dog Creek and Rotten Creek. Eastern tributaries include Booleroo Creek, Old Booleroo Creek, Coonatto Creek, Boolcunda Creek, and Kanyaka Creek. Western tributaries to the Willochra include Campbell Creek, Spring Creek, Stony Creek, Beautiful Valley Creek, Mt Brown Creek, Castle Creek, Mt Arden Creek and Buckaringa Creek.

Average annual rainfall within the catchment varies from 650 mm in the southwestern region of the catchment and decreases northwards across the Willochra Plain to less than 250 mm. Potential annual evaporation varies from 2400 mm in the south of the catchment and increases to 2600 mm in the north.

The topography of the Willochra catchment varies considerably from steep ranges to undulating hills to the Willochra Plain. Elevation varies from 965 m at Mt Brown in the southwest region of the catchment to 70 m near Lake Torrens in the northwest.

Due to the vastness of the catchment this report has focused primarily on the Southern Willochra catchment (see Figure 3) where development is greatest. The Southern Willochra catchment incorporates the sub-catchments of Beautiful Valley Creek, Stony Creek, Spring Creek, and Campbell Creek to the west, Yellowman Creek, Wild Dog Creek and Fullerville (Doughboy Creek) to the south. Booleroo Creek and Old Booleroo Creek sub-catchments are on the east. All sub-catchments drain toward the central catchment of Willochra Creek.

Major land use (Figure 2) in the southern portion of the catchment includes cropping and grazing rotation (48% of the total area), grazing modified pastures (41%), conservation areas (5%), livestock grazing (native vegetation) (4%), and irrigated modified pastures, irrigated horticulture and intensive animal production (< 1%). Irrigation is assumed to be predominantly for viticulture and intensive animal production but flood irrigation of cereal crops is practised within the catchment.

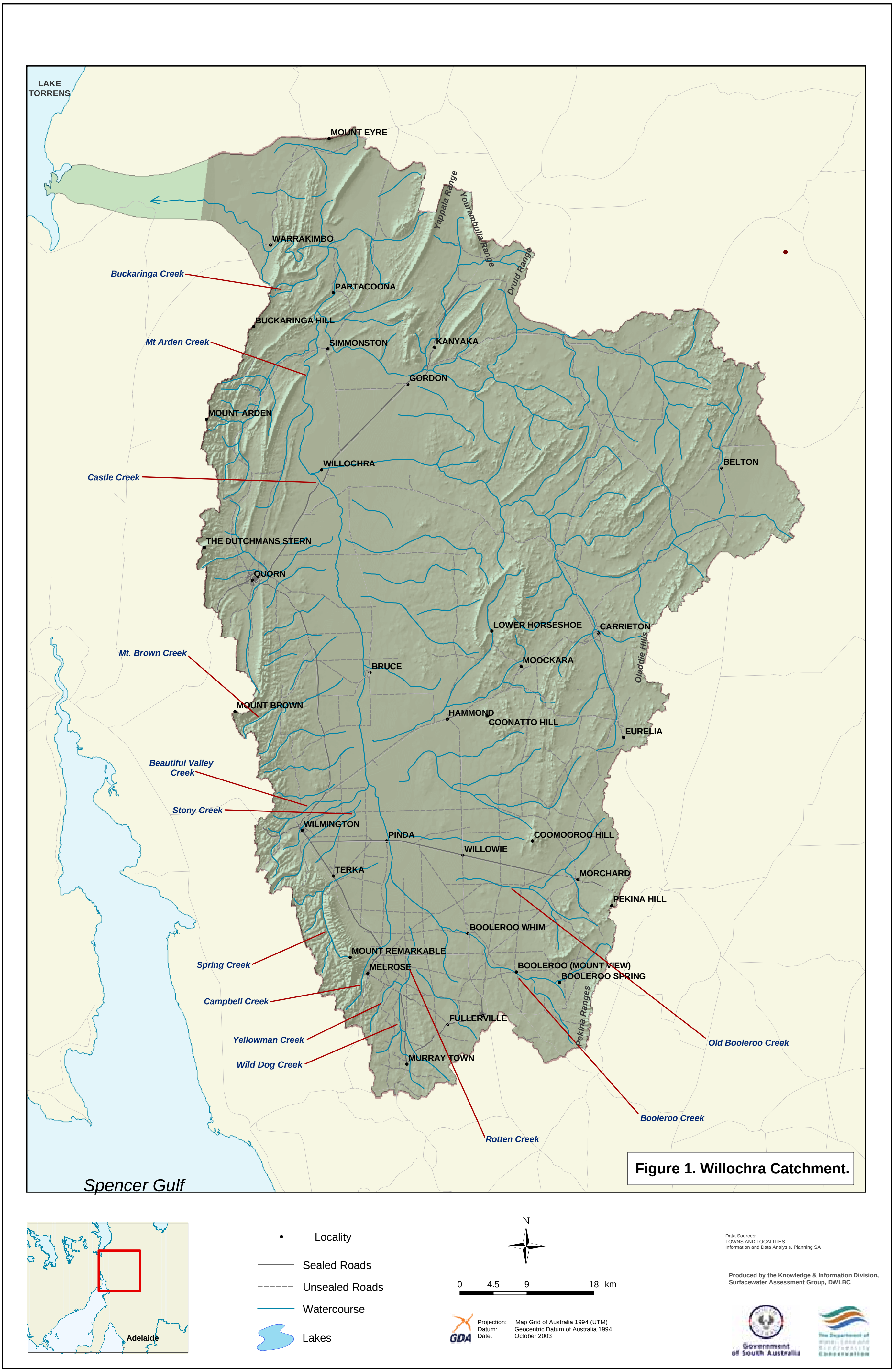

Figure 1. Willochra Catchment.

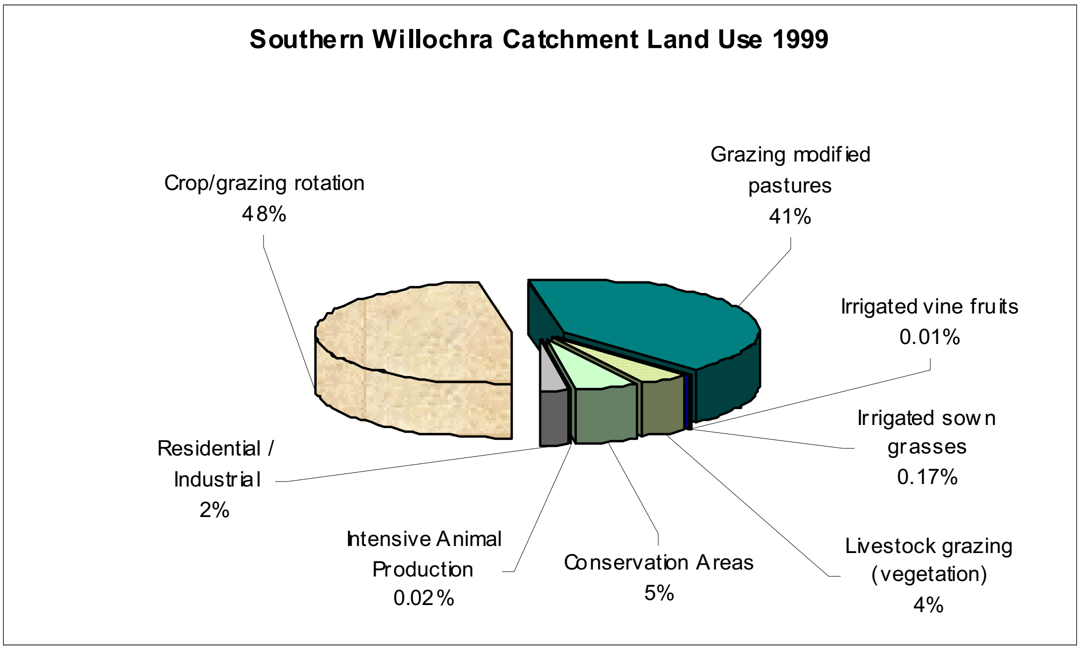

Figure 2. Southern Willochra catchment land use

Based on 1987 and 1988 aerial surveys, there are 648 farm dams with an estimated total capacity of 1400 ML within the study area. Aerial videography conducted in June 2003 revealed numerous in-stream diversion structures within the study area. Based on information provided by landholders/irrigators, aerial videography and the 1999 land use survey data an estimated minimum of 2000–3000 ML can potentially be diverted from the surface water resource, provided seasonal conditions are adequate. This figure is a conservative estimate only and because of the nature of the diversion mechanisms it has the potential to be significantly greater.

Sub-catchments

Major sub-catchments

For the purpose of gaining a greater understanding of catchment response to rainfall and to aid hydrological model construction, large catchment areas are divided into sub-catchments. For example the Southern Willochra catchment has been divided into ten sub-catchments (Figure 3).

The division of the catchment into sub-catchments is based primarily on the location of major streams and the area surrounding them that contribute runoff to the streams, that is the major streams and the surrounding catchment area. This initial process is achieved through close examination of the contours (Figure 4) and then the catchment boundaries are digitised using GIS ArcMap. The areas of the sub-catchments are calculated using GIS ArcMap and are displayed in Table 1.

Table 1. Sub-catchments within the Southern Willochra catchment

No.	Sub Catchment Name	Area (Sqkm)
1	Beautiful Valley	29.4
2	Booleroo Creek	305.8
3	Campbell Creek	34.2
4	Fullerville	99.9
5	Old Booleroo Creek	353.0
6	Spring Creek	52.8
7	Stony Creek	22.0
8	Wild Dog Creek	101.3
9	Willochra Creek	165.8
10	Yellowman Creek	23.1
Total		**1187.2**

Minor sub-catchments/sub-divisions

A number of features within a sub-catchment affect the catchment's response to rainfall. For example a high rainfall area will generate more runoff than a low rainfall area and a steeper area will generate runoff faster than a flatter area. A densely vegetated area intercepts more rainfall before it reaches the ground so runoff generated in the area is significantly less than that generated in an area with sparse or very little vegetation cover.

The number and location of farm dams also affect catchment hydrology. A large number of off-stream dams reduce surface runoff compared to a catchment with no farm dams. To account for these variations in catchment characteristics, the sub-catchments are further sub-divided.

These further sub-divisions consider rainfall and the location of rainfall isohyets, contours, land use and the number and location of farm dams. Examination of these catchment features enables a greater understanding of each sub-catchment's hydrological behaviour and a suitable catchment parameter set can be selected for individual sub-divisions within the hydrological model.

The sub-division of sub-catchments improves the efficiency of the hydrological model through a more accurate representation of the hydrological behaviour of each sub-division, rather than assigning one parameter set to each sub-catchment, which in reality is not representative of the natural variations that exist in the areas.

Table 2 displays the sub-catchments and the number of sub-divisions within each of the sub-catchments. Figure 5 shows the sub-division.

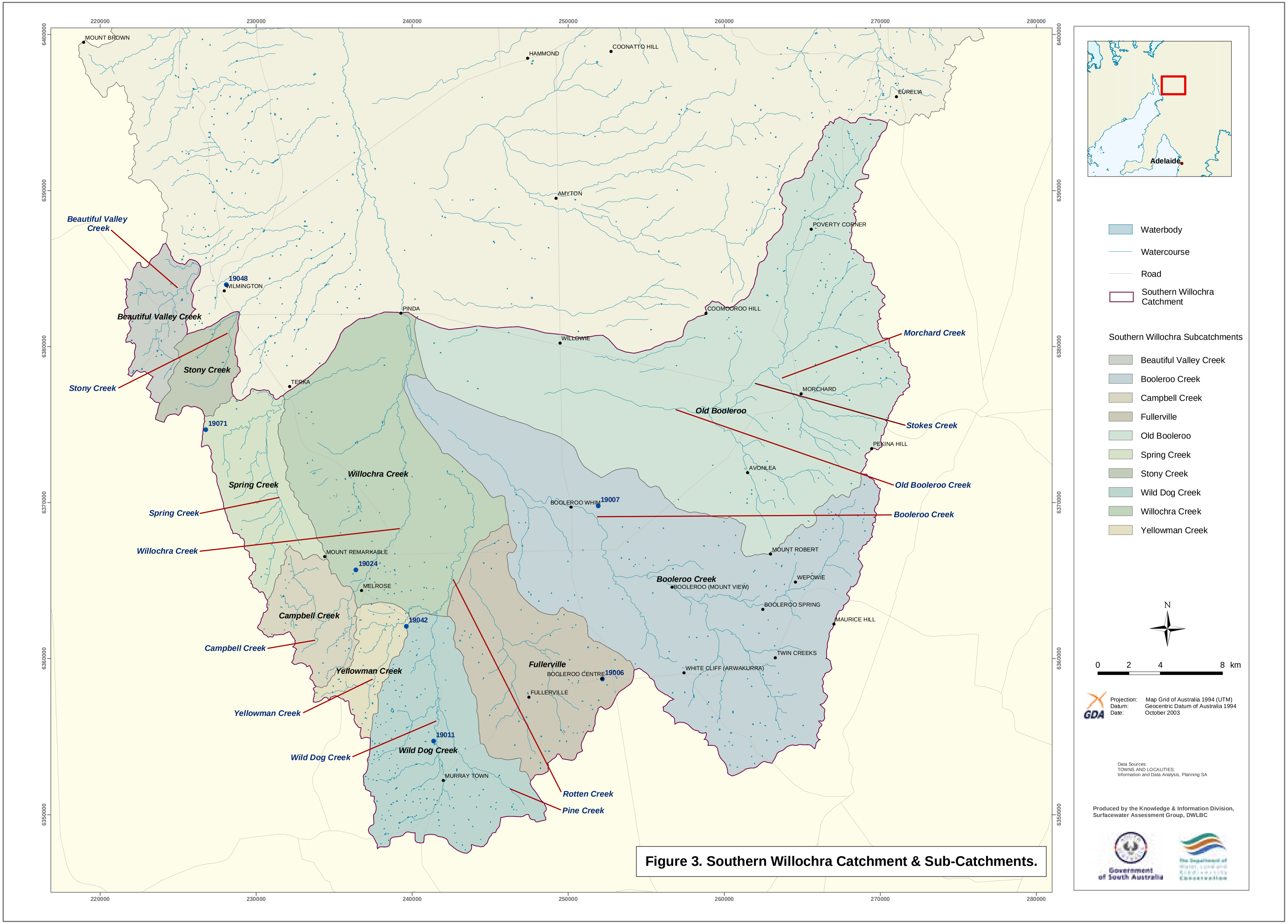

Figure 3. Southern Willochra Catchment & Sub-Catchments.

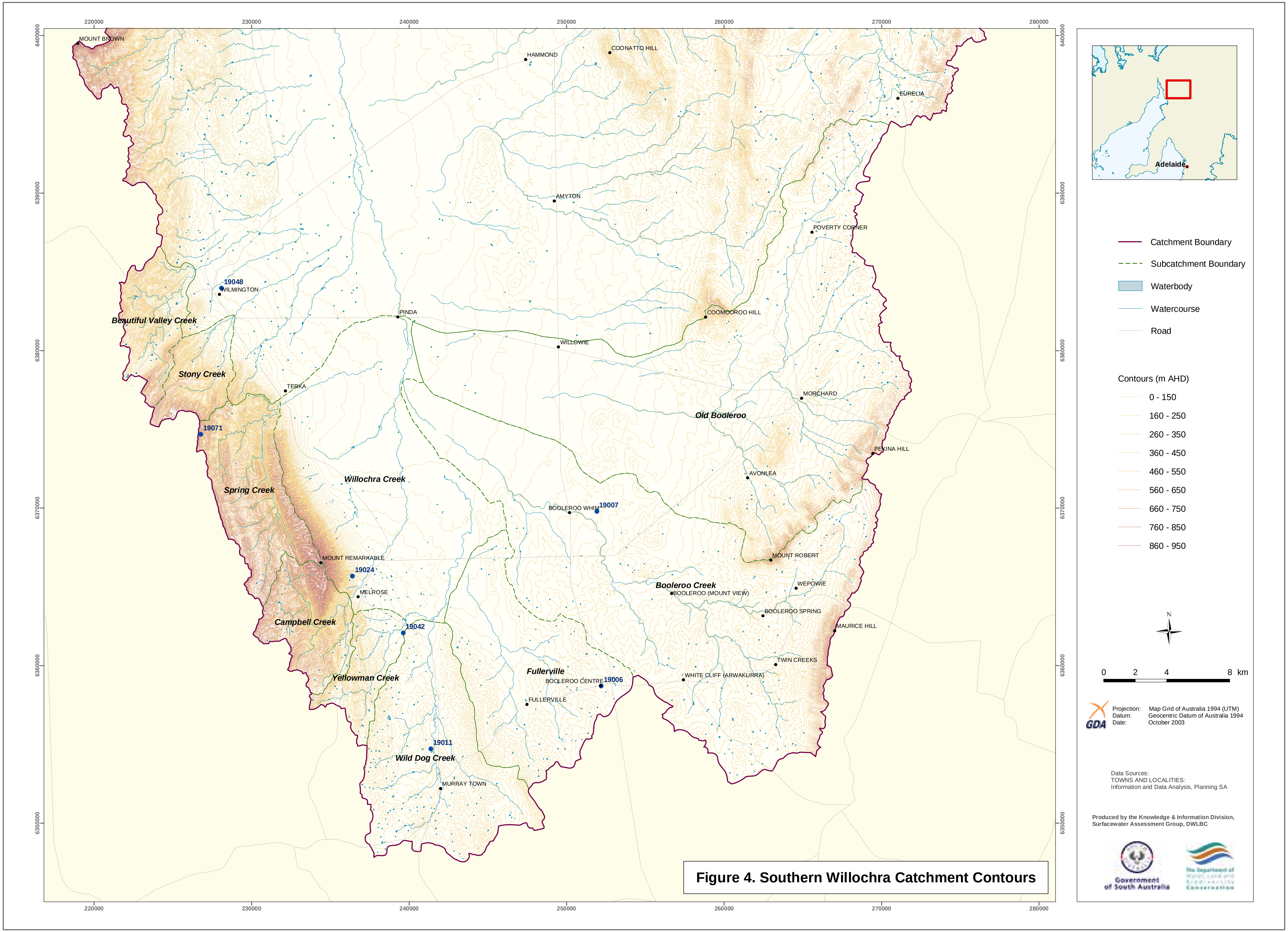

Figure 4. Southern Willochra Catchment Contours

Table 2. Sub-divisions within the Southern Willochra catchment

No	Sub Catchment	Area (Sqkm)	Number of Sub Divisions
1	Beautiful Valley	29.4	5
2	Booleroo Creek	305.8	8
3	Campbell Creek	34.2	5
4	Fullerville	99.9	4
5	Old Booleroo Creek	353.0	8
6	Spring Creek	52.8	4
7	Stony Creek	22.0	4
8	Wild Dog Creek	101.3	7
9	Willochra Creek	165.8	8
10	Yellowman Creek	23.1	4
Total		**1187.2**	**57**

The sub-division of sub-catchments and area calculations of each sub-division was performed using GIS ArcMap and is displayed in Appendix E.

Land use

Land use classification

Land use data for the catchment area was obtained from the Bureau of Rural Sciences. The data was compiled using remote sensing, cadastre and ancillary data for 1999, it was field verified and final land use maps produced. The data sets are available in spatial format and are able to be interpreted using GIS ArcMap.

For the purpose of the report land use information was grouped into the following 8 categories (Figure 6).

1. **Crop/grazing rotation:** Land under cropping at time of mapping that may be in a rotation system; includes cereals, hay and silage, oil seed and legumes
2. **Grazing modified pastures:** Land in a rotation system classed under the land use at the time of mapping; includes pasture and forage production and displays a significant degree of modification of native vegetation
3. **Irrigated modified pastures:** Includes irrigated pasture production and irrigated sown grasses
4. **Irrigated horticulture:** Irrigated vines
5. **Livestock grazing (vegetation):** Grazing by domestic stock on native vegetation with limited / no attempt to modify the pasture
6. **Intensive animal production**: Piggeries
7. **Conservation**: Includes national parks and protected natural features
8. **Residential/industrial:** Includes manufacturing and industrial, residential, services, utilities, transport and communications and waste treatment and disposal

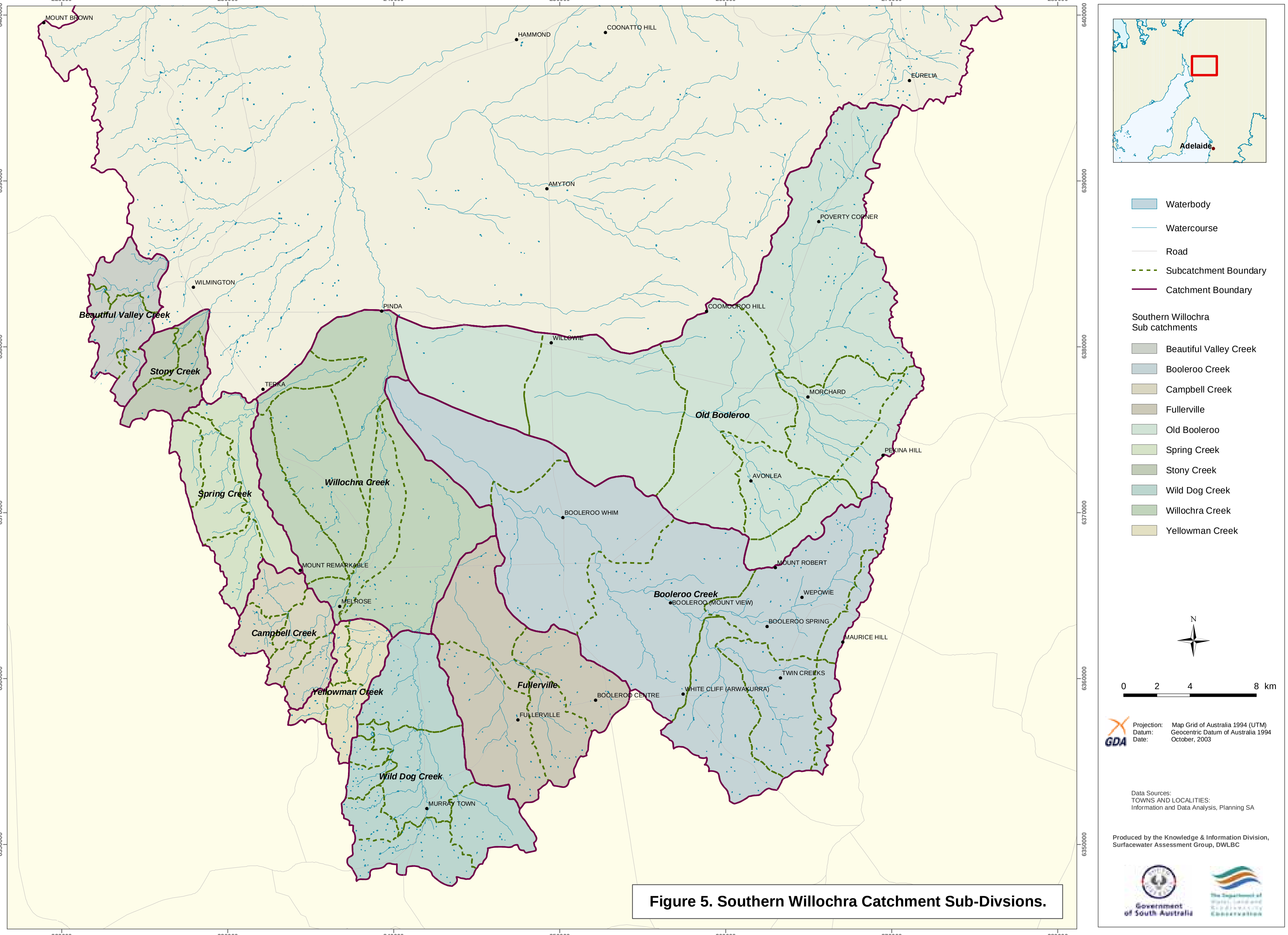

Figure 5. Southern Willochra Catchment Sub-Divsions.

Land in a rotation system, for example crop grazing rotation and grazing modified pasture, was classed according to the land use at the time of mapping exercise in 1999 (Bureau of Rural Sciences 2001)

Although the land use data extended to the Northern Agricultural District boundary it did not cover the entire area of the Willochra catchment. For the purpose of this report the focus of the land use data was on the southern reaches of the catchment (see Figure 6) where increasing development and water use would have the greatest detrimental effects on the catchment water resources as a whole, due to it being the highest rainfall area contributing to both the surface and groundwater resource.

Table 3. Land use of the Southern Willochra catchment

Category	Landuse	Area (Sqkm)	Percentage (%)
1	Crop/grazing rotation	559	47
2	Grazing modified pastures	488	41
3	Irrigated modified pastures	2	0.2
4	Irrigated horticulture	0	0.01
5	Livestock grazing (vegetation)	51	4
6	Conservation Areas	60	5
7	Intensive Animal Production	0	0.02
8	Residential / Industrial	27	2

Based on the land use data collected in 1999, 88% of the total study area was subject to production from dry land agriculture where native vegetation has been replaced by introduced species. Approximately 4% of the study area was attributed to livestock grazing (vegetation) where production is from relatively natural environments and native vegetation has not been deliberately modified. Conservation areas that include national parks and protected natural features occupy 5% of the study area. A total of 0.01% of the area is attributed to production from irrigated agriculture, and a further 0.02% was intensive animal production (Bureau of Rural Sciences 2001)

Assuming the greatest demands on the water resource are irrigated agriculture and, to a lesser extent, intensive animal production, the land use data suggests that irrigation is not a major land use of the catchment. Less than one quarter of a percent of the total study area is subject to increase in demand and water use. Recent development suggest that resource use is increasing, as identified by:

1. The sub-catchments used for the computer model did not include the township of Wilmington and surrounding areas where there has been an increase in irrigated horticulture in recent years.

2. The land use data is a snapshot of conditions in 1999, and land use is subject to change. Development since 1999 would not be included in the current data.

3. The District Council of Mt Remarkable has reported receiving numerous development applications proposing a change in land use since 2000. It is likely that some of these applications would be proposing irrigated horticultural development.

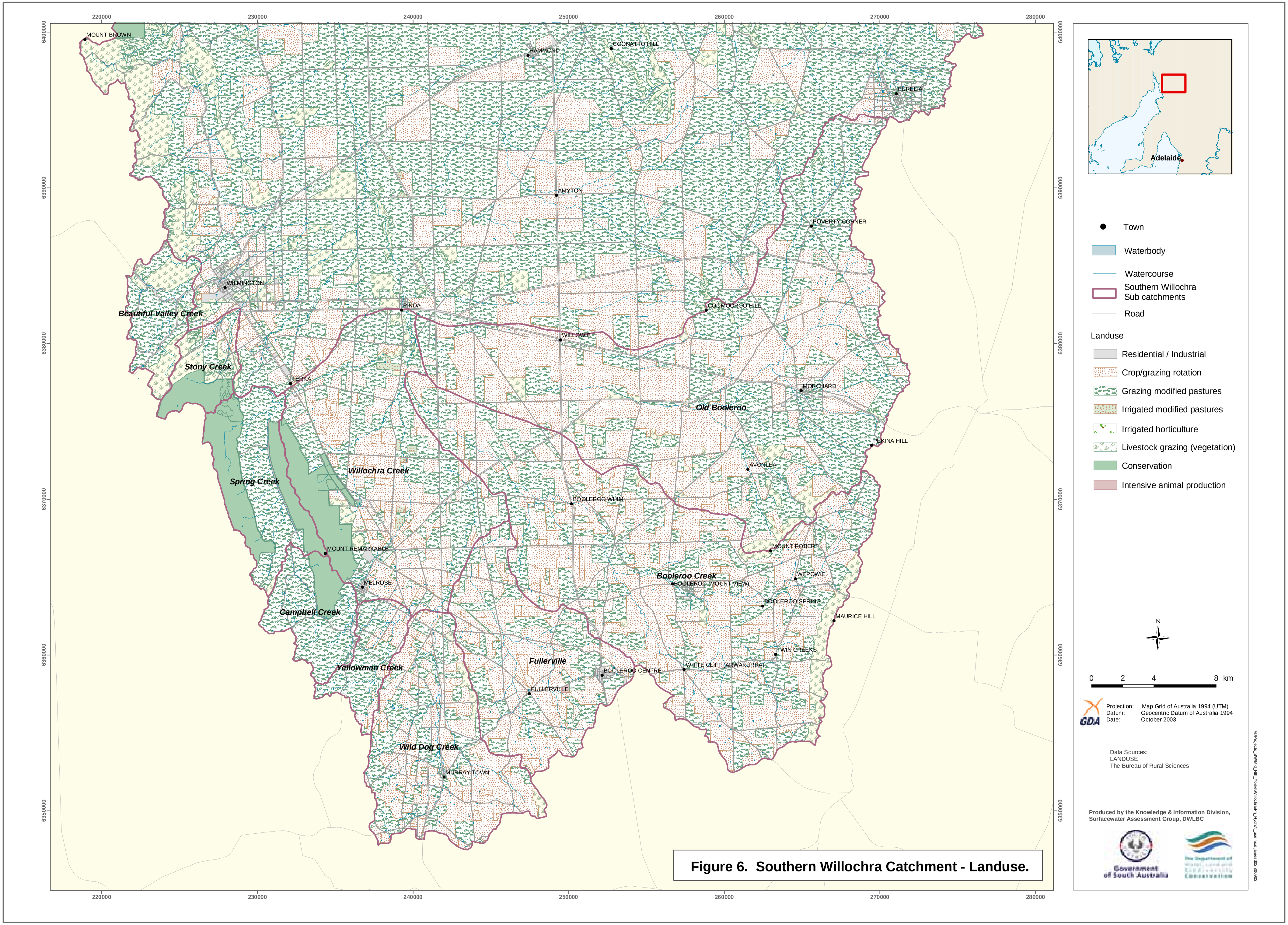

Figure 6. Southern Willochra Catchment - Landuse.

Although from inspection of the land use data development with the greatest demands on the water resource seem relatively low, more accurate classification of land subjected to flood irrigation is further required.

A GIS coverage of the location of diversion structures was produced following processing of the data collected from the aerial videography footage. The diversion coverage was overlaid on the land use coverage and inspection of the spatial data revealed that land under the categories of crop grazing rotation and grazing modified pasture were adjacent to in-stream diversion structures. This suggests that areas not categorised as being irrigated are irrigated when conditions are suitable.

This is further supported by information received from the community and irrigators. Flood irrigation of Cereal crops and grazing land is conducted providing the conditions are adequate.

For further information regarding individual sub-catchments land use refer to Appendix E.

Farm dams

Farm dams are generally constructed to provide water for stock, domestic and irrigation purposes. There are typically two types of farm dam, on-stream dams that are constructed in-stream and off-stream dams usually constructed in gullies or low lying areas of a property.

On-stream farm dams capture stream flow and prevent the flow of water downstream until the dam fills and spills (unless it has been constructed with a low flow by-pass). High densities of on-stream farm dams may cause a delay in the onset of stream flow downstream by capturing the stream flow. The larger the dam's water-holding capacity the longer it takes to fill and spill. Delays of stream flow can be to the detriment of both downstream water users and for components of the environment that rely on early seasonal stream flow.

Off-stream farm dams capture surface water runoff before it enters a watercourse and therefore lead to an overall reduction of runoff and stream flow. This again may delay the onset of stream flow events and depending on the number of off-stream dams within a catchment may also cause a reduction in peak flows.

The impact of farm dams on water resources is reduced catchment runoff resulting in an overall reduction of stream flow and a change in flow characteristics. This is particularly noticeable in areas where rainfall is generally low. Martin (1984) and Srikanthan and Neil (1989) found in arid to semi-arid areas where annual rainfall is highly variable, the length of season during which flow passes downstream is reduced, and the frequency of low flow events and periods of no flow increases (Beavis 1996). These effects of farm dams on flow characteristics have implications for both downstream water users and environmental water requirements.

A study by Meigh (1995) on the impacts of farm dams on mean annual runoff and seasonal flow characteristics in semi-arid regions of Botswana showed the most significant factor affecting runoff is the total capacity of small dams. A large number of small dams have a greater effect on mean annual runoff than a small number of large dams with the same water holding capacity. This is due to inefficiencies related to evaporative losses and greater proportions of area controlled by the dams. The impact of farm dams was found to be greater the further downstream they are within the catchment, as it increased the catchment area controlled by dams. (Beavis 1996).

Studies of numerous catchments within South Australia have revealed a growing trend in the construction of farm dams at alarming rates. For example a recent study by Savadamuthu (2002) of the Upper Marne catchment revealed that total farm dam capacity has increased by greater than 50% from 1991 to 1999. Cresswell (1991) identified that from 1980 to 1989 the farm dam capacity within the Barossa Valley had increased by 140%. Information provided by community members and landholders within the Willochra catchment have identified a growing trend in the number of farm dams constructed in recent times. However, due to lack of data the rate of development of farm dams is currently not known.

Regions within the Southern Willochra catchment, where the average annual rainfall is greater than 450 mm are likely to be perceived as having sufficient rainfall to make the use of both surface water and groundwater feasible for irrigation. As is shown later in the report (Figure 21) rainfall of greater than 450 mm is capable of generating around 15 ML/km^2 of surface water runoff. As the flow in the Willochra Creek relies heavily on these regions of the catchment (that include Stony Creek, Spring Creek, Campbell Creek and Yellowman Creek sub-catchments) even modest increases in catchment water use may significantly impact on the water resources of the whole catchment.

The farm dam data for the Willochra catchment was provided by the Department of Environment and Heritage in 1995. The data was compiled using GIS to digitise dams captured by aerial photography during aerial surveys in 1987, 1988 (and possibly 1994). The data sets are available in spatial format and can be interpreted using GIS.

Farm dam volumes have been calculated using a surface area to volume relationship, developed by Doug McMurray (2002). The equation for dams with a surface area of less than 20 000 m^2 is as follows:

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

Farm dam density is a parameter used for determining the extent of farm dam development in a given catchment. Farm dam density has been calculated using the equation below:

$$\text{Dam density (ML/km}^2\text{)} = \text{Total dam volume (ML)} \div \text{Total catchment area (km}^2\text{)}$$

The data has been summarised in Table 4 and shows that a total of 648 dams exist in the Southern Willochra catchment. The farm dam storage capacity is estimated to be 1400 ML and the farm dam density 1.19 ML/km^2.

The majority of farm dams within the Southern Willochra catchment are relatively small with a water holding capacity less than 2 ML, and have been constructed primarily to provide water for domestic stock. As mentioned above, a large number of small dams has a greater impact to stream flow regimes than a small number of large dams.

Table 4. Farm dam summary of the Southern Willochra catchment

Sub Catchment Name	Number of Dams	Area (Sqkm)	Volume (ML)	Density (ML/Sqkm)
Beautiful Valley	24	29	74	2.5
Booleroo	128	306	291	0.9
Campbell	32	34	34	1.0
Fullerville	71	100	156	1.6
Old Booleroo	122	353	308	0.9
Spring Creek	8	53	13	0.2
Stony Creek	8	22	14	0.6
Wild Dog Creek	152	101	341	3.4
Willochra Creek	70	166	128	0.8
Yellowman Creek	33	23	51	2.2
Total	**648**	**1187**	**1409**	**1.2**

In recent years landholders have reported a number of small dams being constructed in order to supplement diminishing supply of groundwater from springs in the headwaters of the catchment. The fact that these dams are constructed within the upper reaches of the catchment mean they affect very little of the total catchment area. However, in the Willochra catchment the highest rainfall is generated in these regions.

Furthermore, the change in land use from cropping and grazing rotation to irrigated horticulture has led to the construction of larger farm dams with a holding capacity equal to or greater than 5 ML, for the purpose of irrigation. These areas are concentrated within the higher rainfall areas of the catchment and reports from downstream water users indicate that catchment runoff has ceased or is severely restricted.

The greatest developed sub-catchment with regard to farm dam development is Wild Dog Creek catchment with 152 dams, 341 ML storage capacity and a farm dam density of 3.4 ML/km^2. This figure is substantially low in comparison to catchment areas in the Mount Lofty Ranges (Table 5) where, for example, the farm dam density for the Finniss catchment is calculated at 30 ML/km^2 (Savadamuthu 2003), this figure is low. Farm dam densities for some of the catchments in the eastern Mount Lofty Ranges are displayed below.

Table 5. Farm dam density of catchments in the eastern Mount Lofty Ranges

No	Catchment	Farm Dam Density ML/SqKM)
1	Finniss Catchment	30 *(38)
2	Angas Catchment	32
3	Currency Creek Catchment	32
4	Mt Barker Creek Catchment	27
5	Dawesley Creek	18
6	Marne	10

* Farm dam density for catchment area excluding forests and protected areas
Source: Savadamuthu K. (2003) Surface Water Assessment of the Upper Finniss catchment

It should be noted that farm dam density is comparatively low in the southern Willochra catchments to that of the eastern Mt Lofty Ranges catchments. However, due to the semi-arid nature of the catchment the impact of farm dams may be far greater because of the lower rainfall resulting in decreased runoff. The Finniss catchment produces runoff on average of 144 ML/km^2 where as in the Southern Willochra this rate (as will be shown later) is only around 7 ML/km^2. Furthermore, stream flow duration is relatively short in the Willochra in comparison to the Mount Lofty Ranges. Farm dams further reduce the duration of stream flow and could potentially result in no flow during drought periods.

For further information regarding farm dam development in each sub-catchment within the Southern Willochra catchment refer to Appendix E.

SURFACE WATER

Rainfall

Rainfall data in South Australia is collected by the Bureau of Meteorology (BOM), the DWLBC and by private landholders. The data is stored in the DWLBC Hydstra database.

Data Availability

There are 40 rainfall stations distributed throughout the Willochra catchment with daily recorded rainfall. Some stations have long-term records (greater than 100 years) while others have data recorded for only a few years. The majority of rainfall stations are located within the low-lying areas of the catchment, and very few stations exist in the ranges. Both topographic features and altitude affect rainfall distribution. Development of an accurate rainfall isohyet coverage required for hydrological modelling was impeded by the lack of data from the ranges.

Landholders provided rainfall records from areas where data was not available and the data has been processed and used to generate an improved isohyet coverage. However, further improvements are needed. The process used to generate the improved isohyet coverage is described in the *Data Processing* section below.

Within the Southern Willochra catchment six rainfall stations with long-term records and one rainfall station with a 30-year record have been selected as representative of rainfall within the sub-catchments. The station with the 30-year record was extended to match the period of record of the other stations; the process used is described in the *Data Processing* section.

Table 6 lists the selected daily-read rainfall station names, their identification number, the selected period of record and the mean and median annual rainfall. Figure 7 provides a best estimate isohyet coverage of the region and the location of major rainfall recording stations.

Table 6. Daily read rainfall stations and mean annual rainfall

Station Number	Station Name	Period of Record	Annual Rainfall (mm) Mean	Median
M019006	Booleroo Centre Post Office	1889 - 2002	395.2	398.4
M019007	Booleroo Whim	1889 - 2002	345.9	343.2
M019011	Doughboy Creek	1889 - 2002	456.1	442.7
M019024	Melrose Post Office	1889 - 2002	598.1	578.4
M019042	Melrose Para Gums	1889 - 2002	462.4	439.0
M019048	Wilmington Post Office	1889 - 2002	446.0	426.3
M019071	Alligator Gorge	1889 - 2002	644.7	612.2

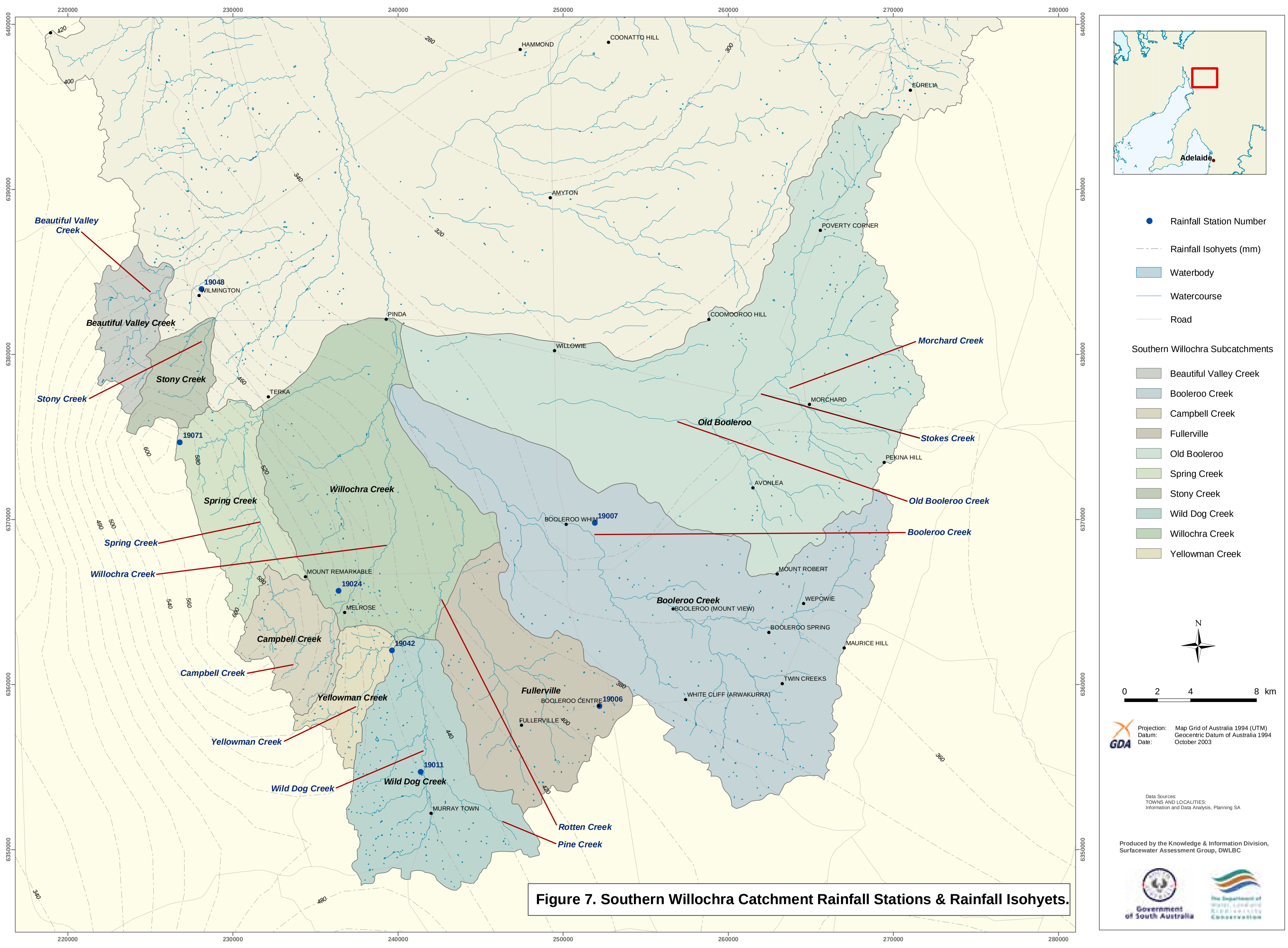

Figure 7. Southern Willochra Catchment Rainfall Stations & Rainfall Isohyets.

The isohyets presented in Figure 7 are based on limited rainfall data and therefore can be considered to be an estimate of the spatial distribution of rainfall across the catchment.

Rainfall records from the seven stations along with the isohyet data show that average annual rainfall in the region ranges from approximately 650 mm in the southwestern ranges and decrease northeasterly across the catchment to less than 320 mm.

The problems with the existing isohyet data are: a lack of data for the ranges and elevated regions of the catchment; and modelled isohyet coverage generated by calculating the average rainfall for each station from the available data. This included stations with both short-term records and long-term records. The average annual rainfall is influenced by the period the record was collected. For example, data collected during the 1970s over estimates the average annual rainfall, while data collected only during the 1930s under estimates the average annual rainfall when compared to long-term records.

To overcome these problems data collected by landholders in elevated regions of the catchment were added to the existing data sets. Data for all stations with short-term records have been extended so that data ranges from 1889 to 2002. Records have been extended in accordance with the methodology detailed under *Data Processing*. It should be noted that although the isohyet coverage has been improved considerably further improvements could be achieved with: more data from elevated regions of the catchment; and the establishment of an isohyet coverage based on an elevation model.

Data processing

Generally, daily read rainfall data is recorded at 0900 hours each day. It is not uncommon however, that a number of days are missed and the recorded rainfall is actually accumulated for two or more days. For example, rain that falls during weekends is often not recorded each day and an accumulated amount is recorded at 0900 hours on Monday. In order to have an accurate data set, accumulated data is required to be disaggregated. It is also common for periods of daily read rainfall data to be missing and once again for an accurate and complete data set the missing records are required to be filled in.

Disaggregation and in-filling of missing data for the daily read rainfall stations listed above was conducted by Sinclair, Knight and Merz (2000) for the DWLBC in order to obtain complete records. The methodology used by SKM for disaggregation of accumulated data and in-filling of missing data is explained in Appendix A.

Extending the period of record for Station M019071 – Alligator Gorge was conducted as part of this study, and all stations were tested for regional homogeneity. Where necessary data was adjusted. Station M019071 was extended by identifying the station in the area with the closest correlation for the given period of record. Station M019042 was found to have the closest correlation of 0.803 and 0.942 for daily and monthly data respectively. A double mass curve for both stations was plotted for the given period of record and tested for homogeneity. The monthly data was then plotted for both stations and a linear relationship was calculated to be $y = 1.37x$, where y = data from station M019071 and x = data from station M019042. The data for station M019071 was extended by in-filling the required period of record with the data from station M019042 multiplied by the average slope of the line 1.37 (Appendix B).

Double mass analysis was used to test the seven stations for homogeneity. The mass of the monthly data of each station is plotted against the mass of the average regional monthly rainfall. If the data is homogeneous the relationship between the data sets should theoretically be a straight line. Where there is deviation of the data from the line or a change in slope of the line greater than +/- 5% of the average slope the data was considered to be non-homogeneous and was adjusted. The adjustment factor was calculated by finding the ratio between the average slope of the line and the slope of the section of non-homogeneous data. The data is then multiplied by the adjustment factor for the given period of record in order to ensure homogeneity of the data set. Further details of homogeneity testing are detailed in Appendix C.

Rainfall data is adjusted proportionally for each sub-divided sub-catchment, in line with the isohyets for hydrological modelling. It is therefore important that the data is reasonably accurate. Errors had been identified with the existing GIS isohyet coverage for the area and while improvements to the existing coverage have been made, further improvements are recommended.

Data analysis

In order to gain an understanding of the spatial and temporal regional rainfall variations of the Southern Willochra catchment the average daily rainfall data was calculated from six of the seven stations listed above. The reason for the selection of the six stations, and not seven prevent bias of the data due to a greater number of stations selected from the wetter areas of the catchment. Further to this, the station M019071 was excluded from the regional data as it was extended as mentioned in the Data Processing section above. The remaining six stations used for the regional rainfall are relatively evenly distributed throughout the Southern Willochra catchment. Individual station records are displayed in Appendix E.

Annual rainfall

Long-term annual rainfall for the average of the six stations indicates little change in trend in average rainfall for the period 1889–2002 as displayed by the trendline in the Figure 8 below.

Analysis of annual rainfall shows that the wettest year on record was 1992 with 797 mm, followed by 1889, 1974, 1890 and 1973 with calculated rainfalls of 792 mm, 767 mm, 748 mm and 739 mm respectively. The driest year of the 113-year record was 1982 when only 237 mm fell. The following driest years on record were 1914, 1994, 1929 and 2002, with annual rainfalls of 237 mm, 239 mm, 243 mm, 243 mm and 247 mm respectively.

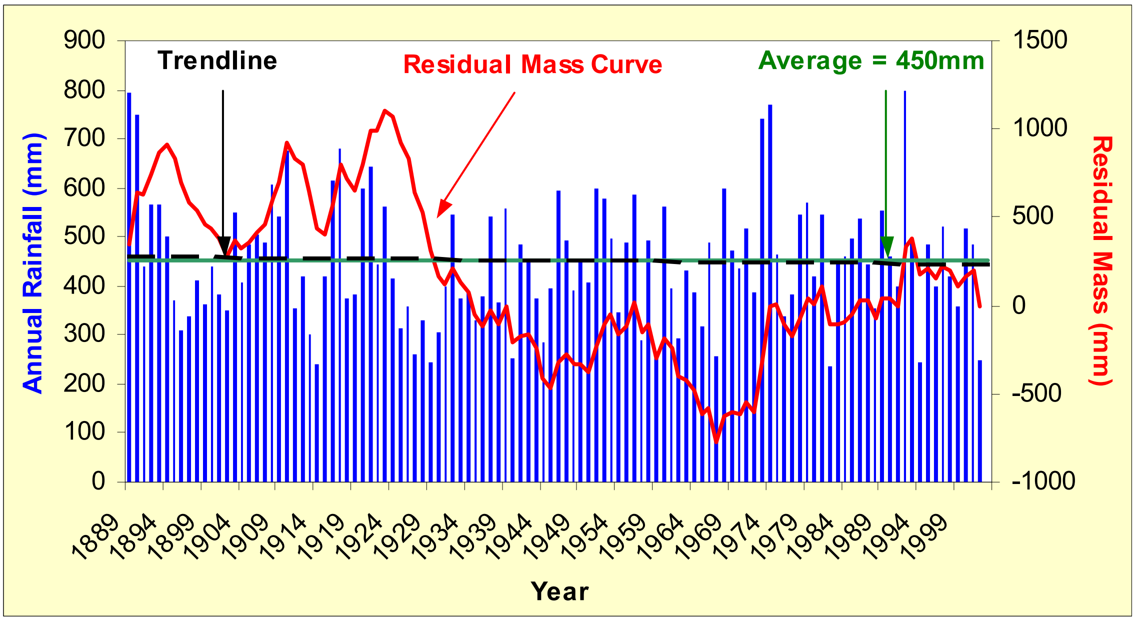

Figure 8. Southern Willochra catchment regional average annual rainfall 1889–2002

The residual mass curve displayed in the chart above is a plot of the cumulative deviation of a set of data from the mean (or average) value of the data set. In Figure 8 the positive slope or upward slope indicates a wetter than average period and a negative or downward slope indicates a drier than average period. For example, from 1916 to 1923 and from 1968 to 1993 above average rainfall was experienced, while below average rainfall was apparent from 1924 to 1967 and is also displayed from 1994 to 2002 however, the following years data is needed to further observe this trend.

Decadal rainfall

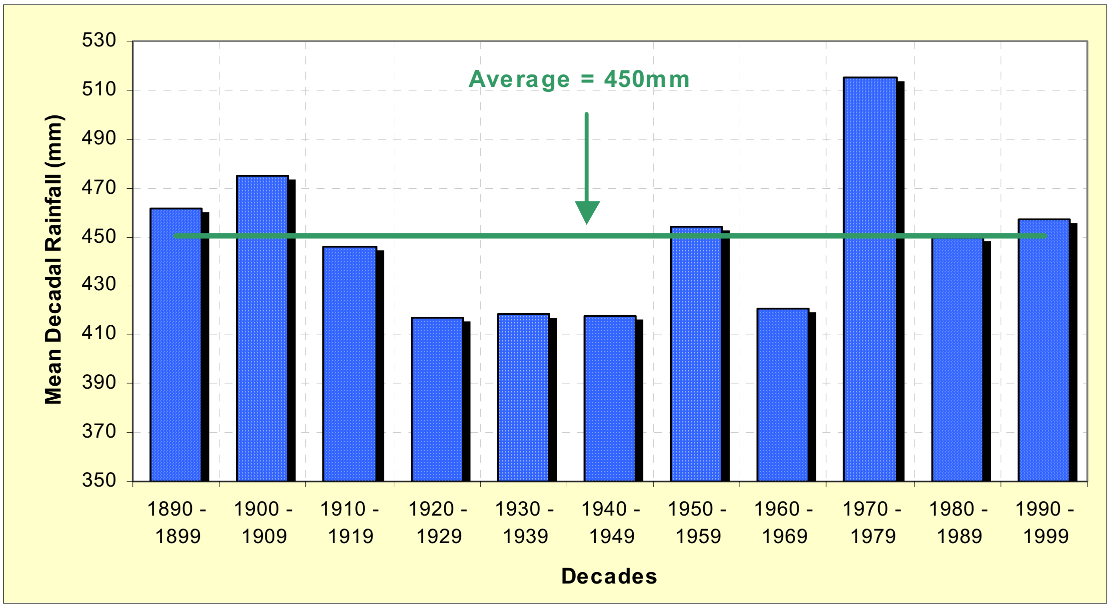

Figure 9. Southern Willochra catchment regional decadal rainfall

Average rainfall for each decade was calculated and is displayed in Figure 9. The data was compiled for 11 decades from the 1890s up to and including the 1990s. The data shows that of the 11 decades, 5 recorded above average rainfall, while 6 recorded below average rainfall.

The data also shows that the wettest decade on record was the 1970s with a regional decadal rainfall of 515 mm, while the driest decade was the 1920s with only 416 mm. This was followed closely by the 1940s and 1930s where the calculated regional average decadal rainfall was 417 mm and 418 mm respectively. It should be noted that this figure does vary slightly with individual rainfall station data. For example the driest recorded decade for station M019048 – Wilmington Post Office was the 1930s, while for Station M019011 – Doughboy Creek the 1920s was the driest decade. Common with all stations is the wettest decade occurring during the 1970s. For further details of each rainfall station and sub-catchment rainfall refer to Appendix E.

Figure 9 shows that rainfall in the last 20 years has averaged close to the long-term mean and are certainly far from the driest conditions experienced in the basin. While the last two decades are close to the average, it can be seen (in Figure 8) that the peaks of rainfall in individual years is far lower (< 510 mm) than any other decade.

As both winter surface water runoff and groundwater recharge are strongly dependent on receiving these above-average events, their absence may explain the community perception of dryness in the basin, evident by declining groundwater levels and reduced creek flows of recent times.

Monthly rainfall

Examination of monthly data shows that the highest rainfall months are June, July and August followed by September. The lowest rainfall month is March. Seasonal examination of the data show that 37% of rainfall falls in winter (June, July and August), 27% in spring (September, October and November), 21% in autumn (March, April and May) and 15% of rainfall is due to summer rainfall events (December, January and February)

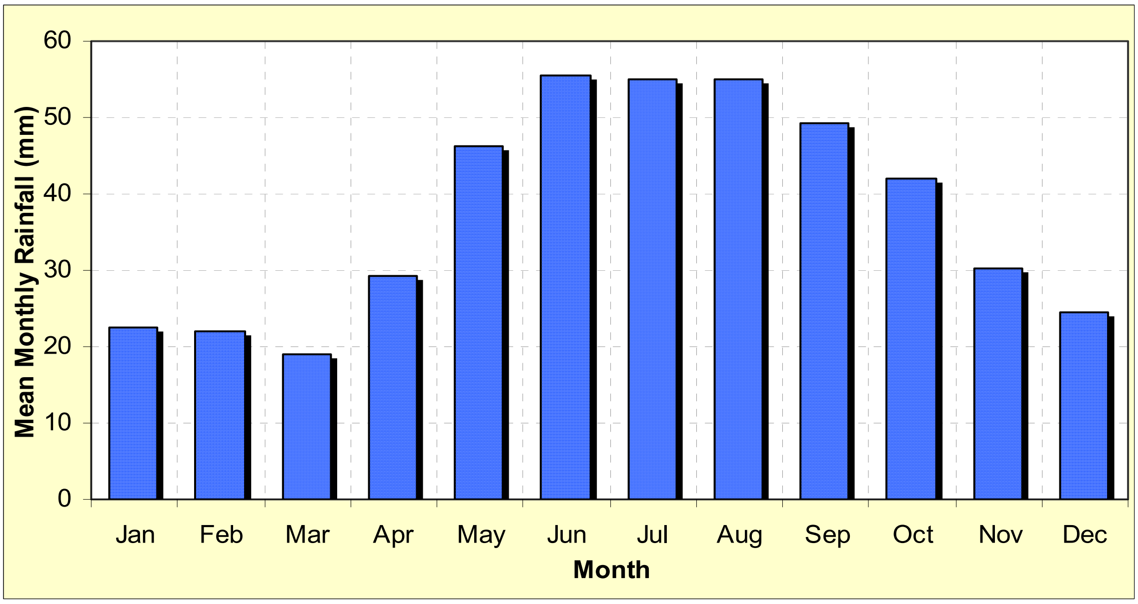

Figure 10. Southern Willochra catchment mean monthly rainfall

Residual mass curves were also plotted for each month along with annual rainfall residual mass for the period 1889 to 2002. This is done for the purpose of identifying the influence of monthly rainfall on long-term annual rainfall. The months found to have the strongest influence on the annual residual mass were June, September and October and are displayed in Figure 11.

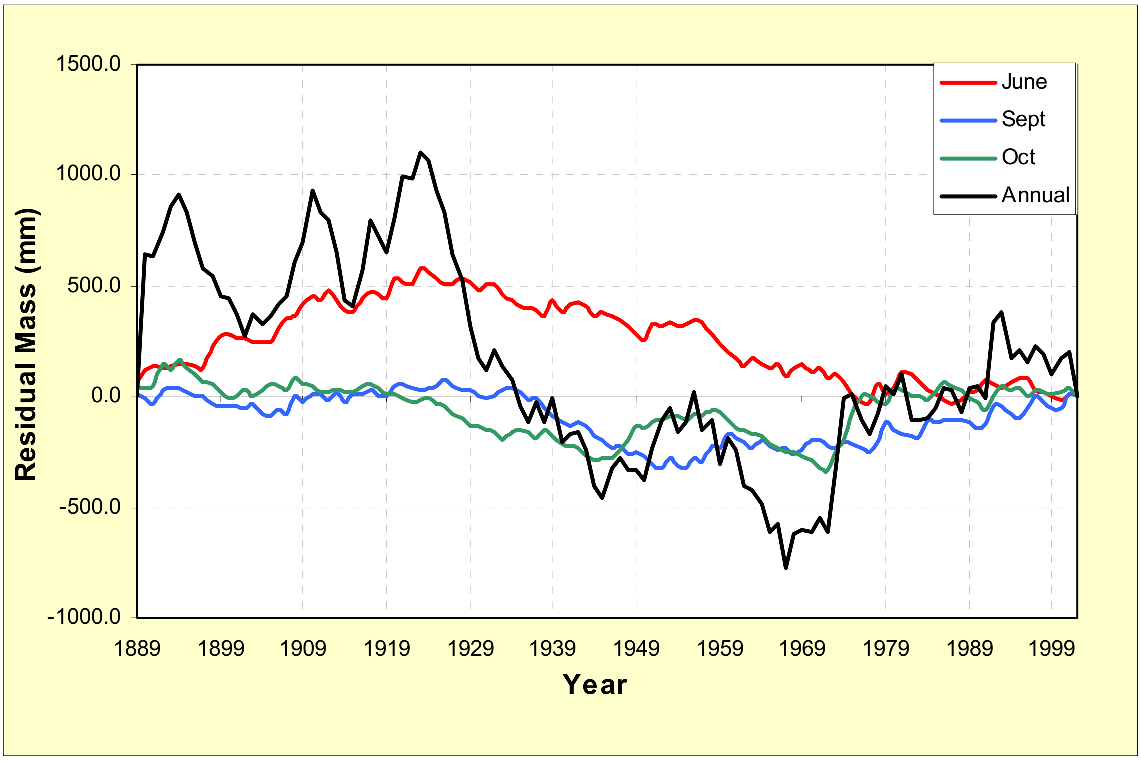

Figure 11. Southern Willochra catchment residual mass for June, September and October

Inspection of the data in Figure 11 shows that there is three distinct rainfall trends, from 1889 to 1920 the annual rainfall is increasing, followed by a distinct downward trend to the early 1970s and then again an increasing trend to the mid 1990s. The plotted residual mass for the month of June also shows a significant downward trend from the mid 1920s to the 1970s, indicating the June rainfall for the period has been declining.

From the 1970s the annual residual mass displays an increase which is not matched by the June rainfall this indicates the rainfall season is starting later in the year, and is evident by the increase in average monthly rainfall for both September and October.

Rainfall events relationship to flood events

Information has been provided by the community members regarding the occurrence of flood events. The information provided has been compared with six of the regional daily read rainfall station records within the Southern Willochra catchment in order to gain a better understanding of the catchment's response to rainfall events. (The stations selected were: M019006 – Booleroo Centre, M019007 – Booleroo Whim, M019011 – Doughboy Creek, M019024 – Melrose Post Office, M019042 – Melrose Para Gums, and M019048 – Wilmington Post Office).

The regional rainfall data for each station was ranked in order to determine the highest rainfall day and the highest consecutive 3-day rainfall period within the 113-year record. The results showed that the flood events reported by landholders were ranked within the highest 100 records and included the flood events of 1921, 1941, 1978, 1989, 1997 and 2001.

The largest flood event within the Willochra catchment is believed to have occurred in March 1921, and is supported by information reported in the *Quorn Mercury, Hawker and Great Northern Advertiser*, Friday, 4 March 1921 which reported *'Disastrous Floods'.*

The rainfall record of six regional rainfall stations within the southern Willochra catchment show the 1 March 1921 being the largest rainfall event to occur in the last 113 years, with a regional average rainfall of 119.3 mm for the day. The highest rainfall occurring at Station M019048 – Wilmington Post Office recorded 180.8 mm on this day.

Further information regarding the flood event was published in the *Quorn Mercury, Hawker and Great Northern Advertiser*, Friday, 11 March 1921. The article was compiled by the Weather Bureau and stated:

> The outstanding feature of the weather for February was the phenomenally heavy rains, which fell towards the close of the month, but more particularly on the last day, the totals for which however, will be included in the March returns. These heavy rains, which were due to an inland monsoon, were very wide spread, and severe floods and wash aways were reported chiefly in the north and north-west. Including the totals to the 1st March, the aggregate for three days ranged from 3 to 6 inches at many stations, while several received 7 to 8 inches, with a maximum of 1,709 points at Wilmington. This remarkable total of 1,709 points in three days is probably unprecedented as far as the settled parts of the state are concerned.

A large flood event was also reported by community members to have occurred in January 1941. It is believed to be the second largest flood event to have occurred within the last 113 years and the Willochra Plain was inundated as displayed in the photographs in Figures 12, 13 and 14.

Source: Reg Noll

Figure 12. Flood waters 24 January 1941, view from Larpina Homestead

Source: Reg Noll

Figure 13. Flood waters 24 January 1941, road to Larpina

Source: Reg Noll

Figure 14. Flood waters 24 January 1941, Willochra Creek Larpina Homestead

The average rainfall recorded from 6 regional rainfall stations for the 24 January 1941 was 42.9 mm and while this is only 35% of the average rainfall experienced on 1 March 1921, significant flooding resulted. Station M019048 Wilmington Post Office again recorded the highest rainfall, with 62 mm.

The *Quorn Mercury, Hawker and Great Northern Courier*, Friday, 31 January 1941 headlined ‘Record Rains for January, Deluge After 13 Months Drought’ and further reported:

> Not since records have been kept for the past 60 years has Quorn received such bounteous rains for January as those that have opened this year. The fall of nearly 4 inches over last week end, together with the 135 points a fortnight before, are reminiscent of those of 1921, when over 5 inches fell in February.

It is interesting to note that while the flood of the 24 January 1941 was the second largest reported flood event within the Willochra catchment in the last 113 years, there are 34 daily records (excluding the records of 1921) with the regional average daily rainfall of greater than the 42.9 mm calculated for the 24 January 1941 (Table 7).

The fact that there are numerous rainfall days with a higher ranked regional average than 42.9 mm as experienced on 24 January 1941, demonstrates that factors other than the amount of rainfall affect catchment runoff. Factors that affect the catchment’s response to rainfall events include the intensity of the rainfall, that is, the rate of rainfall measured in millimetres per hour. A high intensity rainfall event will generate runoff while a low intensity rainfall event is unlikely to lead to runoff event. Another factor influencing runoff is the soil moisture content, dry soils combined with high intensity rainfall generally leads to the generation of surface runoff, and this is the probable explanation for the generation of the second largest flood event in the Willochra catchment on the 24 January 1941, even though greater rainfall events have occurred, drought conditions were experienced for the preceding 13 months before the rainfall event.

Table 7. Ranked daily regional rainfall events of the Southern Willochra catchment

Ranking	Date	Average Regional Rainfall (mm)
1	1/03/1921	119.3
2	14/06/1898	84.2
3	18/02/1946	80.2
4	1/03/1992	76.9
5	30/01/1974	72.7
6	1/12/1966	69.6
7	28/11/1977	69.6
8	17/02/1943	67.4
9	30/11/1937	67.3
10	2/01/1889	61.6
11	9/10/1949	60.0
12	1/06/1920	57.3
13	5/02/1973	56.9
14	14/03/1989	56.7
15	8/07/1993	56.3
16	28/02/1921	55.4
17	19/01/1937	54.9
18	7/03/1910	52.9
19	17/02/1946	52.8
20	3/06/1939	52.5
21	31/10/1997	51.7
22	6/02/1973	50.7
23	19/09/1915	50.5
24	11/07/1939	50.2
25	1/09/1908	49.7
26	31/05/1889	48.5
27	30/05/1893	46.9
28	22/10/1916	46.3
29	2/04/1889	46.3
30	2/01/1921	46.0
31	25/10/1975	45.3
32	8/03/1910	44.9
33	1/09/1984	44.8
34	15/08/1958	44.6
35	23/06/1909	44.4
36	8/02/1997	43.7
37	5/03/1910	43.5
38	24/01/1941	42.9
39	13/10/1976	42.8
40	10/06/1890	42.7

It is also interesting to note that 19 of the 38 wettest days on record occurred in the driest months of the year, December, January, February and March (refer to Figure 10). The fact that half of the 38 wettest days on record occurred during these months indicates that summer rainfall events are relatively common and are likely to occur as indicated in the newspaper report of 11 March 1921, due to monsoonal influences.

Investigation of a number of the local newspapers show that numerous floods have occurred in the region between 1889 and 2002 however, these appear not to have been of the magnitude of the flood events experienced in 1921 and 1941. Rainfall events were also reported and some are detailed below.

The rainfall event of the 30 May 1893, with a calculated average regional rainfall of 46.9 mm, which is ranked 27th, was reported in the *Orroroo Enterprise & Great Northern* Advertiser, Friday, 2 June 1893. The article's headline reads 'A Cheerful Outlook for the North'. And further states:

> A better rain, at a more propitious time, could not have fallen. We wanted two inches just at the time rain set in, and we have had over three inches.

The rainfall event of the 14 June 1898, with a calculated average regional rainfall of 84.2 mm, which is ranked the 2nd largest rainfall event, was reported in the *Quorn Mercury Hawker and Great Northern Courier*, Friday, 17 June 1898. The article stated:

> These rains have been the heaviest that have fallen for years on the plains and some of the oldest residents say there is more water lying about now than there has been for the last 20 years. All the creeks are flooded and the Willochra is expected down a banker …
>
> RICHMAN'S CREEK June 15th
>
> The creeks were all running bankers yesterday. The dams are full and the land has had such a good soaking as it has not had for years; we have not had anything like it since 1893….
>
> WILLOCHRA June 13th
>
> Last week this part had a splendid downpour of rain; somewhere about 800 points was registered … some of the farmers are busy irrigating their lands where it is possible from the creeks.

It is interesting to note from the above article that flood irrigation was being practiced in the late 1800s.

Inspection of Table 7 displays three significant rainfall events occurring in March 1910, the rainfall events occurred on 5, 7 and 8 March 1910 with a calculated regional average rainfall of 43.5 mm, 52.9 mm and 44.9 mm respectively. Each of the above mentioned rainfall events were ranked within the top 38 rainfall events however, there was no mention of flooding in the local newspapers. The *Orroroo Enterprise & Great Northern Advertiser*, Friday, 11 March 1910 reported:

> WILLOWIE SPRINGS March 8th
>
> Heavy rains have fallen here. Water is now plentiful everywhere. The rain has been general all over the districts

The *Quorn Mercury, Hawker & Great Northern Advertiser*, Friday, 11 March 1910 further reported the rainfall event but did not mention flooding. An extract from the article reads:

> The land (and roads), have received a good soaking, and what was dust a week or so ago has now been transformed into mud.

The rainfall event of 30 November 1937, with a calculated average regional rainfall of 67.3 mm, which is ranked 9th, was reported in the *Quorn Mercury, Hawker & Great Northern Advertiser*, Friday, 3 December 1937. The article headlined 'Pastoralists' Christmas Box' and stated:

> All creeks ran heavily and damage caused to roads. Heavy falls at Carrieton, Eurelia, and Langwarren stations caused the Boolcunda Creek to run a banker, while Willochra, Capowie and minor creeks ran heavy floods.

The rainfall event of the 18 February 1946, with a calculated average regional rainfall of 80.2 mm is the third largest rainfall event in the region. The event was reported in the *Quorn Mercury, Hawker & Great Northern Advertiser*, Thursday, 21 February 1946 as 'Record Floods in Quorn District'. The event was further reported in the following week's edition of the newspaper on Thursday, 28 February 1946. Extracts from the article read:

> In the Valley district heavy rain made the roads impassable to heavy vehicles and farmers had to journey to Quorn on horse back. Mr Schnell said this week that some of the creeks were wider than during the 1921 floods.
>
> Water which passed over the ford on the Wilmington road caused considerable damage. The fence several yards back from the creek was swept away, solid cement and stone foundations were torn up and tons of rock piled up feet high in the creek.
>
> The biggest floods since 1921 were seen between Gordon and Hawker and a number of people were stranded in the latter town for some days.

The 1970s was the wettest decade on record for the region (as displayed in Figure 8), and five of the 38 largest rainfall events listed in Table 7 occurred during the 1970s. Two of the events were recorded for 1973 and one each for 1974, 1975 and 1977. Very little information was found in the local newspapers regarding flood events, with the exception of the *Quorn Mercury, Hawker & Great Northern Courier*, Friday, 21 May 1973 which reported:

> The rain was steady and of a soaking nature, but in the hills some sharp and heavy showers fell and delayed motorists until the water in the creeks subsided.

The reference to *steady* rain is indicative of low to moderate intensity rainfall events, while the reference to *sharp* and *heavy* showers indicates high intensity rainfall as discussed previously. Note that the steady rain had time to infiltrate or soak into the soil while the rainfall of greater intensity in the hills regions generated runoff that led to localised flooding. While the intensity, soil type and geology affect a catchment's response to rainfall, other environment factors also contribute such as topography. Runoff is more likely to be generated in sloping terrain even under light to moderate intensity of rainfall events while on flat land or plains it is unlikely that runoff would be generated under the same conditions.

Another flood event occurred in June 1978, and while this particular flood event is not displayed in Table 7, the event was ranked within the top 100 daily rainfall events in the region. For the three-day period 4–6 June 1978 the regional average rainfall was 79.4 mm. Examination of the average rainfall of 3 consecutive days shows that this particular event was ranked the 42nd wettest 3 days in the 113 years record. Flooding resulted and is displayed in Figure 15.

Source: Kevin Daily

Figure 15. Photograph of Beautiful Valley Creek downstream of Three Chain Road Crossing June 1978

Another large flood event occurred in March 1989, the rainfall event was ranked the 14th largest event within the last 113 years; the average regional rainfall for the day was 56.7 mm with the highest recorded rainfall at station M019048 – Wilmington Post Office with 65.0 mm.

Investigation of the daily read rainfall data from the northern reaches of the catchment show that the rainfall was actually greater in the northern reaches of the catchment and the following rainfall was recorded: Station M019038 – Quorn Post Office received 92 mm, M019004 – Belton received 110.6 mm, M019015 – Gordon received 67.4 mm and M019050 – Wilson received 134.4 mm. It was during this period that the gauging station AW509502 – Willochra Creek at Partacoona was torn from its concrete footings and washed downstream.

Source: DWLBC

Figure 16. Gauging Station AW509502 – Willochra Creek at Partacoona following the flood event of 14 March 1989

The rainfall event of 1 March 1992 was the 4th largest rainfall event to have occurred within the Southern Willochra catchment in the past 113 years (Table 7). The calculated average regional rainfall was 76.9 mm, and the highest recorded rainfall was at station M019048 – Wilmington Post Office with 117.0 mm.

The rainfall event of the 8 February 1997, with a calculated average regional rainfall of 43.7 mm, was a slightly larger rainfall event than experienced in 1941. The highest rainfall was recorded at station M019042 Melrose Para Gums with 76.4 mm. The event was reported in the *Flinders News*, Wednesday, 12 February 1997 and headlined 'Floods devastate train service'. An extract from the article reads:

> Torrential rains have fallen throughout The Flinders News area during the last week – leaving some homes and buildings flooded and cutting road and rail services.

It was further reported in *Flinders News* the following week on Wednesday, 19 February 1997 the article stated:

> The roads were damaged when 161 mm (more than 6 inches) of rain fell in a week, and about 100 mm (four inches) fell in a matter of hours … water entered 16 houses in Booleroo Centre, two to three houses in Melrose and water was lapping the doorsteps of houses in Wilmington.

The flood event was further described in the above-mentioned article as "a freak of nature". However, as discussed previously, large summer rainfall events under monsoonal influence are relatively common in the region.

Source: Alex Bishop

Figure 17. Flood waters following the rainfall event of 8 February 1997

Source: Alex Bishop

Figure 18. Effects of floodwaters on local property following the rainfall event of 8 February 1997

The photographs in Figures 17 and 18 demonstrated show the effect of the February 1997 rainfall event.

Consultation with the landholders affected by the flood event reported inundation of paddocks, impassable roads and driveways awash. Strainer posts were lifted from the ground and fences ruined. Large debris was deposited at the high water mark (as evident in Figure 18), and it was further reported that tonnes of gravel and silt washed onto paddocks while tonnes of valuable topsoil were stripped from paddocks (Figure 18).

The rainfall event of 1 September 2001, with a calculated average regional rainfall of 30.5 mm and the highest recorded rainfall at station M019024 – Melrose Post Office of 54.8 mm was reported in *Flinders News* on Wednesday, 5 September 2001. The article headlined 'Tourists marooned in Flinders Ranges IT BUCKETED DOWN' displayed local rainfall in the area and showed Wilpena receiving the most rain with 164 mm recorded.

The Transcontinental Port Augusta on Wednesday, 19 September 2001 also reported on the rainfall event. An extract from the article reads:

> "Generally the rains have been good because they've gone right across the pastoral country which hasn't occurred for many years," Mr McColl said, which covers the area from Willochra Plain through to Boolcunda.

It is evident from the information provided that the onset of a flood event depends not only on the amount of rainfall but more importantly the intensity of the rainfall event and the seasonality. It is also evident that many of the rainfall events that have led to severe flooding have occurred during the summer months under the influence of the northern monsoon.

Stream flow

The Willochra river system is an ephemeral semi-arid to arid river system that flows from the base of Mt Remarkable northward through the Willochra Plain and discharges to the saline Lake Torrens (Figure 1). While the surface water resource is limited with flows in the southern catchment occurring for only 3–4 months of the year, there is a large demand on the resource for the irrigation of cereal crops, vineyards and grazing pasture. Recent increases in development in the region, coupled with declining rainfall, has led to a number of concerns raised by the community regarding the sustainability of the surface water resource and the environment it supports.

Community Information

A number of community concerns have been raised regarding the use of surface water within the region. While the surface water resource is limited, with reliable flow occurring only during the winter months there is a reliance on the surface water resource for flood irrigation of cereal crops. There is also an increasing demand placed on the resource through the establishment of vineyards and olive groves where the harvesting of surface water is becoming increasingly popular amongst growers, to supplement dam and groundwater supply.

Flood irrigation of cereal crops is common practice within the southern Willochra catchment and occurs predominately along the Willochra Creek and tributaries to the Willochra where the land is relatively flat. Flood irrigation is not restricted to the Southern Willochra catchment; community information and aerial videography footage have revealed numerous diversion banks and lock structures within Willochra Creek as far north as Quorn.

Irrigators who practise flood irrigation do so by constructing locks that severely restrict flow downstream, and backs up the water behind the lock until the water spills over the stream banks and subsequently floods the land. The duration or period of time for which flow is reduced depends on the magnitude of the flow event, the volume of water available in the stream, the area of land required to be flooded and the number of irrigators within the given reach of the stream. Consequently if a flow event is small, or the area of land to be flooded increases, the duration of stream flow restricted to downstream water users is greatly increased. Irrigators reported that the Willochra Creek has flowed only once in the last five years. While it is recognised that there has been a regional decline in annual rainfall during this period, the reduction in flow frequency experienced in the region may be further exacerbated by water diverted from streams for flood irrigation.

The practice of flood irrigation is opportunistic, occurring when adequate supply is available. Best results are achieved when areas are irrigated during spring, as the rainfall is sufficient to support cereal crops during the winter months. Flood irrigation of cereal crops has been practised for a number of generations in the region however, a recent decline in rainfall has increased the competition for the resource, which has highlighted its inadequacies.

While the economic and social benefits of flood irrigation are evident from greatly increased crop yields and improved pastures for grazing, there are also economic, social and environmental costs associated with the practice. Some of the issues raised by the community are as follows:

- There is a lack of regard or consideration for downstream water users
- There are large inefficiencies due to a lack of communication between irrigators
- The duration of stream flow is reduced
- The volume of water in stream is severely reduced
- The connectivity between the southern and northern catchments is largely absent with the exception of large flood events
- The travel time and attenuation period of high flow events between the southern and northern Willochra reaches has increased
- There is a lack of regard for environmental water requirements

Within the region there is the general attitude regarding the use of the water resource as “first in, first served” and while this is beneficial for upstream irrigators there is little regard for the downstream water users’ right to take water and environmental water requirements. Further to this, due to the nature of flood irrigation a downstream water user may begin to flood irrigate and half-way through the process the flow may be cut off as an upstream user begins to flood irrigate. The downstream water user is then required to wait until flow is restored before the process can be continued and then floods the area of land previously flooded. Clearly large volumes of water are wasted due to the lack of communication between irrigators. This inefficiency could be overcome by the establishment of an irrigators committee and water share arrangements between all water users including the environment.

Landholders have reported that in recent years the volume of water flowing in streams is less than previously experienced and the period of time that the streams flow is shorter. Reduced flow volumes and periods are likely to have resulted in the reduction of the connectivity of the river system, which in turn impacts on the environment the river system supports. Landholders have reported the following environmental changes in the region:

1. stress on eucalyptus trees, and very little to no regeneration that typically occurs following high flows

2. Reduction in pools (springs) and soaks, which are of great environmental significance in an ephemeral river system as they provide refuge areas for aquatic flora and fauna during times of no stream flow

3. Reduction in the distribution of fish species, due to the lack of connectivity between the northern and southern reaches of the catchment combined with the reduction of refuge areas from the southern reaches of the catchment

Another issue raised by the community regarding the surface water resource is the risk of contamination caused by the dumping of rubbish in the watercourse. It has been reported that numerous items have been found following flow events including old pesticide drums. Aerial videography footage revealed several suspected rubbish dumps within the watercourses supporting information provided by community members.

Clearly the anecdotal information and concerns raised by the community and stakeholders suggests that the resource is under significant pressure.

Data availability

While concerns over the sustainability of the surface water exist, there are currently no gauging stations that directly measure the flow in the southern catchment study area.

South Australia's gauging of stream flow is conducted by DWLBC, and information relating to stream flow is stored in the DWLBC database Hydstra. Further information is available on the DWLBC website at www.dwr.sa.gov.au/water/index.html and www.dwr.sa.gov.au/water/technical/surface_water_archive/a1pgs/index.htm.

Three gauging station are located within the Willochra catchment AW509504 – Spring Creek at Terka, AW509502 – Willochra Creek at Partacoona and AW509503 – Kanyaka Creek. A new gauging station has also recently been constructed at Spring Creek however, no data is currently available.

The closest station to estimate flow in the southern catchment is located adjacent to but outside of the Willochra catchment, station AW508500 – Baroota Creek at Baroota Reservoir.

Table 8 shows gauging stations within and adjacent to the Willochra catchment, the length of recorded data and the quality codes assigned to the data. The quality codes indicate the suitability of the data and an explanation of the codes is displayed below (see Table 8 notes).

Table 8. Gauging stations within and adjacent to the Willochra catchment

Station No	Station Name	Period of Record	Quality Codes
AW509502	Willochra Creek @ Partacoona	18/07/1973 - 28/02/2002	9, 76, 103, 150
AW509503	Kanyaka Creek @ Old Kanyaka Ruins	17/07/1973 - 07/10/2002	9, 76, 255
AW509504	Spring Creek @ Terka	17/10/1973 - 07/12/1976	108
AW508500	Baroota Creek @ Baroota Reservoir	17/11/1978 - 04/02/2003	9, 26, 76, 149,

9 = good record, 26 = good daily read records, 76 = estimated – reliable estimation, 103 = doubtful - unreliable estimation, 108 = provisional rating, 149 = missing data – daily values only, 150 = caution – rating table extrapolated, 255 = data not recorded.

Within the catchment Spring Creek at Terka could be expected to provide stream flow information for the valuable higher runoff areas of the western boundary. However, reference to Table 8 shows the data set is poor.

The data from Station AW509504 was derived by the use of rating tables. The entire data set was assigned the quality code 108 meaning the data is a provisional rating. This is due to fact that not only was the data derived by extrapolation from a rating table, the control at the gauging station was an unstable natural channel which is subject to change.

An attempt was made to analyse this data and some of the results are displayed within the Surface Water Modelling section of this report. Due to the lack of credibility of the data set, there was little confidence in the results produced, and further analysis using the data set was not attempted.

This lack of data is concerning particularly given the value of these western highlands (particularly Spring Creek) for the domestic and irrigation needs of the region.

The best record within the catchment boundary is on the main channel of the Willochra Creek at Partacoona, just upstream of its influence with Lake Torrens. The original gauging station at the site was destroyed in the 1989 flood event (refer to Figure 16) and a new station was built in 2002. While the record is long and accurate, it provides little insight into the resource availability of the southern catchments. This is largely due to the lack of connectivity between the southern and the northern catchments, consequently gauged flows at Partacoona are not seeing surface water flows generated within the southern catchment. There are further differences in catchment characteristics between the southern and northern catchments that make it unrealistic to attempt comparison of these two distinct catchment areas. These characteristics include topography, land use, rainfall, evaporation and baseflow.

Flow discharging from the catchment

Investigation of the data from Station AW509502 shows 85% of the data from 1978 to 1989 has been quality coded as reliable data. The 1989–1998 data was estimated using a rainfall runoff model (National Land and Water Resources Audit 2000).

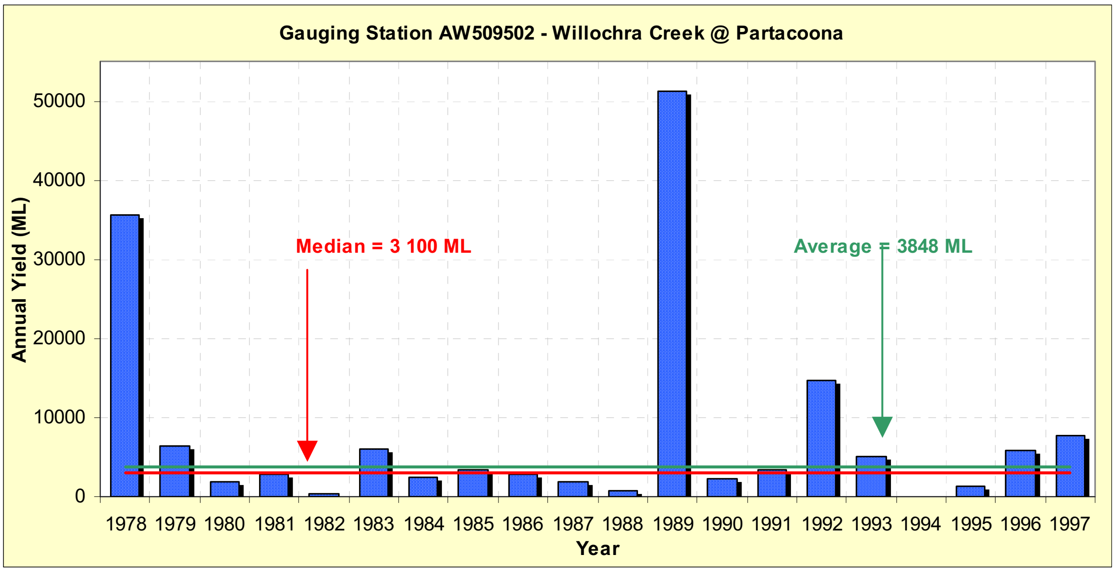

Figure 19. Annual gauged flows from Station AW509502 Willochra Creek at Partacoona

The largest flow was recorded in 1989 with greater than 50 000 ML, followed by 1978 with 35 677 ML. The lowest flow years were recorded in 1994 and 1982 with 27 ML and 436 ML respectively. The median annual flow measured at the gauging station is 3100 ML/year and is displayed in the chart above. The average flow has also been calculated excluding the extreme rainfall years of 1978 and 1989, to ensure the data is unbiased. The average annual yield is 3850 ML, and 12 of the 20 years recorded have experienced below average yields.

Figure 20 shows the flow duration curve for daily flows at gauging station AW509502. The flow durations are defined as the percentages of time during the total period of record for which the flow exceeded various rates.

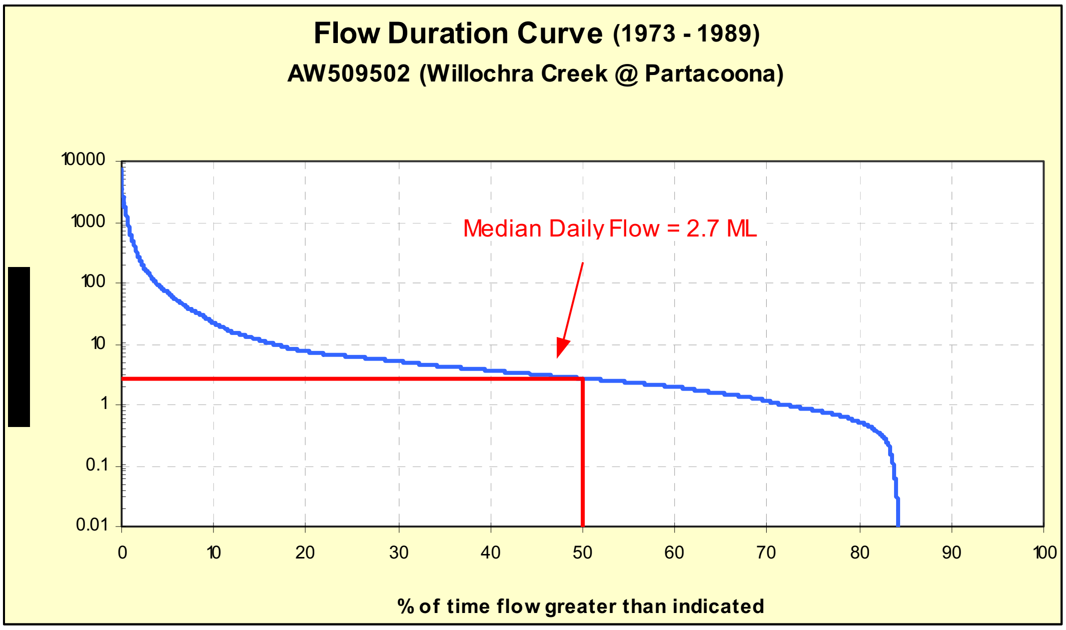

Figure 20 Flow duration curve for Gauging Station AW509502 Willochra Creek at Partacoona

The current flow-duration characteristics of the catchment indicate that in an average year:

- The catchment flows 84% of the year
- A flow of at least 1 ML/day will be available on 260 days in a year (71% of the year)
- A flow of at least 10 ML/day will be available on 60 days in a year (16% of the year)
- A flow of at least 50 ML/day will be available on 22 days in a year (6% of the year)
- A flow of at least 100 ML/day will be available on 13 days in a year (3% of the year).

The permanency of flow in the lower reaches of the Willochra catchment is not seen in its middle reaches. Permanent flow is understood to be generated by discharge of groundwater (baseflow) to the Willochra Creek from the regional fractured rock aquifer system associated with the Southern Flinders Ranges. High flows are likely to be generated in any number of the creek's numerous tributaries in response to intense localised rainfall.

The permanent water and the long duration of flow in this reach are vital for water dependent ecosystems, which is magnified by the dryness of the surrounding region.

Flow generated in the Southern catchment

Without direct measurement of resource availability in the southern catchments a number of methods were employed to estimate the volume of flow generated. These were:

- rainfall–runoff relationship from an adjacent catchment with similar characteristics
- rainfall–runoff relationship from a sub-catchment within the Willochra catchment

- rainfall–runoff model construction and calibration for the catchment.

Annual rainfall runoff relationship from adjacent catchment

The Baroota catchment is located adjacent the southwestern boundary of the Southern Willochra catchment. The catchment has similar catchment characteristics to a number of sub-catchments within the Southern Willochra, particularly Beautiful Valley, Stony Creek, Spring Creek, Campbell Creek and Yellowman Creek. Due to the similarity in catchment characteristics and the availability of data, the rainfall–runoff relationship of Baroota catchment was used to estimate the likely surface water resource generated within the Southern Willochra catchment on an annual basis.

The rainfall–runoff curve displayed in Figure 21 was plotted using a Tanh function (Appendix D) to visually best fit the scatter of the recorded data. The x-axis displays annual rainfall (mm) and the y-axis display the corresponding runoff (mm). The recorded runoff data was derived from the Water Supply records from Baroota Reservoir, for the period 1941–1994. Corresponding daily read rainfall data was recorded at station M019012 Port Germain (Baroota Reservoir) from 1922 to 1998. Data was also recorded from station AW508504 – Baroota Reservoir catchment Pluvio at Glenlossie from 1989 to 2002. The data from the catchment pluvio better represented the overall catchment rainfall, for this reason the data from station M019012 was adjusted accordingly using linear regression techniques.

The rainfall-runoff relationship curve indicates the annual runoff that can be expected from the catchment for various annual rainfalls. Inspection of the curve shows that little or no runoff occurs for annual rainfall values below 300 mm. It also shows that for 500 mm of rainfall around 20 mm of runoff would be generated.

The runoff coefficient, which is the average annual runoff divided by the average annual rainfall for the catchment, is used as an indicator to compare its relative efficiency. The higher this coefficient, the more efficient is a catchment in terms of runoff leaving the catchment, in comparison to a similar catchment with the same rainfall pattern. The average runoff co-efficient for the Baroota study area is 0.06 for the period 1941–1994, or in simpler terms, an average 6 mm of runoff leaves the catchment for every 100 mm of rainfall. It should be noted however, that this figure varies depending on rainfall as the relationship between rainfall and runoff is non-linear.

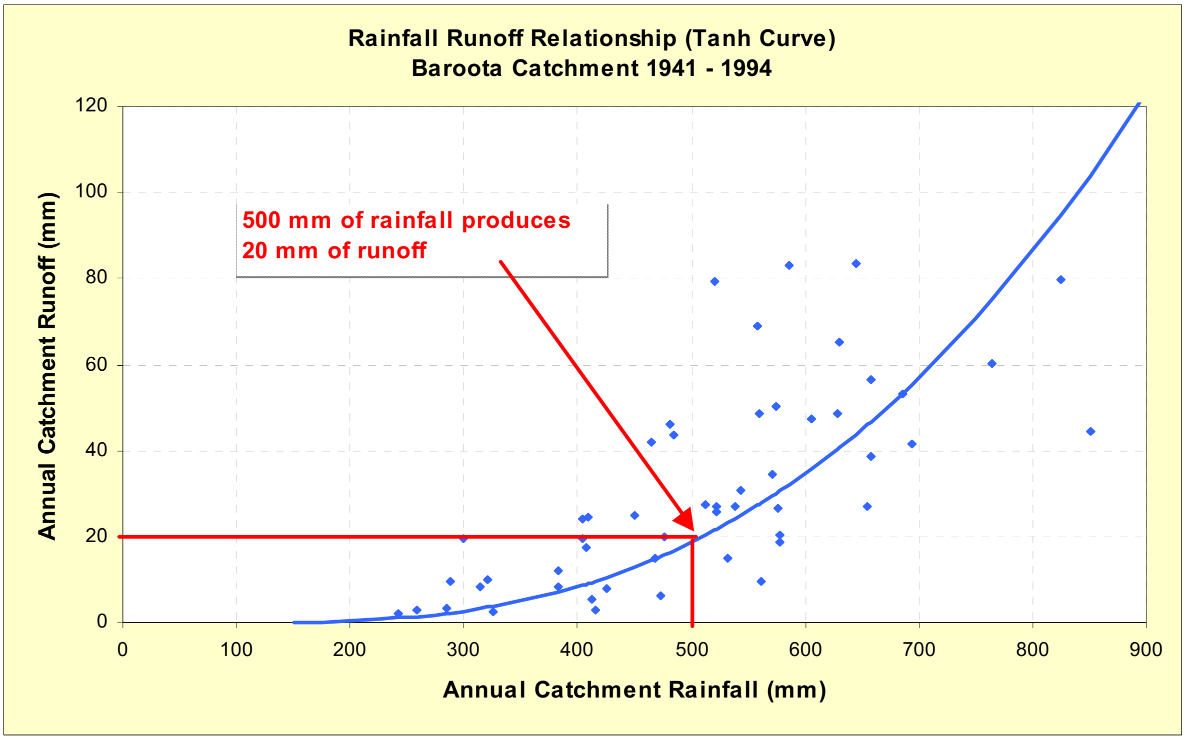

Figure 21. Rainfall–runoff relationship for Baroota catchment

The rainfall–runoff curve can be used for initial estimates of runoff for ungauged neighbouring catchments. In this case, the rainfall–runoff curve for Baroota catchment has been selected for initial runoff estimates for the Southern Willochra catchment based on rainfall from within the catchment. The results are displayed in Table 9 below and show that the Southern catchment generates approximately 8000–9000 ML.

Table 9. Estimated volume of runoff generated in the Southern Willochra catchment and sub-catchments

Sub Catchment	Runoff (ML/Sqkm)	Total Volume Runoff (ML)	Runoff Coeffiecient
Beautiful Valley	14.5	420	0.03
Booleroo	3.8	1200	0.01
Campbell	28.2	960	0.05
Fullerville	6.4	640	0.02
Old Booleroo	3.2	1100	0.01
Spring Creek	27.5	1500	0.05
Stony Creek	21.5	470	0.04
Wild Dog Creek	13.4	1360	0.03
Willochra Creek	4.8	800	0.01
Yellowman Creek	17	390	0.03
Total	**7.4**	**8000 - 9000**	**0.02**

The average annual rainfall was estimated by extrapolation of the isohyet data for each sub-divided sub-catchment. The average annual rainfall data for each sub-division was then incorporated into the rainfall–runoff equation (Tanh, Appendix D) and the runoff was determined.

The calculated runoff was then multiplied by the area of each sub-divided sub-catchment to determine the volume of runoff generated. The area of each sub-divided sub-catchment was included in the calculations however, runoff from plains regions was considered negligible and consequently these areas were assumed not to generate runoff.

The estimated average runoff for the Southern Willochra catchment is 7.4 ML/km^2. While this is an average for the whole Southern Willochra catchment, this value varies considerably between sub-catchments as displayed in Table 9. Campbell Creek and Spring Creek sub-catchments produce more runoff than all other sub-catchments, generating approximately 28 ML/km^2. Both of these sub-catchments have the highest runoff coefficient of 0.05, indicating that they are the most efficient sub-catchments in terms of water leaving the catchment. Spring Creek sub-catchment is the highest yielding sub-catchment within the Southern Willochra catchment.

The average runoff coefficient for the Southern Willochra is 0.02. This figure is comparatively low in comparison to the Baroota catchment and is reasonable due to lower annual rainfall and differing topography, that is, there are no plains regions within the Baroota catchment like those of the Southern Willochra catchment.

Booleroo Creek and Old Booleroo Creek sub-catchments generate comparable volumes of surface water to that of Spring Creek sub-catchment however, they are roughly six times the size of the Spring Creek sub-catchment. The runoff for these sub-catchments is estimated to be only around 3 ML/km^2, both with a corresponding runoff coefficient of 0.01, which demonstrates their inefficiency in terms of runoff leaving the catchment. Willochra Creek sub-catchment also has a runoff coefficient of 0.01 and contributes only 5 ML/km^2 to the surface water resource. While this region is the main area where flood irrigation is concentrated, the majority of water diverted from the Willochra Creek is generated in the sub-catchments upstream.

The estimated total volume of flow generated from the Southern Willochra catchment is approximately 8000–9000 ML. The sustainable development limit[2] is assumed to be approximately 50% of this figure which equates to between 4000–4500 ML. Current estimates of water used for flood irrigation are around 2000–3000 ML (see Appendix H), and a further 1400 ML of surface water runoff is captured in farm dams. Consequently 3400–4400 ML of surface water is captured or diverted from the watercourse. This is approaching 50% of the available resource and the sustainable development limits for non-prescribed areas.

Annual rainfall–runoff relationship from Willochra catchment

In the drier sub-catchments of the Southern Willochra it is unlikely that the rainfall–runoff relationship of Baroota will hold and alternative stations AW509502 – Willochra Creek at Partacoona and AW509503 – Kanyaka Creek at Old Kanyaka Ruins were examined.

Investigation of rainfall and stream flow data at those stations failed to establish a meaningful rainfall–runoff relationship. Figure 22 the rainfall and runoff data points, the

2 The sustainable development limit, detailed in the State Water Plan (2000) allows landholders to capture 50% of the estimated median annual runoff generated from their properties.

large scatter of the data points show that a rainfall–runoff (Tanh) curve cannot be fitted to the data.

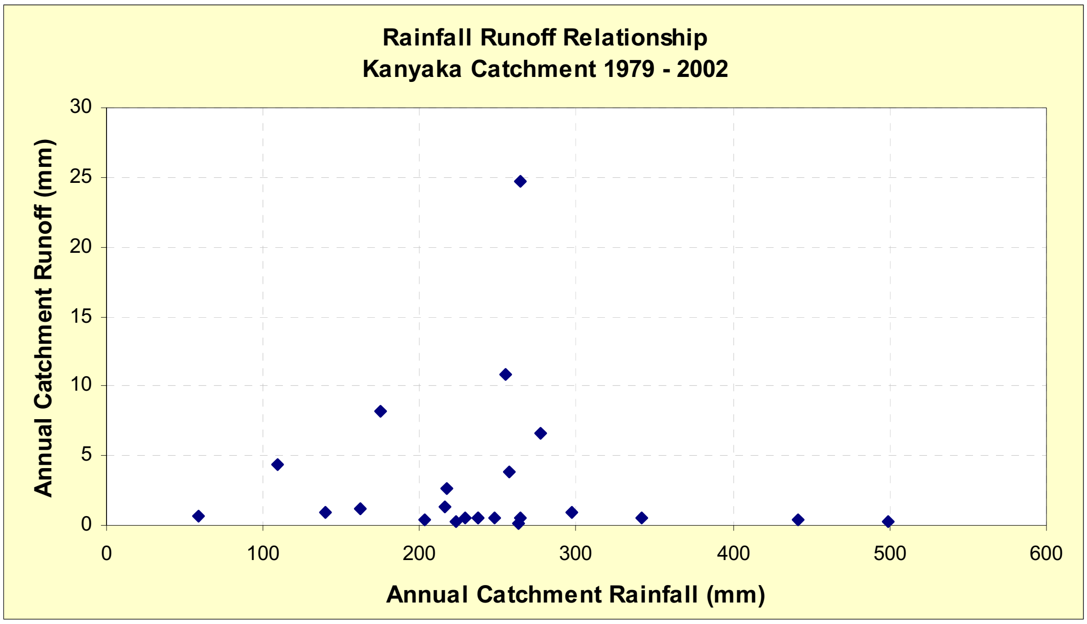

Figure 22. Rainfall–runoff data of Kanyaka catchment 1979–2002

Inspection of the data further shows that an annual rainfall of approximately 260 mm is capable of producing 25 mm of runoff while an annual rainfall of 500 mm produces less than 1 mm of runoff. A Tanh curve cannot be fitted to the data, as runoff in semi-arid low rainfall catchments is dependent on the intensity of individual rainfall events and not average annual rainfall.

The Tanh curve was developed in the temperate regions of Victoria and translates meaningful results to areas with higher rainfall than that experienced in the Willochra (Ed Pikusa DWLBC pers. comm., August 2003). The large scatter in rainfall–runoff data of the drier catchments is typical of data of drier regions and suggests that runoff is primarily driven by rainfall intensity and/or timing of the rainfall within the winter and spring period. Suitably located pluvio's that measure rainfall intensity would greatly aid establishment of meaningful rainfall-runoff relationships in these drier regions.

While it was not possible to estimate runoff generated within the Southern Willochra catchment by use of gauged data from within the Willochra catchment, using the adjacent catchment, Baroota did provide an initial estimates of the overall annual runoff of the Southern Willochra. In order to improve on the initial runoff estimates (Table 9) a model was set up to represent the Southern Willochra catchment in greater detail. The procedure and results of the hydrological model are detailed in the following *Surface Water Modelling* section of this report.

*Surface water modelling**[3]

*Overview**

Surface water models are conceptual models that are constructed using computer programs and used to simulate catchment conditions for assessment of current, past and future conditions. This provides a good tool for a better understanding of the long-term hydrological behavior of catchments and for further assessment of impacts on the catchment hydrology due to various changes.

In the case of this study, long-term daily rainfall data was used to simulate long-term runoff data for the Southern Willochra catchment using recorded rainfall data. However, this process was limited by the inability to calibrate flows against a well-rated gauging station. To overcome this, the model was calibrated against recorded data at Baroota and poorly rated gauged data at Spring Creek, which compromises the accuracy of the data. As a result the information in this section should be considered as a guide only until better-gauged information becomes available.

Surface water modelling involves the following processes:

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

Model calibration is an iterative process of solving the above-mentioned set of mathematical equations. Some of the main steps involved in this process are:

1. Input data to the model – one or more measured sets of hydrological parameters (e.g. daily rainfall data set)

2. Iteratively vary the other unobserved hydrological and catchment characteristics parameter sets (e.g. pan factor for soil, interception storage, groundwater discharge) to mathematically simulate one or more hydrological parameters that have been measured (e.g. simulation of catchment runoff)

3. Compare the simulated values to the measured values and continue the iteration process until a ‘good correlation’ is obtained between the simulated and measured values.

4. Use the estimated set of unobserved hydrological and catchment characteristics parameter sets obtained at this stage of ‘good correlation’ for modelling further scenarios.

The level of efficiency of the calibration process depends on the availability and accuracy of the number of hydrological parameter data sets. Since the hydrological cycle involves a

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[3] * denotes sections of the report adopted from Savadamuthu, K. (2003) *Surface water assessment of the Upper Finniss catchment.* These sections have been modified to suit the Willochra catchment.

large number of parameters that are not measured, efficient calibration of hydrological models requires good knowledge of the catchment conditions.

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

*Methodology**

WaterCress (Cresswell 2002), a computer based water-balance modelling platform was used for construction of the model in this study. This modelling platform incorporates some of the most widely used models in Australia to convert rainfall into runoff namely, AWBM, SFB, HYDROLOG, and WC1. WC1 (Appendix G) is a water balance model that was used to construct and calibrate models for various catchments in South Australia and hence was used in this study.

WaterCress allows the incorporation of different components in its water balance models. The components that can be incorporated are:

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

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

*Model construction**

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

For the Southern Willochra catchment the model was set up as a series of rural catchment nodes and off-stream dam nodes. Each rural catchment node in the model represents a sub-division within the whole of the Southern Willochra catchment (refer to Sub-catchments section of this report and Figure 5). Each off-stream dam node in the model represents the accumulation of dams or diversions within that sub-division. The drainage paths link each rural catchment node to the corresponding dam node, which in turn is linked to the next downstream rural catchment node until each sub-catchment is represented as displayed in Figure 23.

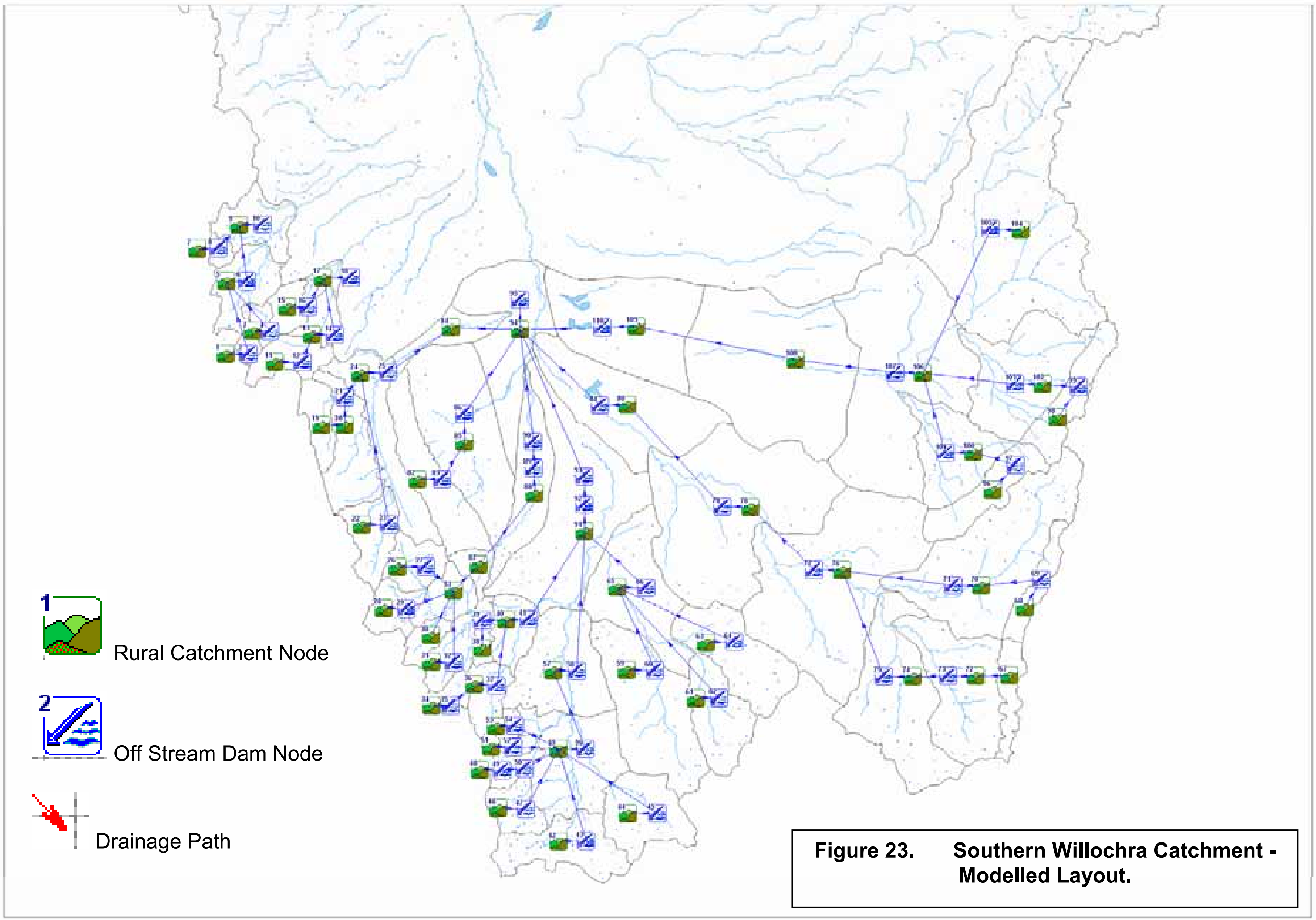

Figure 23. Southern Willochra Catchment - Modelled Layout.

The input data for each rural catchment node were:

1. Area of the sub-division
2. Corresponding measured daily rainfall and monthly evaporation data files
3. Runoff model to be used, which was WC1 in this case and initial estimated values for the catchment parameter set, namely, median soil moisture content, interception storage, catchment distribution, groundwater discharge, soil moisture discharge, pan factor, fraction groundwater loss, storage reduction coefficient, groundwater loss and creek loss
4. The set of measured daily rainfall across the catchment.

The input data for each off-stream dam nodes were:

1. Dam storage volume, which in this case, was the cumulative storage capacity of all the dams in the sub-division
2. Corresponding measured daily rainfall and monthly evaporation data files
3. Dam capacity to dam surface area relationship
4. Maximum daily diversion to the dam, which in this case was the maximum capacity of the dam
5. Fraction of total catchment runoff diverted to the dam. This is dependent on the location of the dam(s) and the probable catchment runoff captured by the dam(s). For example, this fraction was 1.0 if there was an on-stream dam located on the downstream end of the catchment, as it would be a controlling dam that is deemed to control or block the runoff from the entire sub-catchment. This fraction was reduced when the dam was located further upstream or when the dams were off-stream dams
6. Water usage from the dams, which, due to lack of further information was assumed to be 30% of the total dam capacity, on an annual basis. This rate of water usage was found to allow for some carry over of storage to following years in previously calibrated models for other catchments in the Mount Lofty Ranges.

The whole of the south Willochra catchment was hence represented as a series of rural catchment nodes and off-stream dam nodes that were all connected based on the catchment's drainage pattern (Figure 23).

Off-stream dam nodes were also used to represent the diversion of water for flood irrigation however, a number of input parameters were varied in order to reflect the different behavior of areas subjected to flood irrigation to that of farm dams. This was done by:

1. Firstly the area of land subject to flood irrigation in each sub-catchment was estimated by a combination of information provided by landholders, data captured by aerial videography, land use data and the assumption that 40% of the land under a particular land use located adjacent to in-stream diversion structures could potentially be flood irrigated.

2. In order to calculate the storage capacity of the "off-stream dam" the area of land subject to inundation was multiplied by the estimated depth of water of 0.5 m. The initial storage condition was set at zero (0.0) so that the model identifies that the

"dam" is empty prior to flood irrigation. This differs from dams as the initial dam conditions were set at 0.5 meaning they were half full.

3. The evaporation pan factor for water diversions was set at 2.0 for January, February, November and December. This ensured that all the water used for flood irrigation only remained in the "dam" for a short period of time and so the following year the model runs, the initial conditions would again be zero.

4. The maximum fill rate in megalitres (ML) was calculated depending on the area of land subject to inundation; generally this was 1/5 of the storage capacity meaning that it would take five days to flood irrigate the area. For farm dams the maximum fill rate was equal to the storage capacity of the dam meaning that the dam could potentially fill in one day.

5. The internal annual use as a fraction of storage was set at 1.0 for diversions meaning that 100% of the water captured is used. Farm dams internal annual use as a fraction of storage was set at 0.3 or 30%. The demand distribution for both diversions and farm dams assumed highest demand over the summer months. The diverted fraction of flow for flood irrigation was 1.0 meaning 100% of the water generated within the catchment was diverted for the given period of time required to fill the storage capacity. The diversion for flood irrigation was limited to the months of September and October, while diversion of water for farm dams occurred in all months. The volume to area relationship was calculated as a simple linear relationship.

Calibration*

Once the water balance model for the catchment was constructed, the model was calibrated with daily rainfall data, monthly evaporation data and farm dams capacity data as recorded inputs.

Rainfall data input to the model was in the form of daily rainfall data from seven Bureau of Meteorology (BOM) rainfall stations, to account for the variation in rainfall within the Southern Willochra catchment. The rainfall stations and the major sub-catchments for which the rainfall data was used are shown in Table 10.

Table 10. Rainfall stations representative of each sub-catchment

No	Station No. and Name	Mean Annual Rainfall (mm)	Major Sub Catchment
1	M019006 - Booleroo Centre Post Office	395.2	Fullerville
2	M019007 - Booleroo Whim	345.9	Old Booleroo Creek Booleroo Creek
3	M019011 - Doughboy Creek	456.1	Wild Dog Creek
4	M019024 - Melrose Post Office	598.1	Campbell Creek
5	M019042 - Melrose Para Gums	462.4	Yellowman Creek Willochra Creek
6	M019048 - Wilmington Post Office	446	Beautiful Valley Creek
7	M019071 - Alligator Gorge	644.7	Stony Creek Spring Creek

The next step was to account for the variation in rainfall within each of these major sub-catchments and to obtain rainfall data for the sub-divisions within those major sub-catchments. This was calculated as the ratio of value of the isohyet passing through the corresponding BOM station to the value of the isohyet passing through that sub-division. For example, rainfall data recorded from Station M019011 at Doughboy Creek was used for the entire Wild Dog Creek sub-catchment. The mean annual rainfall at Doughboy Creek is 458 mm. The sub-division WD1 within the Wild Dog Creek sub-catchment has the 470 mm isohyet passing through its centre. Hence, the rainfall for the WD1 sub-division was calculated as:

Rainfall data set for sub-division WD1:

= (470 mm / 458 mm) * Doughboy Creek Rainfall Data
= 1.026 * Doughboy Creek Rainfall Data

The rainfall data used for all the sub-catchments are listed in Table 10 above. Further details are of each catchment are listed in Appendix E (along with information regarding farm dams, water diversions and land use).

Once the input data was finalised, the model was first calibrated by comparing the data produced by the model with the monthly-gauged data from Station AW509502 – Willochra Creek at Partacoona for the period 1973–1989. The results of the modelled data when compared to the gauged data did identify peak flows however, it also displayed large losses within the system (up to 20 GL) which may indicate that the model may be grossly overestimating flows and there was little confidence in the results produced.

In order to reduce the volume of runoff generated in the modelled data it was assumed no runoff was generated on the plains, and the catchment parameter set was altered for all sub-catchments on the plains. The modelled results still showed large losses between the southern and northern Willochra catchments. It also displayed rapid recession of peak flows and underestimated low flows.

Due to the variation in catchment characteristics between the Southern Willochra catchment and the Northern Willochra catchment, such as rainfall, evaporation and topography, it was decided that it was unrealistic to attempt to calibrate the model to the data from gauging station AW509502. Further, the northern reaches of the catchment are sustained by base flow for approximately 80% of the year. This is not the case in the Southern Willochra catchment.

The alternative to using the gauged data at station AW509502 at Partacoona was to use the gauged information at Baroota. The Baroota catchment has similar catchment characteristics to the southwestern catchments within the Willochra catchment and it was assumed that the rainfall runoff relationship of Baroota would be similar to that of Spring Creek, Campbell Creek, Stony Creek and Beautiful Valley Creek sub-catchments. A rainfall runoff relationship (Tanh curve) was produced for the Baroota catchment and a further attempt to calibrate the model was conducted by iteratively varying the data for the catchment parameter set for the above mentioned sub-catchments until the output data produced a similar rainfall runoff curve to that of Baroota.

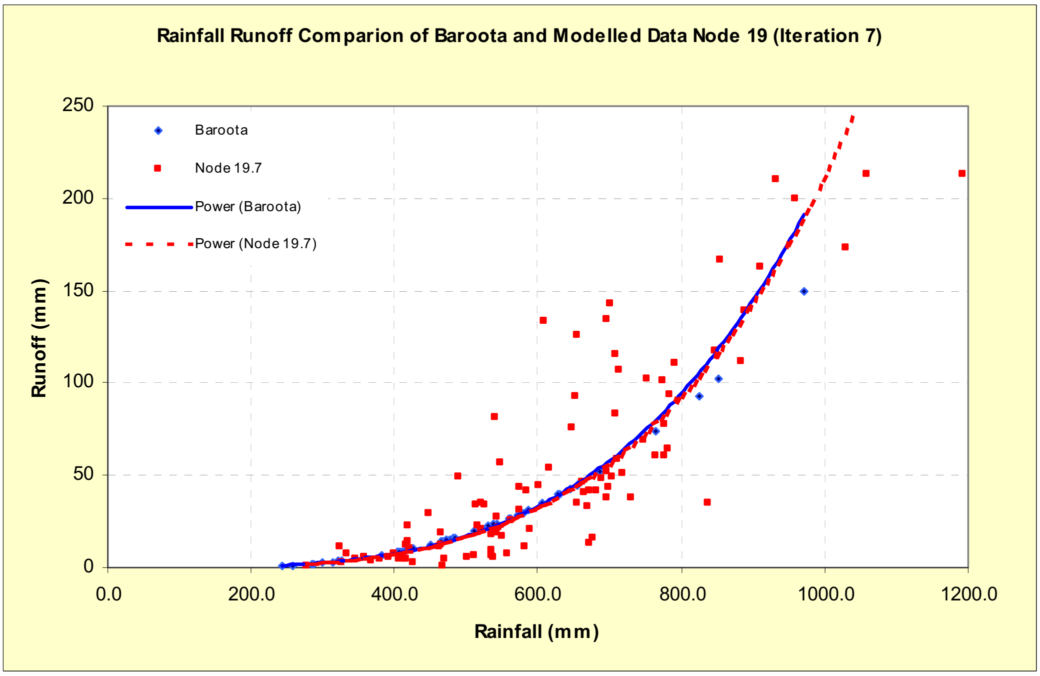

Figure 24. Rainfall–runoff relationship of Baroota and modelled data

Having established a catchment parameter set to mimic the observed rainfall runoff relationship of the Baroota catchment, investigation of the parameter set found many of the input parameters values were unrealistic. For example, typically the catchment distribution value is one third of the value for median soil moisture (David Cresswell DWLBC pers. com., August 2003) but in the modelled parameter set this value was closer to one half of the value given for median soil moisture.

The model was run with the new parameter set. Investigation of the results showed rapid onset of stream flow following rainfall events, which while reasonable also showed rapid decline of stream flow and under estimated low flows. As a result of the lack of confidence in both the output data and the catchment parameter set, the data was not used.

A final attempt to refine the calibration of the data was conducted by using the gauged data from Station AW509504 – Spring Creek at Terka. This was initially avoided for the following reasons:

1. There existed only water level data, and although numerous ratings had been performed no data existed in the Hydstra database relating to flow.

2. The data from the station was collected for only 3 years, during one of the wettest periods on record from 1973 to 1976. For the purpose of model calibration average flows are preferred as they are more representative of the long-term record. It is also preferable to have a record longer than 3 years of data to calibrate to.

3. The quality codes assigned to the data show the majority of the data is estimated.

4. A minute dated 14 December 1976 from the Engineering and Water Supply Department stated that the station was abandoned due to no determinable cease to flow and no definite control. Due to the instability of the control the records prior to 9 June 1976 would be doubtful.

5. Gauging data was estimated by extrapolation from rating tables. It is estimated that low flows are likely to have up to 10% error while high flow errors could be as large as 30%.

The gauged data from Station AW509504 was used in an attempt to calibrate the model to the existing 3 years of data. An auto calibration model NLFit was used to identify the catchment parameter set that best fits the modelled data to the observed data. The bounds of each of the 11 input parameters are set within the auto calibration model, the model runs thousands of iterations of all values between the upper and lower bounds for each parameter until the best fit to the data is identified.

Examination of the calibrated modelled data from Spring Creek with the observed data from the Spring Creek gauging station (Figures 25) demonstrates the model produces flow events that coincide with observed flow but the model also predicts flow events when no flow events were observed. Furthermore, many of the high flows are overestimated by the modelled data and while some of the recession curves of the hydrographs have a close correlation to the observed data often there is a rapid decline in the receding flows and an underestimation of low flows.

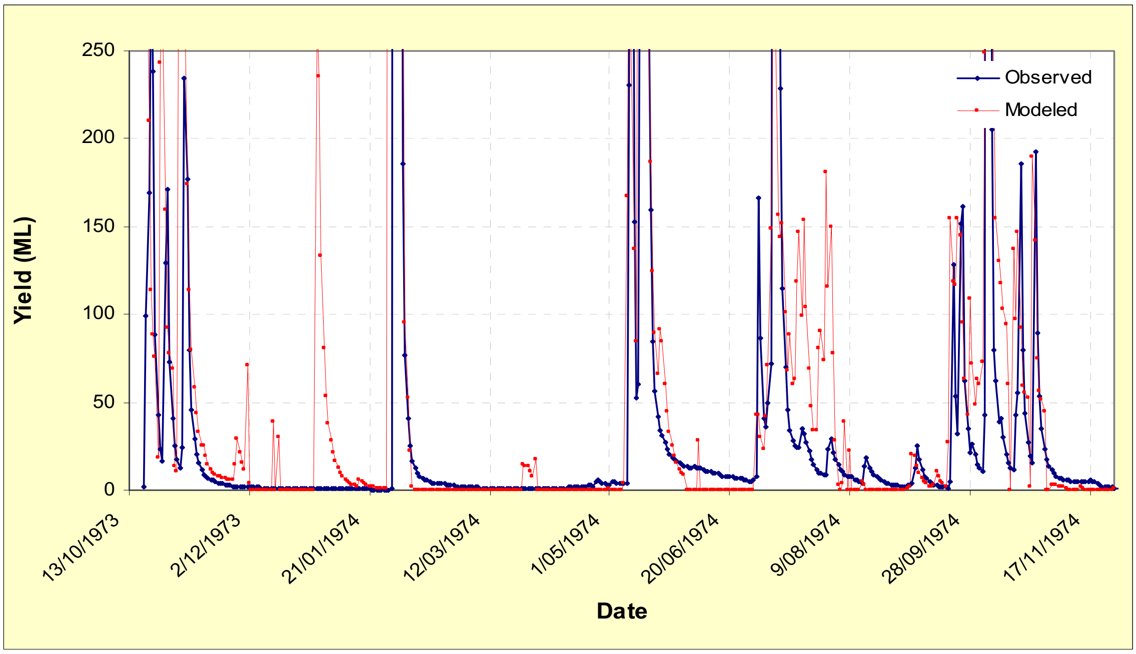

Figure 25. Comparison of observed daily flows from Spring Creek Gauging Station AW509504 with Spring Creek modelled daily flow

The monthly-modelled data displayed in Figure 26 shows a good correlation to the observed monthly data from February 1974 to October 1974. The deviation of the modelled data from the observed data for the initial 3 months of record may be attributed to the wetting up of the catchment, and is a typical modelled response. For the data following October 1974 there is clearly not a good correlation between the modelled and observed data. This is likely to be due to the poor quality of the gauged data for the given period. The model does show promise however it is impaired by poor quality data.

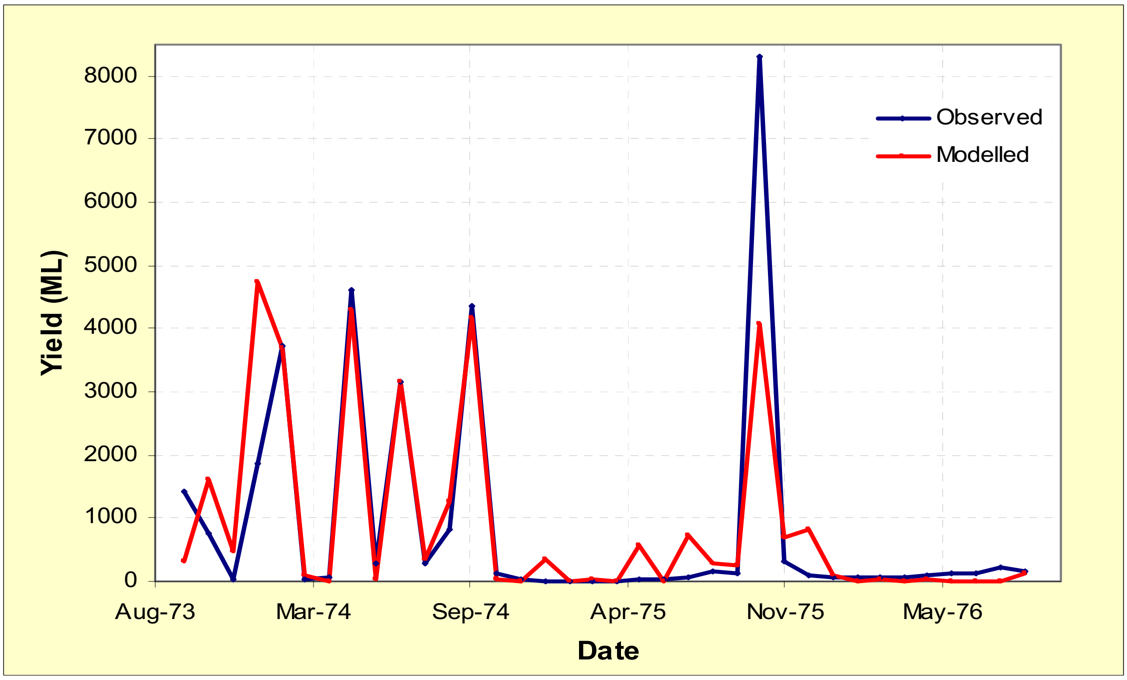

Figure 26. Comparison of observed monthly flows from Spring Creek Gauging Station AW509504 with Spring Creek modelled monthly flows

Examination of the mean monthly flows for the 100-year period shows that the months of January, February, March, November and December yield greater than 200 ML for Spring Creek. Anecdotal information provided by landholders suggests that flows occur only in winter to spring with the exception of summer flood events. The modelled results display summer flows that clearly demonstrate the modelled data does not accurately predict stream flow. This is likely to be the result of attempting calibration of the model using above average rainfall years.

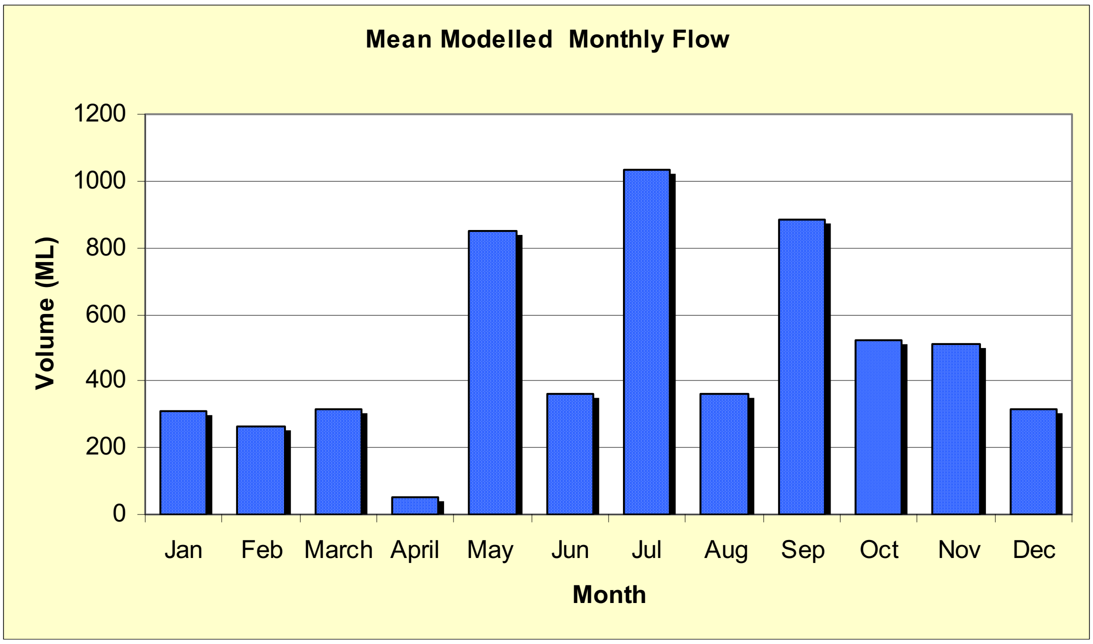

Figure 27. Spring Creek mean modelled monthly flows

The data also under estimates flows in June and August and is likely to be the result of using the auto calibration model to select the catchment parameter set that reflects above average rainfall years where runoff was generated in the summer months.

As with most hydrological models, modelling in general, and more specifically simulation of low flow events, high flood events, summer events and late season base flows, improvements could be made by using:

1. hourly rainfall data rather than daily rainfall data, as runoff hydrographs (the start, duration, peak and volume of runoff events) can be more accurately simulated using rainfall intensity data rather than daily rainfall data

2. daily evaporation data rather than mean monthly evaporation

3. further improvements of the isohyets data coverage, with a greater number of rainfall stations located within the elevated regions of the catchment

4. suitably located gauging stations representative of a variety of catchments within the Willochra

5. a better range of low flow data

6. a better range of high flow data. In the current rating curve used for calculating runoff from water level, the high flows are calculated from the extrapolated part of the rating curve. More water level observations at the gauging sites would further refine this extrapolated part of the rating curve and hence improve high flow data.

All these factors would lead to better input data and hence better calibration of the runoff events.

Model scenarios

Once a catchment rainfall-runoff model is calibrated it is then used to generate runoff data for any period of available rainfall records. It is further used to model desired case-scenarios to study the impacts of those scenarios on the catchment runoff behavior. This is used as an important tool in the catchment water management decision-making process.

Due to the lack of reliable data, the model was unable to be calibrated with a level of confidence suitable to conduct scenario modelling. It should be noted that once suitable gauging data becomes available the existing model, established as part of this study will be able to be used with a greater certainty.

Surface water supply for township reticulation

Surface water, until around 1994, was an integral component of township water supply in the region. Its lack of reliability and quality has forced a change to a sole groundwater supply. While improving the quality of water this has reduced the flexibility of the water supply system and placed greater stress on an already limited resource.

Details of the past surface water use is included in the later section Groundwater Supply for Township Reticulation.

GROUNDWATER

Due to the semi-arid environment of the Willochra catchment and the ephemeral river systems, there is a heavy reliance within the catchment on groundwater. Groundwater is relied upon for the reticulated water supply of many townships within the catchment and also provides water for stock and irrigation purposes. With water restrictions in place for the township of Wilmington and a recent increase in the development of irrigated horticulture coupled with declining groundwater levels, members of the community and landholders are concerned about the sustainability of the groundwater resource.

Hydrogeology

The Willochra Basin is an intermountain (between ranges) basin located approximately 300 km north of Adelaide. The basin covers an area of 1165 km^2, being 80 km in length and has a maximum width of 25 km. Geologically it is a sediment filled series of bedrock depressions between Booleroo Centre in the south and Simmonston in the north (Martin et al. 1998). The basin is bound by late Proterozoic and Cambrian rocks of the Adelaide geosyncline that forms a line of prominent hills including Mt Remarkable (959 m) and Mt Brown (965 m) along the western boundary. The maximum thickness of sediment within the basin is 140 m. (Shepherd 1978)

Quaternary (recent) sediments consist of mottled clays, with frequent thin sand and gravel beds, particularly near drainage lines. Tertiary sediments consist of clays and sandy clays with carbonaceous silts and lignitic sands. A confined aquifer within the Tertiary sediments of relatively fine grained sand bed, has a maximum thickness of 15 m in the south decreasing to 6 m in the north and is reported to be continuous over the basin, yielding artesian water, with a potentiometric (pressure) level greater than the ground surface level in the north. (Shepherd 1978).

The salinity within the confined aquifer is lowest, less than 1400 mg/L in the south near Mt Remarkable, increasing gradually across the basin to greater than 7000 mg/L in the north (Shepherd 1978). Read (1980) concluded that there must be a groundwater divide roughly co-incident with the surface water divide and recharge is by direct infiltration through outcrops in the southwest ranges. This is supported by low groundwater salinity in close proximity to the southwest and western ranges. Shepherd (1978), estimated recharge to the Tertiary sediments to be 5–10 mm/year from infiltration as cited in Martin et al. (1998).

O'Driscoll (1957) and Shepherd (1978), estimated the sustainable yield of the basin to be 400 ML/year. Martin et al. (1998) estimated the sustainable yield of the basin to be 4000 ML/year. The Engineering and Water Supply Department (1987) as cited in Martin et al. (1998) estimated groundwater use in the area to be 3250 ML/year indicating that the basin is approaching its sustainable limit.

Further to this Shepherd (1978) acknowledged that the southern half of the basin yielded water suitable for irrigation of pasture and that aquifer depletion was probable if large-scale irrigation occurred.

Table 11. Summary of hydrogeology of the Willochra Basin

Age	Unit, Lithology	Maximum known thickness (m)	Hydrogeology
Recent	*Unnamed* : Mottled sandy clays, thin sandy clays and thin sandy beds, overlain by a hard marly limestone.	90	Comprises an *unconfined aquifer* over part of the basin where more sandy facies occur. Yields generally low. groundwater varies from stock quality to saline - unsuitable for domestic use or irrigation.
Tertiary	*Unnamed:* White to creamy clays, sandy clays and clayey sands, slightly pyritic, lignitic in part. Aquifer consists of fine clayey sand overling basement rocks at base of Tertiary.	50	*Confined aquifer,* in sandy section overlying basement. Yields generally moderate, 200-300 kL/day. In southern half of basin groundwater is generally suitable for irrigation purposes (1000-2000 mg/L). Salinity higher in northern part of basin. Recharge by runoff from flanks of ranges. Measured permeability is 3 m3/day/m.
Proterozoic	*Adelaidean* : Phyllites and slates		Small supplies occur in fractured and folded rocks. Salinities generally similar to that of the confined Tertiary aquifer.

Source: Underground Water Resources of South Australia. Department of Mines and Energy. Bull 48. Pg 29.
NB. Recent = Quarternary.

Data availability

Observation well data is available from the State drill hole database, SA Geodata. Within the Willochra catchment there are 17 current observation wells that measure the standing water level (the distance in metres from the ground surface to the water surface). There are also 15 observation wells that measure groundwater salinity. Water level monitoring was conducted initially in 1976 – 1979; during this period each well was sampled only once. Typically ongoing observation well monitoring commenced in 1985 and continued for a varying time period there after. As a consequence only seven wells with records from 1985 to 2003 were used in this study. Figure 28 displays the location of these observations wells within the Willochra catchment and the salinity of water within each well. Observation well data is available on the DWLBC Obswell website https://info.pir.sa.gov.au/obswell/new/obsWell/MainMenu/menu.

Other information regarding the groundwater resources has been provided by landholders in particular, information regarding past and current groundwater use and the fluctuation of standing water level both historically and recently. Information was also obtained through the review of existing hydrogeological literature; details of the source of this information are contained within the *Reference* section of this report. Further information regarding the regions reticulated water supply was provided by the SA Water.

Observation wells data

The annual rainfall from station M019048 – Wilmington Post Office for the period 1985 to 2002 and data obtained from seven of the current operational observation wells (WLW001, GRG013, GRG005, GRG008, WLR012, WLR018 and GRG012) is displayed in Figure 29.

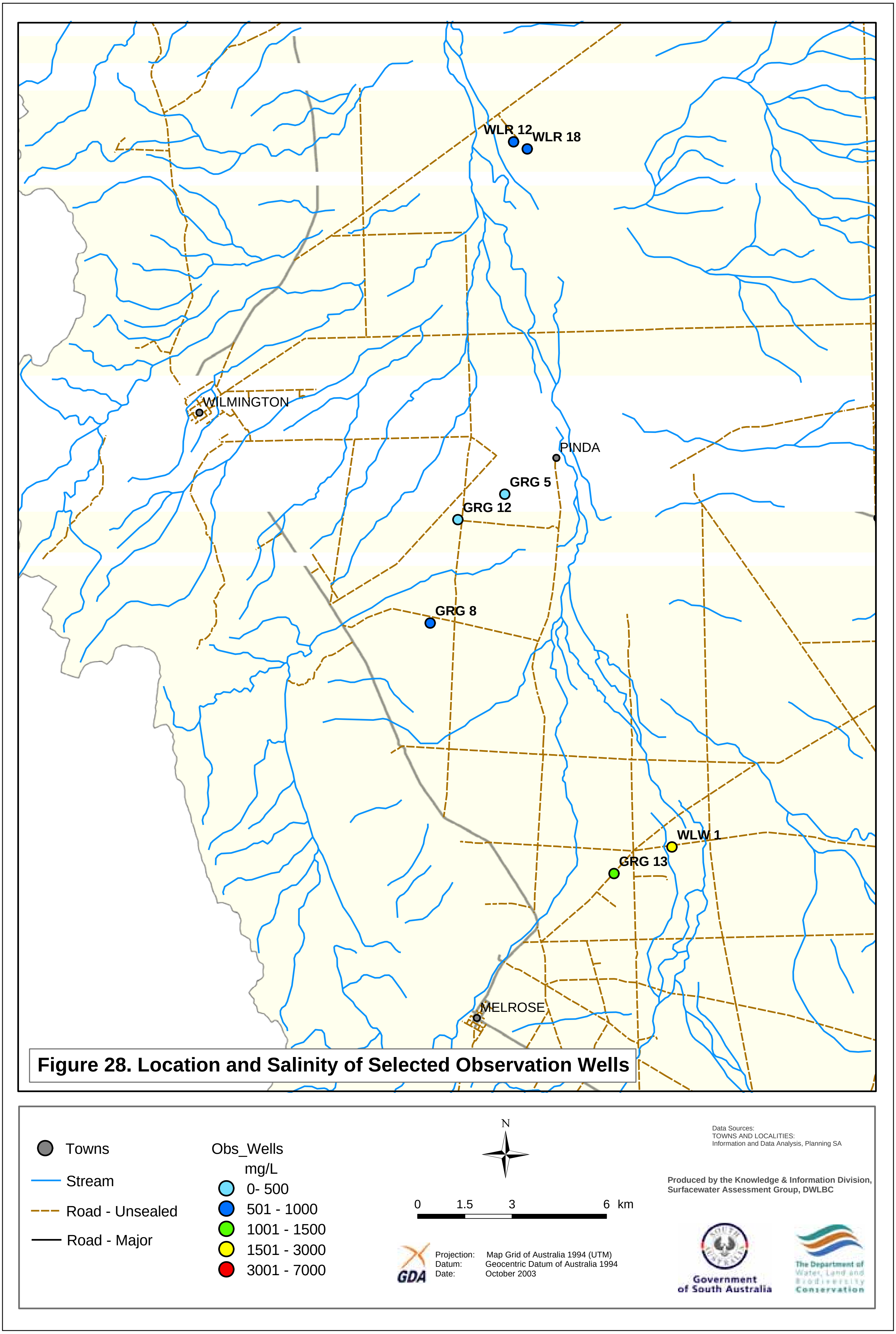

Figure 28. Location and Salinity of Selected Observation Wells

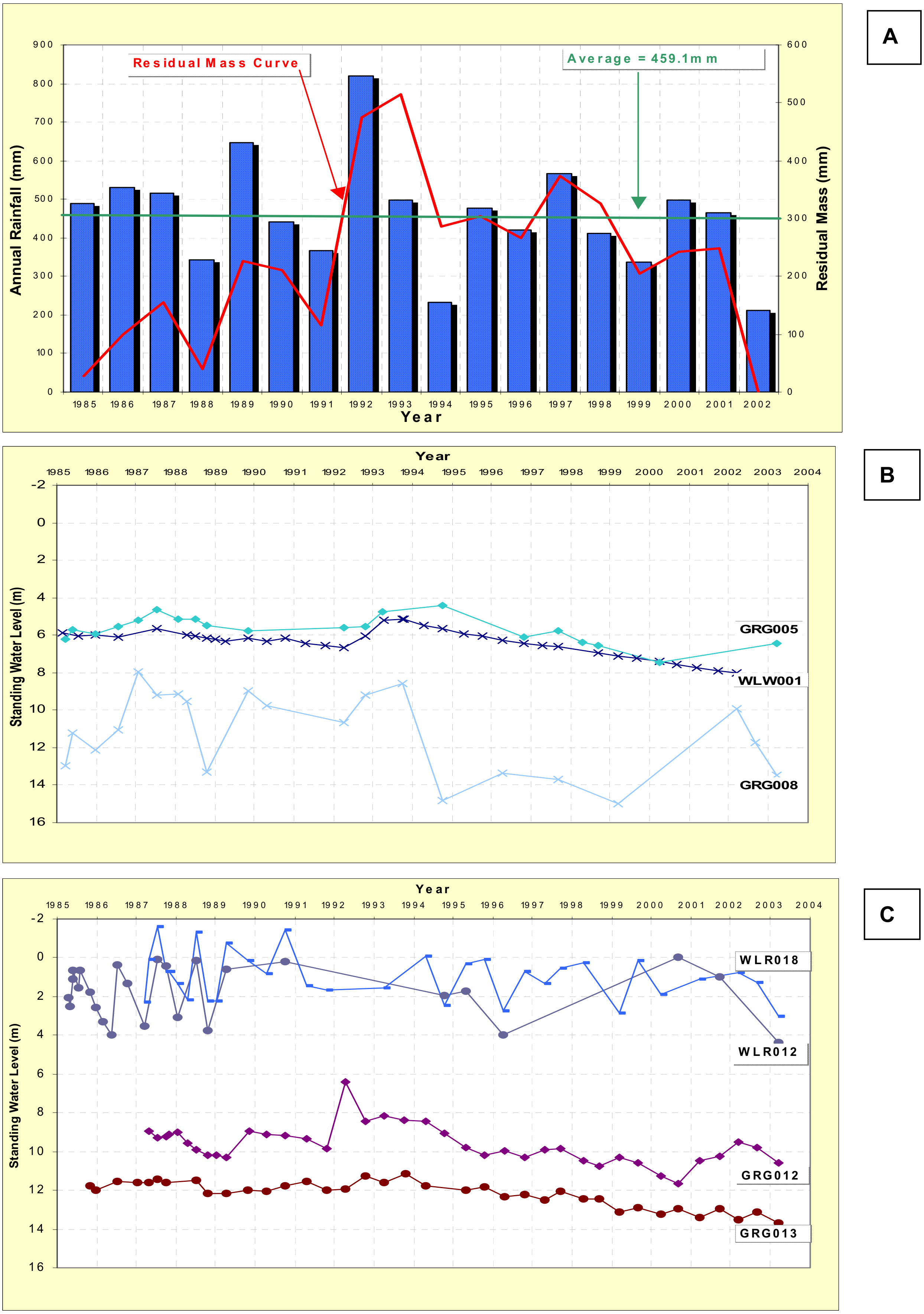

Figure 29. Annual rainfall at Station M019048 – Wilmington Post Office and observation well hydrographs, 1985–2002

Figure 29(A) displays the annual rainfall of station M019048 – Wilmington Post Office and the residual mass of the rainfall. The residual mass curve of the rainfall indicates periods of above average rainfall with a positive slope and periods of below average rainfall with a negative slope. Inspection of the data shows that above average rainfall was experienced for the period from 1985 to 1993, while below average rainfall was experienced post 1993 to and including 2002.

Figure 29(B) displays the hydrographs of observation wells GRG005, GRG008 and WLW001. The locations of these wells are displayed in Figure 28. Inspection of the hydrograph for GRG008, constructed to a depth of 17.8 m shows a relatively close correlation to the rainfall residual mass curve displayed in Figure 29(A). This close correlation is not displayed in either of the other medium depth wells GRG005 (constructed to a depth of 8.53 m) or WLW001 (constructed to a depth of 28.4 m). Generally speaking it would be expected that the shallower well hydrograph (in this case GRG005) would be more responsive to recent recharge events than the deeper well hydrographs, which in this instant is not the case. Given that GRG008 is more responsive to trends in the rainfall pattern suggests it is more responsive to recent rainfall patterns. Inspection of the location map (Figure 28) of the observation wells shows that GRG008 is in closer proximity to the western boundary of the catchment, which has been identified as the likely recharge area. Further to this, GRG005 and WLW001 lack of responsiveness to rainfall trends indicate that the groundwater system in these locations are not seeing recent recharge events.

A further reason for the responsiveness of GRG008 to rainfall trends may be attributed to local creek losses, as GRG008 is in relative close proximity to a stream than well GRG005.

Inspection of the hydrographs of GRG005 and WLW001 (Figure 29(B)) shows that water levels from 1985 to 1992 remained relatively constant. Both hydrographs peak following the high rainfall year of 1992 and then show a gradual decline in the water level. From October 1994 to March 2003 the water level of GRG005 had fallen 2.03 m, from 4.39 m to 6.42 m. Examination of WLW001 water level data for a similar time period, from October 1994 to March 2002 shows a decline in the water level of 2.39 m, from 5.63 m to 8.02 m. Data was further collected from the well in September 2002 and was reported to be dry. The well has since been backfilled.

Figure 29(C) shows hydrographs of observation wells WLR012, WLR018, GRG012 and GRG013. The depths to which the wells have been constructed are 120 m, 139 m, 129 m and 99.3 m respectively. Each of these wells is artesian, which is defined by Stranger (1994, p.13) as a well in which the water level rises until it reaches equilibrium (at atmospheric pressure). If the water level of groundwater in the aquifer is above ground level, then the well is said to be artesian flowing. The static water level in an artesian non-flowing well will equilibrate somewhere between the top of the aquifer and the ground surface. Wells GRG012 and GRG013 are artesian non flowing while wells WLR012 and WLR018 are artesian periodically flowing. This is displayed in Figure 29(C) where data points are at or above zero and indicates (if the well was not capped) that water is flowing from the well and discharging to the ground surface.

Both WLR012 and WLR018 display seasonal fluctuations in the standing water level which is most pronounced from January 1985 to January 1990 with the summer months having a standing water level lower than that experienced during the winter months. Without additional information regarding groundwater extraction it is not possible to determine if the seasonal fluctuation is due to only winter recharge of the aquifer, or also from summer pumping from the aquifer. For example, examination of the hydrograph of observation well WLR018, constructed to a depth of 139 m shows in June 1987 the groundwater level was recorded at 1.63 m above the ground surface (indicated on Figure 29 (C) as negative (-) 1.63 m). It may be possible that the standing water level is maintained throughout the year if water is not pumped from the aquifer during summer months however, in the absence of groundwater extraction data it is not possible to draw a conclusion regarding seasonal variation of the hydrographs.

Both WLR012 and WLR018 display a decline in the groundwater level following 1992. Inspection of the data from October 1994 to March 2003 shows water levels in observation well WLR012 to have dropped by 2.24 m, from 1.96 m to 4.38 m and observation well WLR018 dropped by 0.52 m, from 2.48 m to 3.00 m.

Analysis of GRG013 shows small fluctuations in the standing water level from October 1985 to early 1992 however, there is no obvious trend of either rising or falling groundwater levels for this period. Following the winter of 1992 the hydrograph rises slightly reflecting the high rainfall year and falls again during summer. Following 1993 the hydrograph shows a steady decline to March 2003 (with the exception of slight seasonal variation). The decline in groundwater level from October 1993 to March 2003 is 2.53 m, from 11.15 m to 13.68 m. The hydrograph of GRG012 displays a similar trend with a peak in the hydrograph during 1992, followed by a gradual fall in the groundwater level from October 1993 to March 2003 of 2.44 m, from 8.36 m to 10.6 m.

Common with all hydrographs of both the medium and deeper level aquifer systems is a fall in the groundwater level following the peak in the rainfall trend during 1992 and 1993 (as displayed by the residual mass curve in Figure 29(A)). Due to the lack of historical and current data regarding the extraction rates of groundwater it is not possible to attribute declining groundwater levels to specifically irrigation extraction. Clearly there appears to be a reasonable correlation between rainfall and groundwater levels however, the additional irrigation extraction rate cannot be discounted.

The National Land and Water Resources Audit (2000) has identified that the declining groundwater levels indicate that the current abstraction is close to the sustainable yield. The sustainable yield is the rate at which groundwater can be pumped without causing, long-term decline of potentiometric surface (or watertable) or undesirable effects – such as salinity increases.

Community information

Members of the community have provided information regarding fluctuations in groundwater levels of both the confined (Tertiary) and Quaternary aquifer systems. They have also given information regarding permanent pools or springs, which are sustained by groundwater discharge. Many landholders have experienced similar incidents and a few of their experiences are briefly detailed below.

Examples of declining potentiometric surface in artesian flowing wells include a well constructed in the 1950s had originally flowed at a rate of 37.9 L/sec, the well is no longer artesian flowing and the water level in the well has declined. Another artesian flowing well was previously used to irrigate lucerne. The well is still in use and provides water for domestic stock however, the well is no longer artesian flowing.

While these examples may be indicative of a decline in the potentiometric surface it is not known how wide spread these effects are realised and while flow of artesian waters has ceased in some areas, groundwater continues to discharge to the land surface elsewhere.

There have also been numerous reports of declining water levels in wells constructed within Quaternary aquifers that have been identified as having strong correlation with the rainfall patterns. For example a well constructed prior to 1930 to a depth of approximately 6 m was reported dry in 1937. Investigation of the mean decadal rainfall (Figure 9) shows the 1930s as one of the driest decades on record. The well filled again during the early 1970s coinciding with the wettest decade recorded in the area. In the late 1970s the well dried up again and has remained dry. Numerous landholders have reported shallow wells to be dry in recent years, and as with the example above it is not the first time this has occurred. Apparently during the 1950s many of the shallow wells dried and were deepened in order to obtain water supply. When this is compared to the regional rainfall records it shows that the declining groundwater levels of the 1950s occurred following the driest three recorded decades as displayed in Figure 9.

Furthermore, as mentioned in the *Rainfall Data Analysis* section of this report, Figure 9 shows that rainfall in the last 20 years has averaged close to the long-term mean and are far from the driest conditions experienced in the basin. While the last two decades are close to the average it can be seen (in Figure 8) that the peaks of rainfall in individual years is far lower (< 510 mm) than any other decades. The declining groundwater levels of recent times suggest that groundwater recharge is strongly dependent on receiving these above average events.

A number of springs and soaks sustained by groundwater discharge have also been reported to have disappeared in both the fractured rock aquifers in the ranges and the sedimentary aquifers of the plains, again indicating regional declining groundwater levels. An example of this is the permanent pools located to the north of Pinda Bridge. The pool was located approximately 220 m downstream of the Old Pinda Bridge, was approximately 5 m wide, 1.2 m deep and 20 m in length. The water was suitable for human consumption and an old section map displayed the area as a “Water Reserve”. Landholders reported that even during the drought experienced in 1944 and 1945 water was always present in the spring. The spring was located on a stock route and supported 50 – 60 head of local cattle along with water for transient cattle. During the mid 1970s the water became saline, and cattle died as a result. During the mid 1980s the level in the pool declined and there has been no water in the pool since the early 1990s.

Permanent pools, springs and soaks in semi-arid to arid regions are of great environmental significance in ephemeral river systems as they provide refuge areas for numerous invertebrates, fish and other species when the surrounding streams are dry. Landholders have reported fish species within the main Willochra channel north of Melrose however, these species have not been sighted in the southern area of the catchment for a number of years.

Due to the declining groundwater levels and loss of permanent pools and/or springs, community members and landholder have expressed concerns regarding groundwater use in the region, that include both inappropriate and inefficient water use. Concerns have further been raised regarding metering groundwater extractions and restrictions to future water use, and while these concerns are valid they are not within the scope of the report, which aims to establish baseline information on the hydrology of the catchment.

Community concerns have been raised regarding the development of irrigated horticulture in the area, in particular surrounding the township of Wilmington. Wilmington has been under water restrictions for the past 3 years and community members view the development of irrigated horticulture as placing additional stress on the groundwater resource. They further question being placed under restrictions while irrigators are supplied township water for the purpose of irrigation.

It has been intimated that due to the cost of reticulated water irrigators in the vicinity of Wilmington have had private wells constructed. Members of the community are concerned about the impacts caused by the additional extraction of water from the groundwater resource.

Community members have also questioned the suitability of the establishment of irrigated horticulture in the region given its semi-arid nature and lack of reliable water resources. The appropriateness of using potable water for preventing dust at truck depots has also been raised and is viewed as misuse of a valuable resource.

Further issues have been raised regarding inefficient water use practices such as a) pumping groundwater into dams where evaporative losses are high, and b) having windmills continuously pumping groundwater from wells to tanks, which are left to overflow. It has also been reported that numerous wells constructed in artesian aquifers have not been capped and have been left free to flow. Such practices, particularly in semi-arid environments cannot be considered sustainable practice and need to be addressed. There are provisions under the *Water Resources Act 1997* for protection of the resource from wastage, pollution, deterioration or undue depletion. Some of the relevant sections of the *Act* have been detailed in Appendix F.

Groundwater supply for township reticulation

Because of the lack of reliability of surface water, groundwater is used extensively through-out the Willochra catchment to provide town water supply. Currently groundwater is used to supply the townships of Quorn, Wilmington, Hammond / Willowie and Melrose.

The *Draft Northern Region Water Resources Management Review* (Engineering & Water Supply Department 1985) assessment of the capabilities of the water resource to meet the demands of communities within the region identified that management attention was required for the following areas: Melrose, Quorn, Willowie and Wilmington. Details are provided in Table 12.

Table 12. Water Supplies Identified as being Under Stress.

Location	Consumption ML/year	Salinity mg/L	Projected Growth to 1990	Comments
Melrose	74 (GW)	850 - 1370	0 - 2%	Quantity barely adequate
Quorn	170 (GW)	1140 - 1530	3 - 8% (Tourism)	Investigations currently underway
Willowie	24 (GW)	4048	-	Bacterial Contamination Frequent
Wilmington	74 (GW) 36 (SW)	298 351	2 - 5% (Tourism)	Quantity barely adequate

Source: Draft Northern Region Water Resource Management Review (1985) Engineering & Water Supply Department.

The table above demonstrates that the water resource has limited capacity to meet demands of the projected growth, due to yield limitations of groundwater and bacterial contamination.

Current extraction records have indicated that usage has significantly increased since the publication of the 1985 review. A summary of the annual use by the main towns is shown in Table 13.

Table 13. Willochra Basin surface water and groundwater extraction records 1984–2002

Year	Wilmington Surface Water (ML)	Wilmington Ground Water (ML)	Wilmington Total Extraction (ML)	Quorn Surface Water (ML)	Quorn Ground Water (ML)	Quorn Total Extraction (ML)	Hammond Ground Water (ML)	Melrose Ground Water (ML)
1984-85	40	74	114		200	200	22	66
1985-86	46	64	110		180	180	21	77
1986-87	44	25	69	85	61	146	17	73
1987-88	32	67	99	4	169	173	25	78
1988-89	56	48	104		168	168	26	68
1989-90	56	62	118	26	156	182	34	64
1990-91	24	88	112	52	149	201	35	81
1991-92	32	66	98	47	135	182	24	54
1992-93	89	10	99		145	145	17	46
1993-94	69	72	141	70	104	174	31	58
1994-95		124	124		186	186	24.1	60.5
1995-96		118	118		172	172	25.4	56
1996-97		141	141		199	199	26	57
1997-98		110	110		184	184	21	50
1998-99		133	133		207	207	28.1	65
1999-00		153	153		207	207	25	55
2000-01		154.5	154.5		223	223	21.6	65
2001-02		139	139		202	202	25.4	60
Total	**488**	**1648.5**	**2136.5**	**284**	**3047**	**3331**	**448.6**	**1133.5**

Source of Data: SA Water Crystal Brook SA and Engineering and Water Supply Department Annual Report Northern Regions 1988 – 89 and 1993 –94.

Wilmington

Currently Wilmington is supplied water from the Spring Creek mine and a newly constructed well west of the Spring Creek mine on the opposite side of Spring Creek. Salinity is low at approximately 400 mg/L TDS, supplies are limited and water restrictions have been imposed since the 1998–1999 summer.

The Spring Creek mine shaft has supplied Wilmington with water since 1917 however, concern regarding the ability of the installation to provide an adequate supply of water to match the increasing demand required further investigations and a discharge test was performed in 1980. Following the test it was concluded by Read (1980) that the pump installed in the existing Spring Creek Mine shaft was operating at the safe yield of the well at approximately 870 kL/day and in order to increase the yield a new well would need to be constructed.

Historically surface water was also used to supplement town water supply however, the practice has ceased due to the risk of contamination of the water by faecal coliforms. A sump (concrete tank) and weir structure was constructed in the late 1920s to early 1930s in Spring Creek to capture surface water. The sump has a holding capacity of 270 kL (60 000 gallons) and gravel was used to filter the water. The weir structure behind the tank was built to prevent erosion. The water from the tank was then gravity fed to Wilmington. A valve within the Wilmington Chart House was used to regulate the flow of water. (Tom Wills pers. com., May 2003). It should be noted that although the practice has ceased since 1995 the infrastructure still exists and could potentially be recommissioned should the need arise in the future.

Extraction records provided by SA Water and the Northern Regions 1988–89 and 1993–94 Annual Report compiled by the Engineering and Water Supply Department show annual extraction from 1984–2002. The data shows that there has been a significant increase in extraction of groundwater since 1995 due to the absence of surface water supplementing town supply. The total extraction of groundwater from 1984 to 1994 was 576 ML, once surface water was no longer used the total volume of groundwater extracted increased to 1072.5 ML from 1995–2002, resulting in an 86% increase in demand on the groundwater resource.

Total recorded extraction for Wilmington has increased significantly since the 1985 Review, most noticeably from 1995–2002. The average surface and groundwater extraction from 1984–1994 was 106 ML and from 1995–2002 the average extraction was 135 ML, and is displayed in Figure 30.

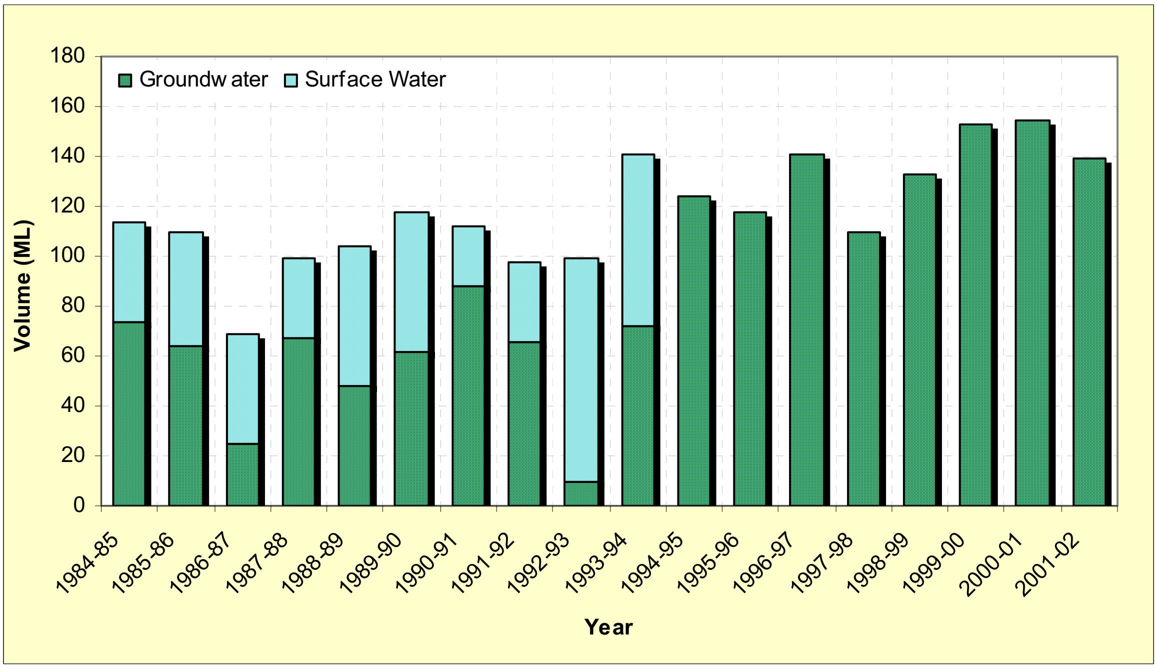

Figure 30. Wilmington town water supply extraction records 1994–2002

Of increasing concern is the change from the conjunctive use of surface water and groundwater (from 1994–1995 season) to the use of groundwater only. This, if not carefully managed could impact greatly not only on the groundwater resource itself but also the ecology of Spring Creek.

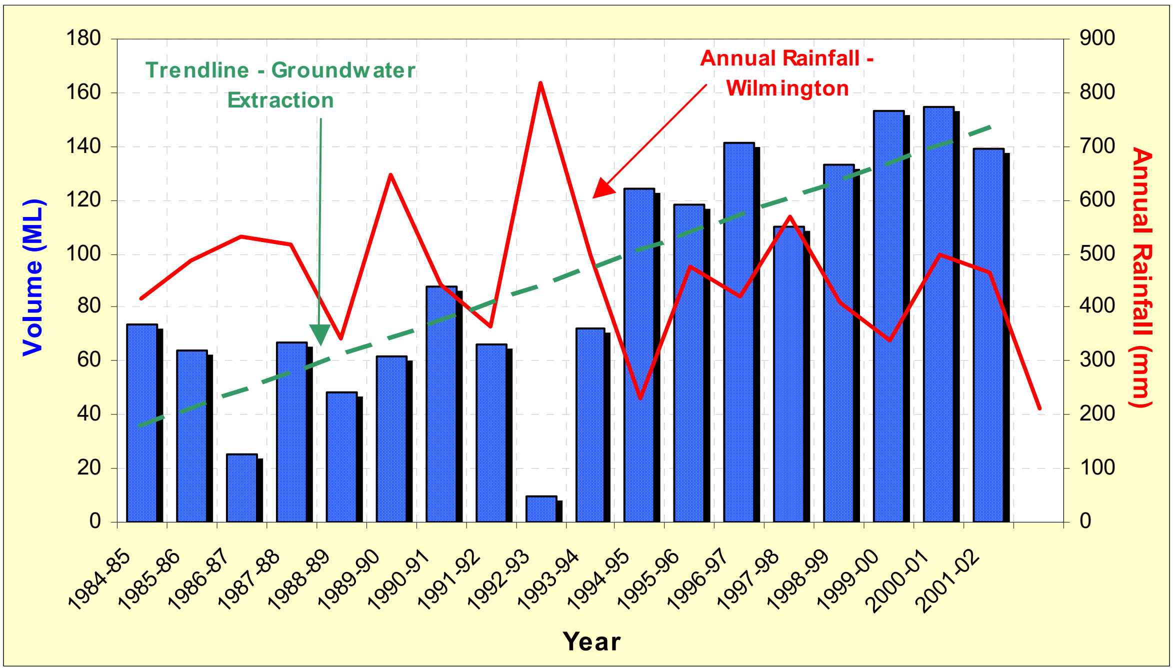

Figure 31. Wilmington groundwater extraction and annual rainfall

Figure 31 shows annual rainfall for station M019048 – Wilmington Post Office and the annual extractions of groundwater. A trendline has been fitted to the data and show that the increase in groundwater extraction coincides with the cessation of surface water supply and a decline in annual rainfall.

Melrose

The Willochra Basin supports the township of Melrose and groundwater is extracted from two wells. Salinities range from 1200–1400 mg/L (Jolly et al. 2000). The volume of water extracted has remained relatively constant over the past 18 years. The highest recorded extraction year was 1990–91 with 81 ML. Average annual extractions are calculated to be 63 ML.

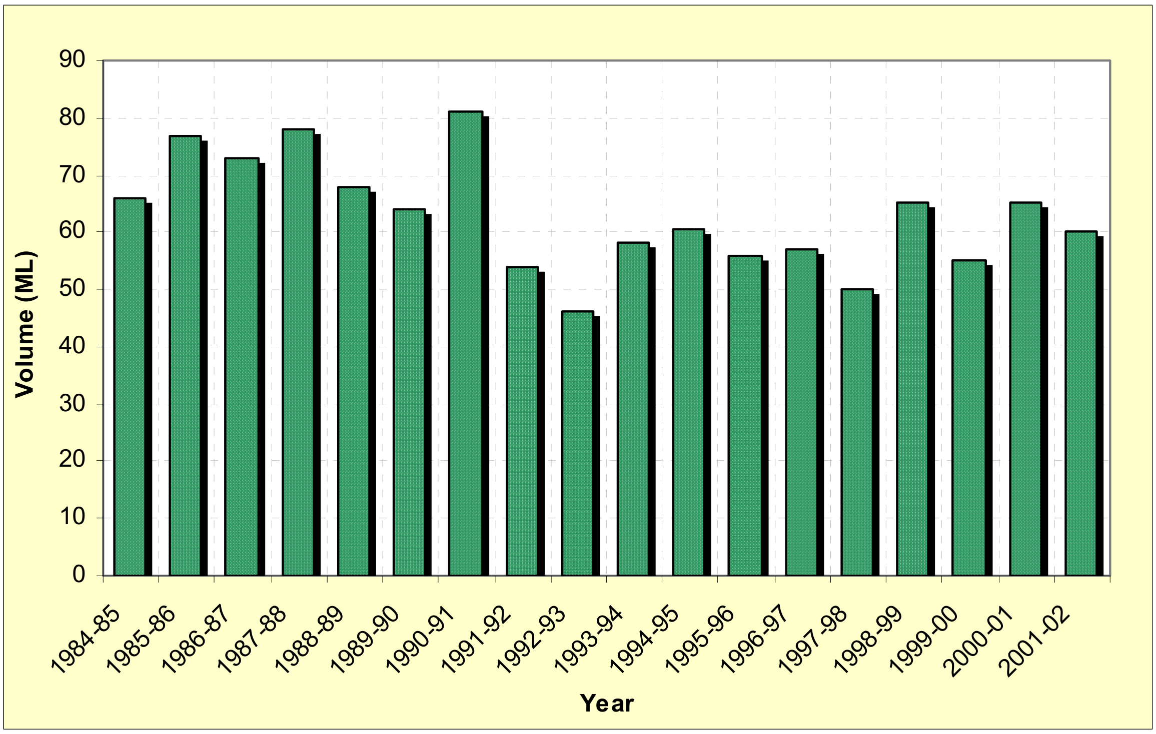

Figure 32. Melrose groundwater extraction records 1984–2002

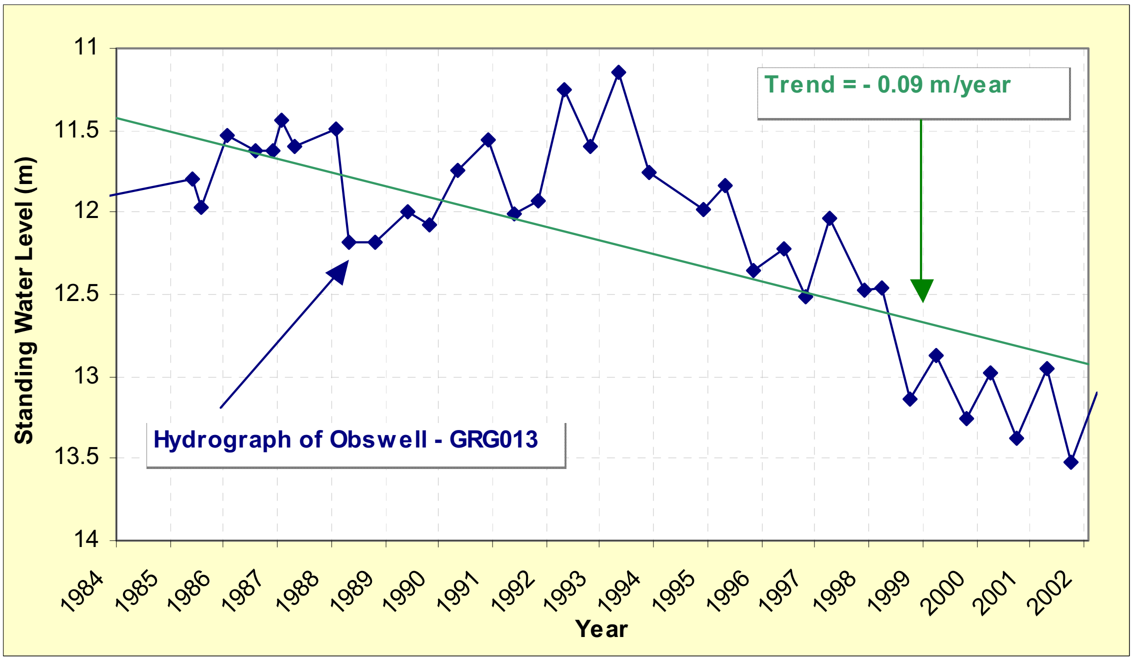

Figure 33. Hydrograph of Observation Well GRG013

Figure 32 indicates that from 1992–2002 extraction has reduced by approximately 18% compared to the period 1982–1992 previous one. Monitoring information available from the groundwater basin shows that while groundwater extraction has reduced by 18% the water level in a nearby well (observation well GRG013) continues to decline at a rate of 0.09 m/yr as displayed in Figure 33. Unfortunately no information is available to determine what impacts this reduction has had on salinity.

Hammond/Willowie

Hammond and Willowie are supplied water from Willowie bore and Coonatto Springs and have been found to adequately supply water throughout the year. Current records only report extractions from the Willowie bore. The Hammond reservoir, which provided some surface water to the town water supply, was decommissioned during the late 1980s.

The 18 years of records shown in Table 13 indicates that the extraction rate has remained relatively constant. The average annual extraction is approximately 25 ML/yr.

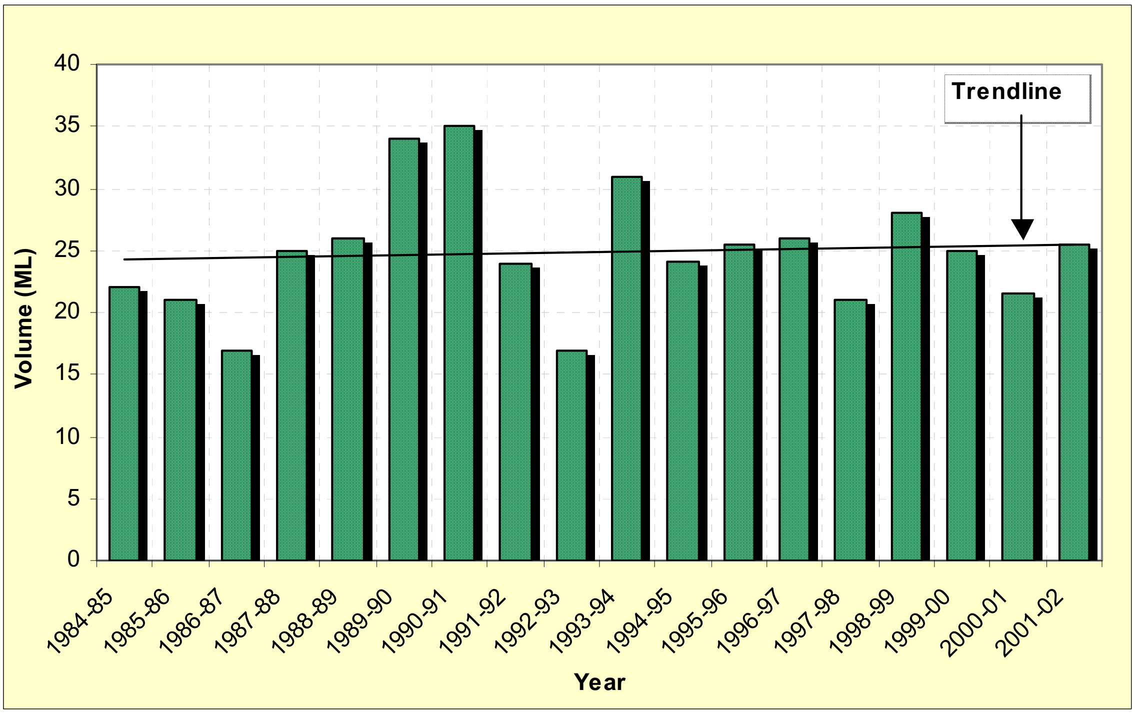

Figure 34. Hammond/Willowie groundwater extraction records 1984–2002

A trend line has been fitted to Figure 34 demonstrates that extraction has remained relatively constant for the given period of record.

Quorn

Quorn's town water supply is from 3 wells located within the fractured rock aquifer system to the north of the township. Groundwater salinities range from 1200 to 1400 mg/L (Jolly et al. 2000). Historically water was supplied to the township from the Mt Arden Reservoir however, due to contamination problems the reservoir has not been used for township supply since 1994. Groundwater and surface water extraction records are displayed below.

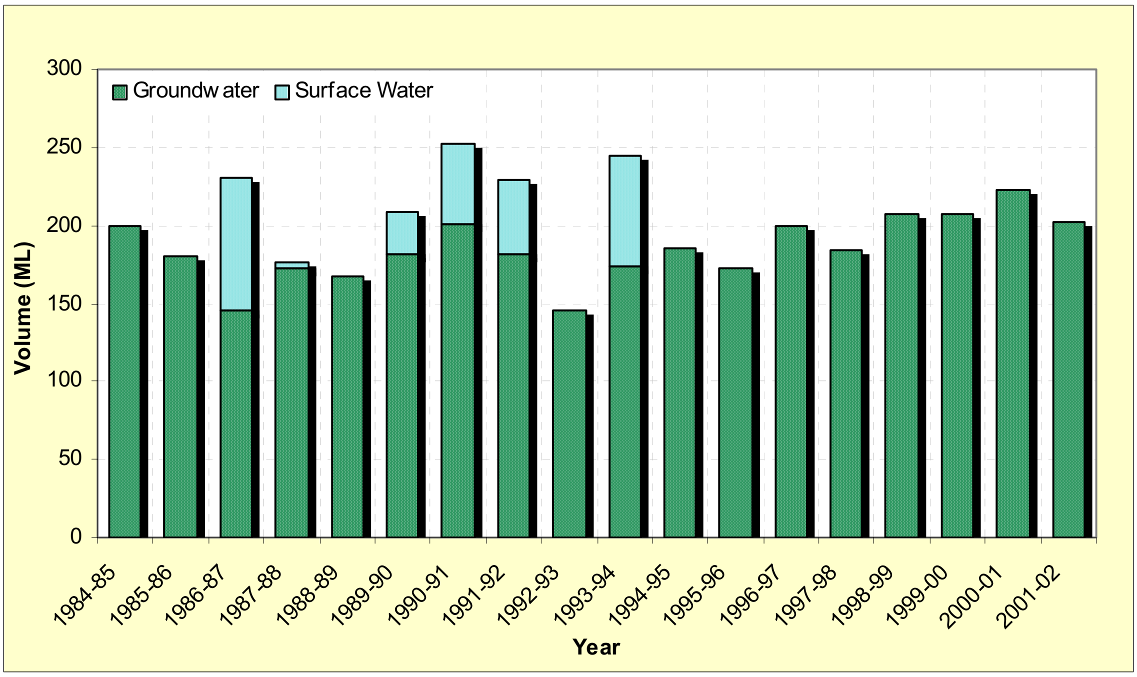

Figure 35 Quorn groundwater surface water extraction records 1984–2002

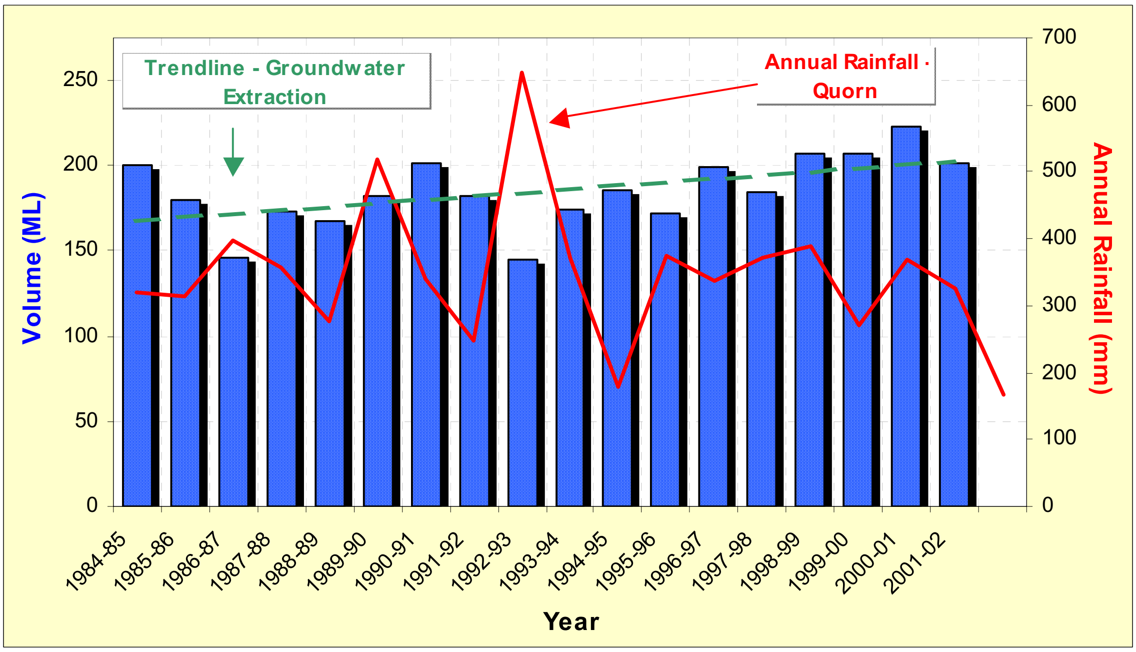

Figure 36. Quorn groundwater extraction 1984–2002

Figure 36 demonstrates that groundwater extraction is increasing, while annual recorded rainfall recorded at station M019038 – Quorn Post Office is decreasing. Concerns have been raised regarding the ability of the well field to supply adequate yield during summer when demand is greatest and the resource is under stress. Recent groundwater investigations have been conducted into obtaining a new potable water supply (Osei-Bonsu and Evans 2002).

CONCLUSIONS AND RECOMMENDATIONS

Risk assessment

Surface water

The combined effects of farm dams, contour banks, flood irrigation, channel modification and point source and diffuse pollution on the surface water resource of the Southern Willochra catchment pose a possible risk to the sustainability of the surface water resource, the environment it supports and regional development.

First order estimates of catchment runoff generated within the Southern Willochra catchment averages around 7 ML/km^2 with an average annual catchment yield of approximately 8000–9000 ML. The sustainable development limit for non prescribed regions, as detailed in the *State Water Plan 2000* (Department for Water Resources 2000) is approximately 50% of this value which equates to 4000 ML to 4500 ML. The combination of farm dams and flood irrigation is estimated to divert between 3400 ML to 4400 ML which is close to or may exceed the sustainable development limit.

The impacts of the capture and diversion of close to 50% of the estimated catchment yield includes:

- A reduction of surface water runoff through capture of initial / early season runoff
- Delay in the onset of stream flow events
- Shorter duration of seasonal flows
- Potentially no flow during drought periods
- Greater frequency of low flow events as opposed to a range of low, medium and high flow events
- Absence of high flow events
- Loss of connectivity between the upper and lower reaches of the catchment.

Each of these impacts listed above are evident by anecdotal information provided by members of the local community and demonstrates that the surface water resource, under current climatic conditions and current development levels is under significant stress.

Farm dams

Current estimates of surface water captured in farm dams is approximately 1400 ML, with a corresponding farm dam density of 1.2 ML/km^2. These figures demonstrate that the level of farm dam development is relatively low and is within the sustainable development limit for the Southern Willochra catchment. On a sub-catchment scale however, there are areas that have been identified as close to or possibly exceeding the sustainable development limit, these areas include sub-divisions within Beautiful Valley sub-catchment, Wild Dog Creek sub-catchment and Willochra Creek sub-catchment. While these areas are close to or exceed the estimated sustainable development limit for the individual sub-divisions, they receive adequate water due to a lack of development in catchments upstream. Never the less careful consideration is required in order to further develop these areas.

Concerns have been raised by community members regarding the construction of large farm dams that have been found to severely reduce surface water runoff to downstream water users. It is recommended that public awareness needs to be raised with regards to farm dam impacts on downstream water users and the environment.

Contour banks

The construction of contour banks reduces the velocity of flow of surface water over paddocks and increase infiltration. While contour banking is considered to be best management practice for soils and water conservation it does impact on the hydrology of the area by further reducing surface water runoff entering watercourses and therefore needs to be taken into consideration when determining sustainable development limits.

Flood irrigation

Conservative estimates of water used for the purpose of flood irrigation within the Southern Willochra catchment was between 2000 ML to 3000 ML. This value, combined with the water captured in farm dams is clearly approaching the catchments sustainable development limit of between 4000 ML to 4500 ML.

The practice of flood irrigation is opportunistic and occurs predominately in high rainfall years when the average catchment yield is likely to be exceeded. If flood irrigation was to occur during average rainfall years, very little of the flow generated within the Southern Willochra catchment would reach the downstream Northern Willochra catchment. Greatly impacting both downstream water users and the environment.

Flood irrigation has been practised in the region since the late 1800s. Flood irrigation occurs predominately within the Willochra Creek sub-catchment (in the Southern Willochra catchment), north of Melrose. It should be noted that diversion channels and locks have also been identified to the north of the Southern Willochra catchment up to the township of Quorn.

The opportunistic use of water for flood irrigation reduces high flows that have been identified as important for environmental water requirements. Not only is water to be shared by irrigators and landholders but water for the environment must also be considered. The area has already experienced a reduction in permanent pools that are ecologically important refuge areas for the maintenance of species of fish, numerous macro-invertebrates and vegetation.

Large inefficiencies in flood irrigation have been identified and could be greatly improved with a coordinated approach to the timing of flood irrigating for each irrigator. The aim of coordinating or scheduling the timing of irrigation is to prevent interrupted flows to downstream water users who are forced to re-flood areas of land previously flooded, in order to irrigate land which had not received flood irrigation waters. The establishment of an irrigators’ committee and a coordinated approach to the timing of irrigation is an opportunity to improve on the efficiency of current practices.

Channel modification

Further risks to the region’s environmental health of the catchment is caused by severe stream modification where native vegetation has been cleared and channels have been ploughed over. Extreme channel modification such as this is likely to result in deposition of sediment in environmentally significant areas such as permanent pools, as thousands of tonnes of sediment is likely to be transported downstream during a large flood event. It is recommended that regions identified in the *Ecological Assessment of the Willochra catchment* as being severely modified are revegetated and the practice of ploughing over river channels (even small ones) is ceased.

Point source and diffuse pollution

Contamination is a further risk to the water resource that might result due to the dumping of waste in-stream. Landholders have reported a variety of debris including pesticide drums found in-stream following periods of stream flow. Aerial videography conducted in June 2003 revealed numerous sites where dumping is suspected to occur. These areas need to be further investigated and the rubbish removed from the stream channels.

Community members also raised concerns regarding diffuse pollution primarily from chemical pesticide sprays used to control locust and the effect that the sprays have on the water resource following initial season rains. Water quality monitoring is recommended to monitor the effect that the pesticides have on stream biota.

Data constraints

A further risk identified is the lack of data, which is required to effectively monitor the relative health of the water resource and environment. The estimates of runoff and catchment yield within this report are first order estimates and more detailed analysis of the region would better aid future management decisions. Given the reliance on the water resource for township water supply, primary industries and tourism, the economic growth and development of the region depends on adequate and sustainable supply of water. Currently insufficient data is available for a more accurate assessment of the current state of the water resource. For further details regarding data requirements refer to the Representivity of Hydrological Data section of this report.

Summary

The construction of farm dams combined with the diversion of water for flood irrigation appears to be approaching the sustainable development limit of 4000 ML to 4500 ML. Land management practices such as the construction of contour banks further reduce runoff thus impacting on stream flow regimes and the environment. Further to this clearing of vegetation, channel modification and both point source and diffuse pollution are also risks identified to adversely impact the sustainability of the surface water resource and water dependent ecosystems within the catchment. The lack of suitable hydrological data impedes the accuracy and confidence of hydrological analysis and results necessary for sound management decisions.

Groundwater

The combined effects of current climatic conditions, increased demand and inefficient use of the groundwater resource of the Southern Willochra catchment pose significant risk to the sustainability of the resource, current and future development and the environment.

O'Driscoll (1957) and Shepherd (1978), estimated the sustainable yield of the basin to be 400 ML/year. Martin et al. (1998) estimated the sustainable yield of the basin to be 4000 ML/year. The Engineering & Water Supply Department (1987) as cited in Martin et al. (1998) estimated groundwater use in the area to be 3250 ML/year indicating that the basin is approaching its sustainable limit. With the recent increase in development of irrigated horticulture in the regions it is highly probable that the current level of groundwater extraction is equivalent to the sustainable yield of the basin.

Anecdotal evidence provided by landholders indicates declining potentiometric surface in both Quaternary and Tertiary aquifers in recent years. While declining water levels have been experienced in the region in the past it is particularly concerning given the current climatic conditions are far from the driest conditions experienced in the catchment. This suggests that the current level of development is close to or may exceed the sustainable development limit of the basin.

The impacts of the current level of groundwater use include:

- Declining groundwater levels in wells constructed to Quaternary aquifers
- Cessation of flow of artesian flowing wells and increased depth to water
- Loss of springs within both fractured rock and sedimentary aquifers systems

Declining groundwater levels

The National Land and Water Audit 2000 identified declining groundwater levels within the Willochra catchment in recent years, which was attributed primarily to a decline in regional rainfall. Community members have also reported declining groundwater levels in Quaternary aquifers and cessation of flow from artesian flowing wells within Tertiary aquifers. Observation wells data further shows declining groundwater levels in both the middle level and deep aquifer systems. While groundwater fluctuations are found to correlate reasonably with rainfall records the declining groundwater levels indicate that the extraction of groundwater is similar to the sustainable yield.

Climatic conditions

Investigations of decadal rainfall in the last 20 years has averaged close to the long-term mean and are far from the driest conditions experienced in the basin. However, there is a notable reduction in above average rainfall years over the last 20 years with the exception of 1992. The declining groundwater levels of recent times may suggest that groundwater recharge is strongly dependent on receiving these above average rainfall years.

Environmental impacts

Springs sustained by groundwater discharge have been reported dry in recent years. The loss of springs within the southern reaches of the catchment has serious consequence for the maintenance of species that depend on the refuge areas they provide. Given that species populations are an indicator of catchment health, and there has been a loss of fish species within the southern catchment this suggests that the groundwater resource is under stress.

It has further been suggested that the die back of eucalypts in the Willowie Forrest may be due to declining groundwater, in order to determine if this is the case piezometers could be used to monitor groundwater fluctuations and salinity levels.

Inefficient water use practices

Community awareness needs to raised regarding efficient use of water. Reported practices such as pumping groundwater to farm dams that suffer large evaporative losses, leaving windmills to continuously pump groundwater to overflowing tanks and not equipping artesian wells to control groundwater flow are not sustainable practices.

Inappropriate water use practices

Many community members expressed concerns regarding the appropriateness of the establishment of irrigated horticulture in the region given the semi-arid nature of the catchment. They also identified that practices such as using potable water to prevent dust at truck depots was inappropriate use of a valuable resource.

Township reticulation

With regards to township reticulation specifically for Wilmington, since the cessation of the conjunctive use of surface water and groundwater during the 1994 – 1995 season the demand on the groundwater resources has increased by 86%. This (if not carefully managed) could impact greatly not only on the groundwater resource itself but also on the ecology of Spring Creek. There are currently no observation wells within the fractured rock aquifer system of the ranges to monitor well water levels and salinity. It is recommended that suitably located observation wells be established in the ranges given the importance of Spring Creek for both supply of township water and its ecological assets. Anecdotal information from landholders suggests the resource is under significant stress as springs in the sub-catchment are reported to be dry.

Contamination

Other risks to the groundwater resource have been identified through consultation with landholders. It is apparent that many of the old wells constructed were only partially cased. Partially cased wells and old eroding well casing can lead to leakage of higher salinity water into aquifers with water of a lesser salinity. Due to lack of knowledge of the aquifer systems within the Willochra catchment it is recommended that this be investigated further.

Data constraints

While there are a number of observation wells monitored within the Willochra basin, much of the water sourced for township water supply is from the fractured rock aquifer system within the ranges near Wilmington and Quorn, where operational observation wells are absent. It is recommended that observation wells be constructed within the fractured rock aquifer system in the Spring Creek sub-catchment to monitor the aquifers response to continual groundwater extraction.

There is no data available regarding groundwater extractions from the basin. Knowledge of extraction rates would aid determination of whether the overall decline of groundwater is attributed to current climatic conditions or current extraction rates or a combination of both. The inability to determine whether groundwater decline is due to climatic conditions or the current level of extraction potentially places the groundwater resource under significant risk of long-term potentiometric decline.

Summary of recommendations

Surface water

- Raise public awareness regarding the impacts of farm dams on catchment hydrology, downstream water users and the environment

- Raise public awareness regarding the impacts of flood irrigation on catchment hydrology, downstream water users and the environment.
- Coordinate irrigation by the establishment of an irrigators' committee.
- Remediate stream degradation and channel modification, and where practical revegetate riparian zones.
- Remove rubbish dumped in streams
- Monitor water quality following initial onset of stream flow
- Monitor surface water discharge with the installation of suitably located gauging stations and water level recorders representative of the variety of catchments within the Willochra catchment. Also monitor salinity and temperature at each site.
- Install pluviometers at suitably located sites
- Improve on existing isohyet data.
- Once suitable gauging data becomes available calibrate existing hydrological model and perform scenario testing.

Groundwater

- Remediate inefficient water use practices
- Investigate recharge rates and residence times through hydrogeochemical techniques in order to determine the sustainable yield of the Willochra Basin
- Determine current extractions
- Monitor fracture rock aquifer systems water level and salinity particularly within the vicinity of the Spring Creek production bore.

Representivity of hydrological data

Rainfall: Rainfall data from 7 Bureau of Meteorology stations were used in this study. The data set provides representation of spatial distribution of the rainfall in the catchment to some degree however, due to the lack of rainfall stations distributed within elevated, higher rainfall regions of the catchment more representative data is recommended. The majority of stations are located within the low lying areas of the catchment and although these stations provide a good temporal distribution with long-term data sets of greater than 100 years, a greater number of stations would improve on further rainfall-runoff analysis and modelling.

Evaporation: Baroota Reservoir and Lake Torrens are the two nearby stations to the Willochra catchment with evaporation data. The data from Baroota Reservoir was used in this study due to its topographic similarity and the availability of long-term data. Data collected from within the Willochra catchment would better represent the catchment characteristics than data from a nearby catchment. Furthermore, due to the lack of daily data, only average monthly evaporation was used in calibration of the daily rainfall-runoff model in this study. Usage of daily evaporation data would probably result in better calibration of the model.

Isohyets: While improvements to the existing isohyet data coverage was conducted as part of this study by extending existing rainfall records and collecting rainfall data from landholders, it is recognised that further improvements to the isohyet data coverage is still required. Improvements to the existing coverage could be made by

1. Collecting more data from the elevated regions of the catchment.
2. Producing an rainfall elevation model using GIS
3. Manual construction of isohyets based on existing rainfall data and topography.

Improvements to the existing isohyet data coverage would improve the catchment rainfall-runoff modelling process.

Stream flow: Stream flow of Willochra Creek at Partacoona, Kanyaka Creek at the Old Kanyaka Ruins and Spring Creek at Terka were examined as part of this study. Due to the variability in catchment characteristics of the Southern Willochra to that of the Northern Willochra - for example the difference in rainfall and the catchment response to rainfall – it was not suitable to attempt calibration of the model to either Partacoona or Kanyaka stream flow records. Further attempts to calibrate the model to the stream flow of Spring Creek for the period 1973–1976 was unsuccessful due to the short duration of the records, collected over the wettest periods on record with an unreliable control at the gauging station.

Greater representation of catchment stream flow is needed in order to improve calibration of the existing model. Gauging stations should be located to represent the vastness of the catchment and the varying terrain.

Within the catchment, gauged stations would therefore be required at the base of steep elevated regions, at the base of hilly/undulating regions and in the low-lying plains regions. Ideally they should be located upstream of the locations where water is diverted for flood irrigation and also downstream of these locations in order to estimate the volume of water used for flood irrigation.

Calibration of rainfall–runoff model

Due to the lack of representative hydrological data attempts to refine the rainfall runoff model to produce results with a high level of confidence was not achieved. Gauging stations representative of the variety of catchments are needed, together with a better distribution of rainfall stations.

The model was calibrated to the gauged station at Spring Creek for a period of only 3 years during the wettest period on record that experienced stream flows during the summer months. This resulted in the model also producing stream flow during the summer months, which is not supported by anecdotal evidence provided by landholders (With the exception of extreme rainfall events). Although the model produced stream flow that coincided with actual stream flow events it over estimated high flows, displayed rapid decline following peak flows and under estimated low flows.

As with most hydrological models, calibration and simulation of flow events could be improved by:

1. Well rated gauging data
2. Daily evaporation data rather than mean monthly evaporation data. While evaporation data could improve the capability for better calibration, prediction of long-term runoff requires long-term daily evaporation data, which is not available.
3. A better rainfall isohyet coverage as discussed above.

Scenario modelling

Due to the lack of confidence in the modelled results scenario modelling was not conducted as part of this study. It should be noted however, that once suitable gauging data is collected scenario modelling could be conducted using the model established as part of this study.

Technical conclusions and recommendations

Rainfall data used in this study were from 7 rainfall stations, 6 having long-term records and being reasonably well distributed. Only one station was located within the elevated regions of the catchment study area with a 30-year record. It is recommended that:

- Collection of data from these stations should be continued in the future for maintaining a representative set of rainfall records.
- New stations should be constructed and monitored within the ranges to improve on existing data sets and the isohyet coverage.
- New stations using pluvio's should be incorporated into the existing network within the ranges and also located upstream of new gauging stations in order to gain a better understand of the rainfall-runoff relationship in semi-arid regions.

The existing gauging stations within the catchment should be continued in order to collect long-term data. Current plans for the construction of gauging stations within the Willochra catchment at Spring Creek and Pinda Bridge are supported. Further to this it is recommend that in order to improve the current understanding of the hydrology of the area:

New gauging stations should be constructed at suitably located sites representing the variety of catchments that exist within the Willochra catchment. Possible locations for representative gauging stations would include:

1. Willochra Creek at Melrose and also upstream of the proposed site at Pinda Bridge before any major confluence with other streams. The combination of the two station sites would greatly improve the current knowledge of, and enable more accurate estimates of the volume of water used for flood irrigation. This would further aid in determining the effects of flood irrigation on environmental water requirements.

2. The construction of the proposed station at Pinda Bridge should continue, as it is representative of the low-lying plains regions of the catchment and will provide information regarding the yield of the Southern Willochra catchment.

3. On Old Booleroo Creek, which represents the drier undulating regions of the catchment, one gauging station should be used in conjunction with a water level recorder downstream on the plains region to gain a greater understanding of stream transmission losses.

Pluviometers are recommended to be located upstream of each proposed gauging site. Not only would it improve understanding of the rainfall runoff response, it would also improving the representivity of the current rainfall stations and further aid improvement of the existing isohyet coverage.

At each gauging site salinity and temperature should also be measured in order to better understand runoff salinity relationships and observe salinity trends. For proposed locations of gauging station and pluviometer sites for the Southern Willochra catchment see Appendix I.

Table 14. Recommended monitoring sites in the Southern Willochra catchment

No.	Creek	Monitoring	Location	Duration	Objectives
1a.	Mt Remarkable / Campbell Creek	Level, flow, EC, temperature and rainfall (pluvio)	Immediately down stream of the township of Melrose	Short term 5 – 10 years.	Accurately measure the volume of water entering Willochra Plain. Monitor salinity. Improve on the current understanding of runoff in the higher rainfall regions of the catchment. Improve accuracy of current isohyet coverage and hydrological model and aid environmental assessment.
1b.	Willochra Creek	Level, flow, EC and temperature	Upstream of confluences with major tributaries such as Booleroo Creek.	Short term 5 – 10 years.	Accurately determine the volume of water used for flood irrigation by comparison with upstream station. Improve accuracy of hydrological model through more accurate input data. Aid environmental assessment.
2.	Willochra Creek	Level, flow, EC and temperature	Willochra Creek at Pinda Bridge on the Orroroo Road.	Long-term ongoing	Measure the volume of water discharging from the Southern Willochra catchment. Observe long-term salinity trends. Improve understanding of the connectivity of the upstream and downstream reaches of the catchment. Improve on existing hydrological modelling and aid environmental assessment
3a.	Old Booleroo Creek	Level, flow, EC and temperature, rainfall (pluvio x 2)	Downstream of confluence of Stokes and Morchard Creek off the Orroroo Road	Short term 5 – 10 years	Gain a greater understanding of the volume of water generated from the Eastern Willochra catchment, gain understanding of the rainfall runoff relationship of the region and hence catchments with similar characteristics. Improve existing isohyet coverage. Improve accuracy of existing hydrological model. Monitor salinity. Gain understanding of the runoff salinity relationship.
3b.	Old Booleroo Creek	Level, EC and temperature	Old Booleroo Creek, due south of Willowie and upstream of the overflow.	Short term 5 – 10 years	The conjunctive use of the upstream station (3a) and the downstream water level record (3b) will enable determination of stream transmission losses, which will improve the accuracy of the existing hydrological modelling. Gain an understanding of spatial changes in salinity on plains regions. Aid environmental assessment.

SI UNITS COMMONLY USED WITHIN TEXT

Name of unit	Symbol	Definition in terms of other metric units	
Millimetre	mm	10^{-3} m	length
Metre	m		length
Kilometre	km	10^{3} m	length
Hectare	ha	10^{4} m^{2}	area
Microlitre	µL	10^{-9} m^{3}	volume
Millilitre	mL	10^{-6} m^{3}	volume
Litre	L	10^{-3} m^{3}	volume
Kilolitre	kL	1 m^{3}	volume
Megalitre	ML	10^{3} m^{3}	volume
Gigalitres	GL	10^{6} m^{3}	volume
Microgram	µg	10^{-6} g	mass
Milligram	mg	10^{-3} g	mass
Gram	g		mass
Kilogram	kg	10^{3} g	Mass

ABBREVIATIONS COMMONLY USED WITHIN TEXT

Abbreviation		Name	Units of measure
TDS	=	total dissolved solids *(milligrams per litre)*	mg/L
EC	=	electrical conductivity *(micro-Siemens per centimetre)*	µS/cm
pH	=	acidity	

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Ed Pikusa DWLBC August 2003.
David Cresswell DWLBC August 2003
Tony Thomson DWLBC December 2003

APPENDIX A. METHODOLOGY FOR DISAGGREGATING DATA AND INFILLING RECORDS

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

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

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

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 fell on day **j** at **k** station over the total rainfall accumulated over **m** days at the same **k** station. That is,

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

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

For 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. Again, the Consultants developed an automated procedure for infilling the data and it was limited to a search of 15 closest rainfall stations only.

APPENDIX B. METHODOLOGY FOR EXTENDING SHORT-TERM RAINFALL RECORDS

For the purpose of establishing a hydrological model the daily read rainfall records of BOM Station M019071 – Alligator Gorge – was extend to match the period of records of other long-term stations used for hydrological modelling in the area. The rainfall data from the station M019071 was correlated to the rainfall data from 45 other stations in and around the catchment. The station M019042 – Melrose Para Gums – was best correlated with correlation coefficient of 0.9424 for monthly data and a correlation coefficient of 0.8031 for daily data.

A double mass curve was then plotted of the rainfall records of the two stations to test for homogeneity of the data sets. Non-homogenous data was excluded from the record. The remaining period of recorded was plotted against the data for the same period of record for Station M019042.

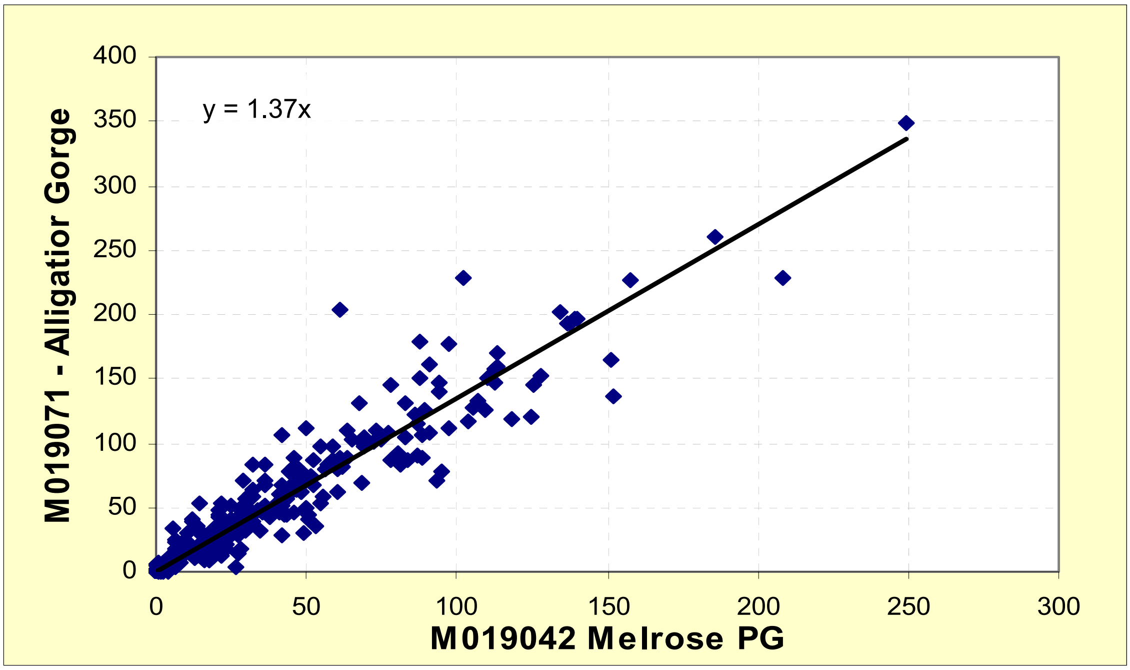


Figure 37. Relationship between Station M019071 and M019024

The average slope of the line was calculated to be 1.37, this factor was then multiplied by the daily read data for station M019042 from 1889 to 1979 in order to extend the existing record of Station M019071.

APPENDIX C. HOMOGENEITY CHECK OF RAINFALL RECORDS

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

Double mass curve analysis is one methodology used to check the homogeneity of rainfall records of stations in a region. A double mass plot of rainfall records of a station against average rainfall of the region would ideally be a straight line if the data were homogenous. If the plot were not a straight line but a line with sections of varying slopes it would indicate non-homogeneity of the rainfall records of the station being considered. In that case the data is adjusted to obtain a consistent slope and hence homogeneity in data across the region being considered.

Homogeneity checks for the long-term rainfall records from Stations M019006, M019007, M019011, M019024, M019042, M019048 and M019071 was undertaken by comparing each individual station to the average of the remaining 6 stations in the region. An example of Station M019011 is displayed below.

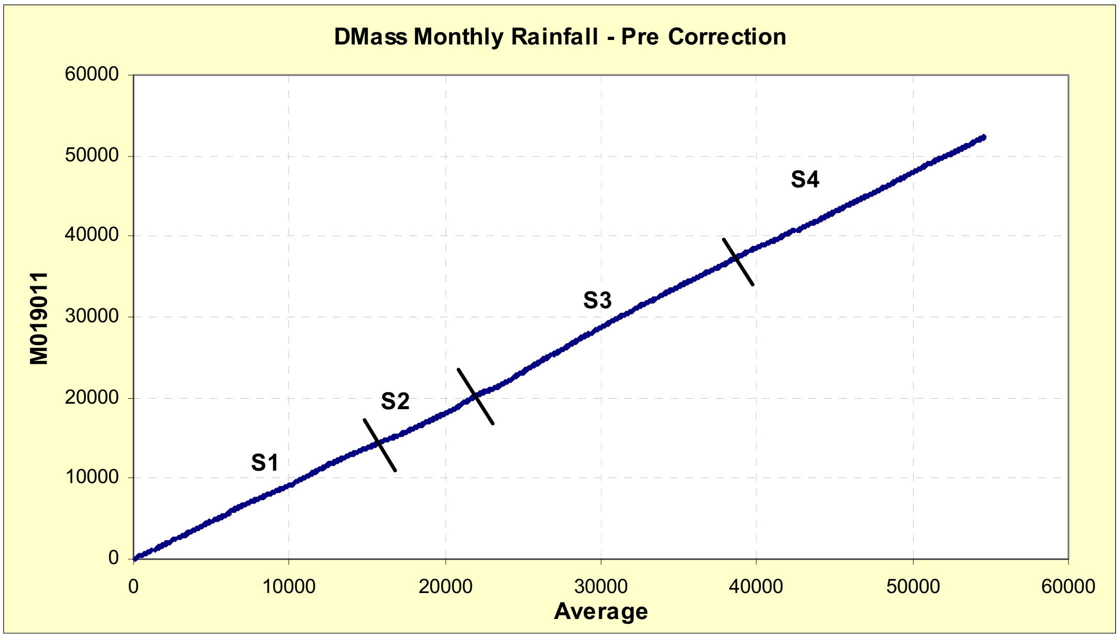


Figure 38. Double mass curve for monthly rainfall records Station M019011 and the average of 6 other stations

The double mass curve was plotted between the monthly rainfall at Station M019011 and the average monthly rainfall of six stations listed above. Slope changes were observed in the plot leading to four sections (S1, S2, …, S4) with varying slopes being identified. The details of these sections are listed in Table 15.

Table 15. Sections within the Monthly Double Mass Curve

Section	Duration	Slope	Change in Slope	Correction Factor
S1	1/1889 - 6/1923	0.90170	6.0%	1.063655
S2	7/1923 - 12/1931	0.93564	2.4%	
S3	1/1932 - 11/1966	1.04463	-8.9%	0.918124
S4	12/1966 - 12/2002	0.94599	1.4%	

Average slope of the curve for the whole duration: 0.95910

A change in slope of 5% or more is generally considered to be a non-homogenous data set. Sections that are non-homogenous are then adjusted by using the average slope of the sections on either side of the curve. In this case, S1 and S3 were considered to be non-homogenous (as change in slope > 5%) and hence S1 was adjusted by a factor of 1.063655, which is ratio of the slope of Section 1 (0.90170) to average slope of the section on either side of the curve (0.95910). S3 was adjusted by a factor of 0.918124, which is the ratio of the slope of Section 3 (1.04463) to the average slope of the section on either side of the curve.

APPENDIX D. TANH FUNCTION

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

Calculation

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

where

Q	runoff [mm]
P	rainfall [mm]
L	notional loss [mm]
F	notional infiltration [mm]

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

Determination of F and L

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

APPENDIX E. SUB-CATCHMENTS

Beautiful Valley sub-catchment

Beautiful Valley sub-catchment occupies an area 29.35 km^2. The catchment is relatively steep and ranges in altitude from 770 m on the western bound decreasing to 340 m. Beautiful Valley Creek is the main stream which flows northeasterly toward the Willochra Plain. The catchment has been divided into 5 sub-catchments based primarily of the location of farm dams, for the purpose of modelling (see Figure 5).

Rainfall–runoff

Rainfall station M019048 Wilmington Post Office has been used to represent the rainfall of Beautiful Valley sub-catchment. While the mean and median annual rainfall for the station M019048 is 466.0 mm and 426.3 mm respectively, the rainfall for each sub-divided sub-catchment has been estimated based on extrapolation of the annual rainfall isohyet data (Figure 7). Table 16 below shows the estimated rainfall of each sub-divided sub-catchment and its associated runoff in megalitres per square kilometre.

Table 16. Beautiful Valley sub-catchments estimated rainfall and runoff

No	Sub Catchment	Area (SqKm)	Average Annual Rainfall (mm)	Runoff (ML/Sqkm)	Volume Runoff Generated (ML)
1	BV1	3.7	520	21.3	80
2	BV2	0.3	515	20.6	7
3	BV3	12.0	480	16.1	194
4	BV4	2.0	440	11.8	23
5	BV5	11.3	430	10.9	123
Total		**29.4**	**477**	**14.5**	**427**

The estimated average annual rainfall for the Beautiful Valley sub-catchment is 477 mm, and generates approximately 14.5 mm of runoff, which equates to 14.5 ML/km^2. The runoff coefficient for the sub-catchment is 0.03, which is 3% of the annual rainfall. In an average rainfall year the sub-catchment is capable of generating approximately 420 ML of surface water runoff.

Annual rainfall analysis

Figure 39 displays annual rainfall from 1889 to 2002. The highest annual rainfall occurred in 1992 with greater that 900 mm of rainfall. Other wet years included 1889, 1921,1973 and 1974 all with recorded rainfall greater that 800 mm. The driest years were recorded in 1940 and 2002 both with an annual rainfall of 234 mm.

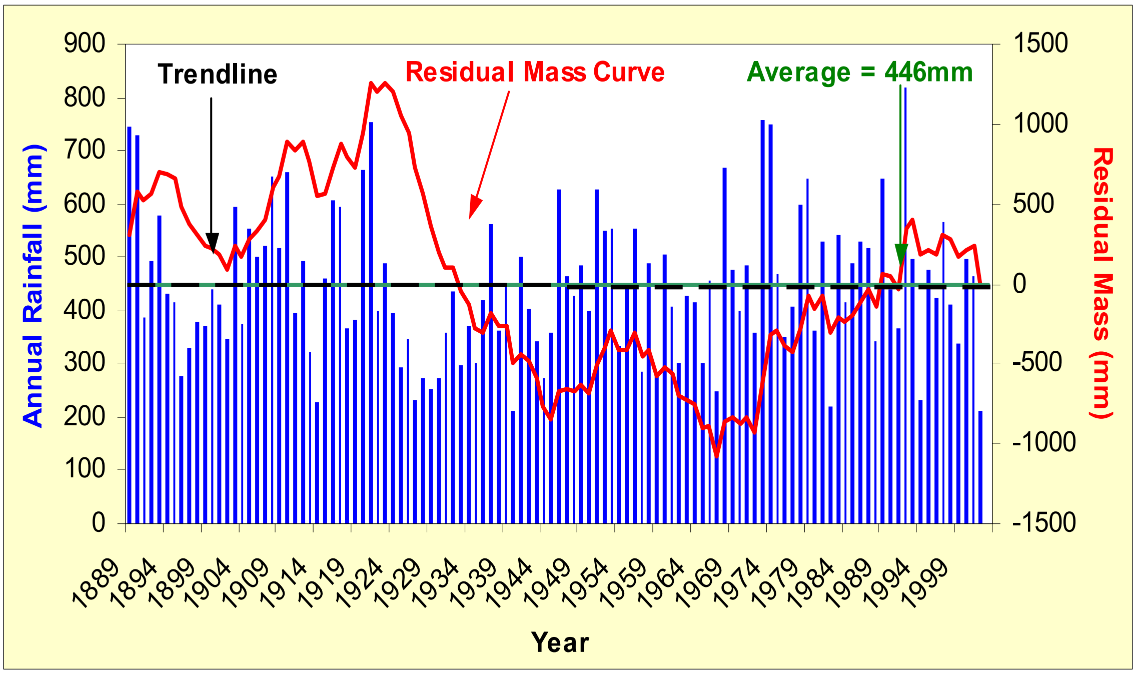


Figure 39. Beautiful Valley long-term annual rainfall

The residual mass curve indicates above or below average rainfall periods. A positive slope is representative of period of above average rainfall while a negative slope represents periods of below average rainfall. Above average periods of rainfall are evident from early 1900 to 1920 and from 1970 to mid 1990. Periods of below average rainfall include mid 1920 to early 1970, and mid 1990 to 2002.

Decadal rainfall

The average decadal rainfall has been calculated for the period 1890 to 2000. The driest decade occurred during the 1930, this has been confirmed by members of the community who recalled drought conditions and large dust storms during this period. The wettest decade occurred during the 1970s and is evident from Figure 40 below. Six of the eleven decades experienced above average rainfall while 5 decades experienced below average rainfall. While the rainfall of the last 2 decades has been close to the long-term average, it is evident that far drier conditions have been experienced in the past.

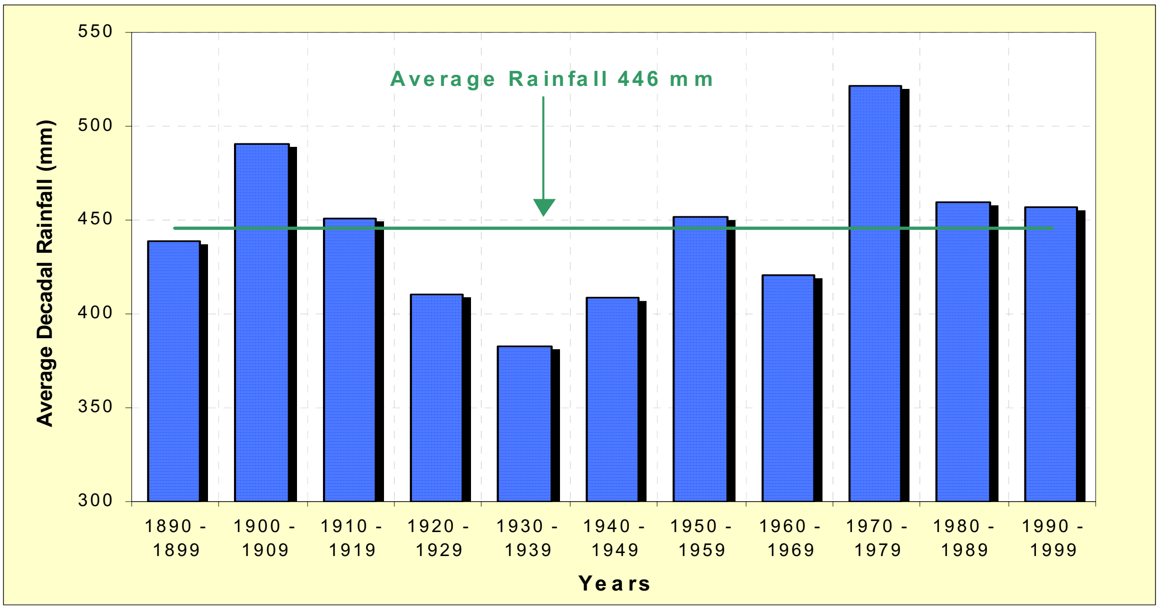


Figure 40. Beautiful Valley mean decadal rainfall

Monthly rainfall

Based on data collect from 1889 to 2002, June and July are the highest rainfall months followed by August and September. The lowest rainfall month is March. The mean monthly rainfall distribution is displayed below.

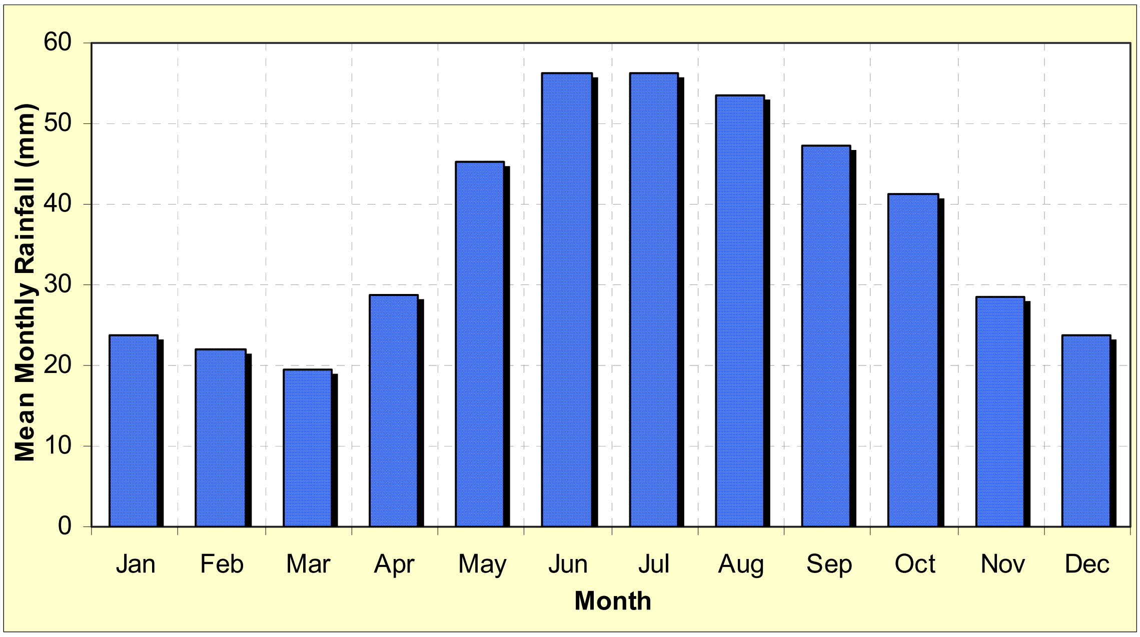


Figure 41. Beautiful Valley mean monthly rainfall

Farm dams

Based on data captured during 1987 and 1988 there are 24 farms dams within the catchment. Table 17 below displays the runoff generated, dam storage capacity and the relative farm dam density of each sub-divided sub-catchments.

Table 17. Beautiful Valley catchment runoff and farm dam density

No	Sub-Catchment	Area (SqKm)	Runoff (ML/Sqkm)	Volume Runoff Generated (ML)	Dam Capacity (ML)	Farm Dam Density (ML/Sqkm)
1	BV1	3.7	21.3	80	4	1
2	BV2	0.3	20.6	7	9	26
3	BV3	12.0	16.1	194	34	3
4	BV4	2.0	11.8	23	14	7
5	BV5	11.3	10.9	123	12	1
Total		**29.4**	**14.5**	**427**	**73**	**3**

Although the farm dam density is relatively low on the catchment scale, once the sub-catchment has been sub-divided it can be seen that the farm dam density is not distributed evenly. For example sub-division BV2 has a farm dam density of 26 ML/km^2, examination of Table 17 shows that the runoff generated is 20.6 ML/ km^2, therefore the volume of water captured by the dam exceeds the volume of runoff generated. Table 17 further shows that the total volume of runoff generated in the sub-division BV2 is only 7 ML while the dam capacity is almost 9 ML. It is unlikely (unless in extreme events) that water generated in this catchment would contribute to catchments downstream.

Water diversions

Due to the steepness of the catchment and rapid flow of surface water, the diversion of water for the purpose of flood irrigation in not practiced. However, water generated within this sub-catchment is reported to be used for flood irrigation in the downstream sub-catchment where the land is flatter and stream flow is reduced.

Land use

The major land use in the Beautiful Valley sub-catchment is grazing modified pasture, and livestock grazing (vegetation) which constitutes 95% of the total catchment area. The main use of water is to provide water for domestic stock. Figure 6 displays the land use of the sub-catchment.

Table 18. Beautiful Valley sub-catchment land use summary

Category	Landuse	Area (Sqkm)	Percentage
1	Crop/grazing rotation	0.10	0.33%
2	Grazing modified pastures	17.11	58.30%
3	Irrigated modified pastures		
4	Irrigated horticulure		
5	Livestock grazing (vegetation)	10.67	36.36%
6	Conservation Areas	0.07	0.24%
7	Intensive Animal Production		
8	Residential / Industrial	1.40	4.77%

Booleroo Creek sub-catchment

Booleroo Creek sub-catchment is 305.84 km^2, the eastern boundary of the catchment is relatively steep at 770 m which decreases becoming undulating and flattens towards the west at 280 m. Booleroo Creek is the main stream that flows northwesterly toward the Willochra Plain. The catchment has been divided into eight (8) sub-divisions based on topography, and the location of farm dams for the purpose of modelling. (see Figure 5).

Rainfall–runoff

Rainfall station M019007 Booleroo Whim has been used to represent the rainfall of Booleroo Creek sub-catchment. While the mean and median annual rainfall for the station M019007 is 345.9 mm and 342.2 mm respectively, the rainfall for each sub-divided sub-catchment has been estimated based on extrapolation of the annual rainfall isohyet data (Figure 7). Table 19 below shows the estimated rainfall of each sub-divided sub-catchment and its associated runoff in megalitres per square kilometre.

Table 19. Booleroo Creek sub-catchment estimated rainfall and runoff

No	Sub Catchment	Area (SqKm)	Average Annual Rainfall (mm)	Runoff (ML/Sqkm)	Volume Runoff Generated (ML)
1	B1	6.8	370	6.2	42
2	B2	6.8	355	5.3	36
3	B3	49.7	355	5.3	263
4	B4	29.6	370	6.2	184
5	B5	36.6	375	6.5	239
6	B6	70.4	360	5.6	394
7	B7	69.1	345	0.0	0
8	B8	36.9	360	0.0	0
Total		**305.8**	**361**	**3.8**	**1158**

The estimated average annual rainfall for the Booleroo Creek sub-catchment is 361.3 mm, which generates an average only 3.8 mm of runoff, which is equivalent to 3.8 ML/km^2. The runoff coefficient for the sub-catchment is a low at 0.01, which is approximately 1% of the annual rainfall. The runoff coefficient is low as it is assumed that no runoff in generated on the plains. In an average rainfall year the sub-catchment is capable of generating approximately 1150 ML of surface water runoff.

Annual rainfall analysis

Figure 42 displays annual rainfall from 1889 to 2002. The highest annual rainfall occurred in 1973 and 1889 with 676 mm and 668 mm respectively. 1974 and 1890 were also wet years with a recorded rainfall greater than 620 mm which is almost double the long-term average annual rainfall. The driest year was recorded in 1940 with only 153.6 mm. 2002, 1994 and 1982 were the following driest years on record with an annual rainfall of less than 180 mm. It is interesting to note that three of the four driest years on record occurred within the last 20 years.

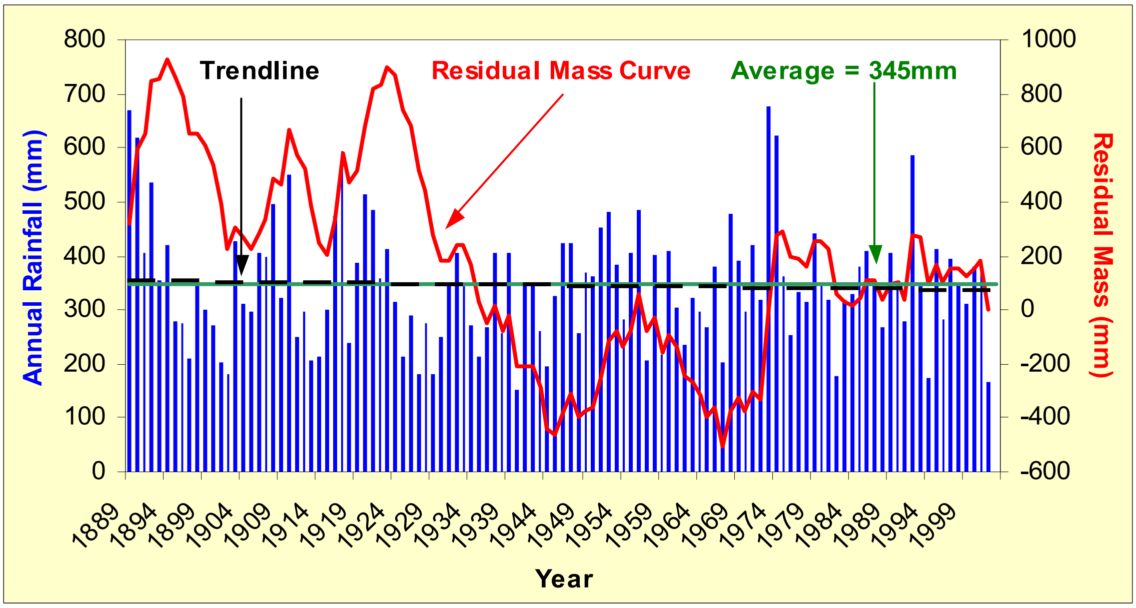


Figure 42. Booleroo Creek sub-catchment long-term rainfall analysis

The residual mass curve indicates above or below average rainfall periods. A positive slope is representative of periods of above average rainfall while a negative slope represents periods of below average rainfall. Generally from late 1970 to 2001 the residual mass curve exhibits no upward or downward trend, suggesting that the rainfall for the period was close to the average. Below average rainfall was experienced from mid 1920 to mid 1940 and above average rainfall is evident from late 1960 to late 1970.

Evident from Figure 42 above in the past 20 years of recorded (with the exception of 1992) the annual rainfall peaks are significantly less approximately 410 mm, which is less than previously experienced.

Decadal rainfall

The average decadal rainfall has been calculated for the period 1890 to 2000. The driest decade occurred during the 1940s. The wettest decade occurred during the 1970s and is evident from Figure 43 below. Six of the eleven decades have recorded below average rainfall.

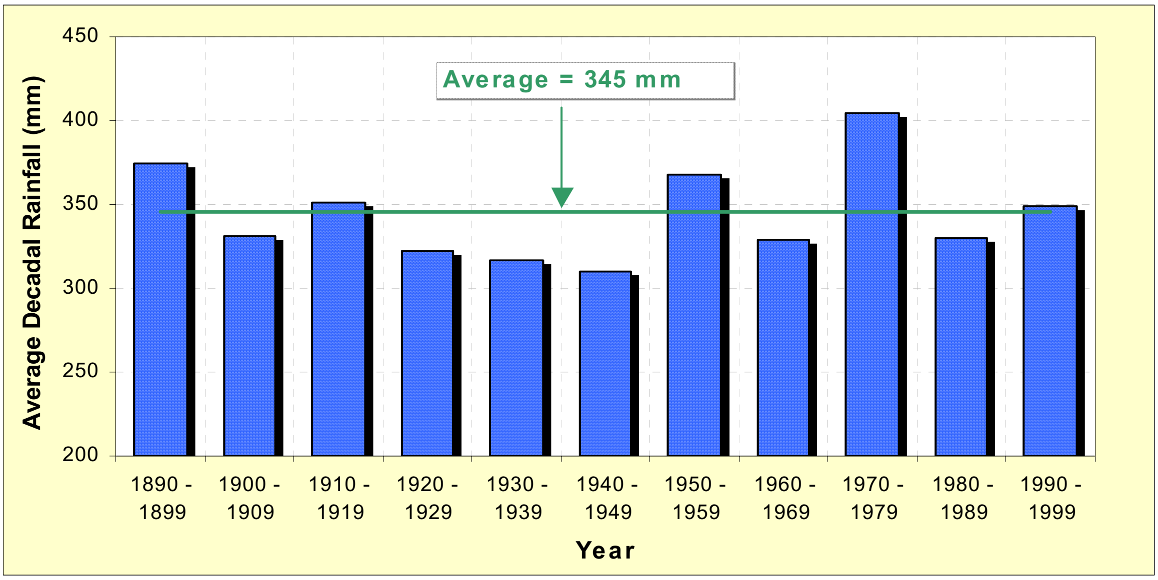


Figure 43. Booleroo Creek sub-catchment mean decadal rainfall

Monthly rainfall

Based on data collected from 1889 to 2002, June and August are the highest rainfall months followed by July and September. The lowest rainfall month is March. The mean monthly rainfall distribution is displayed below.

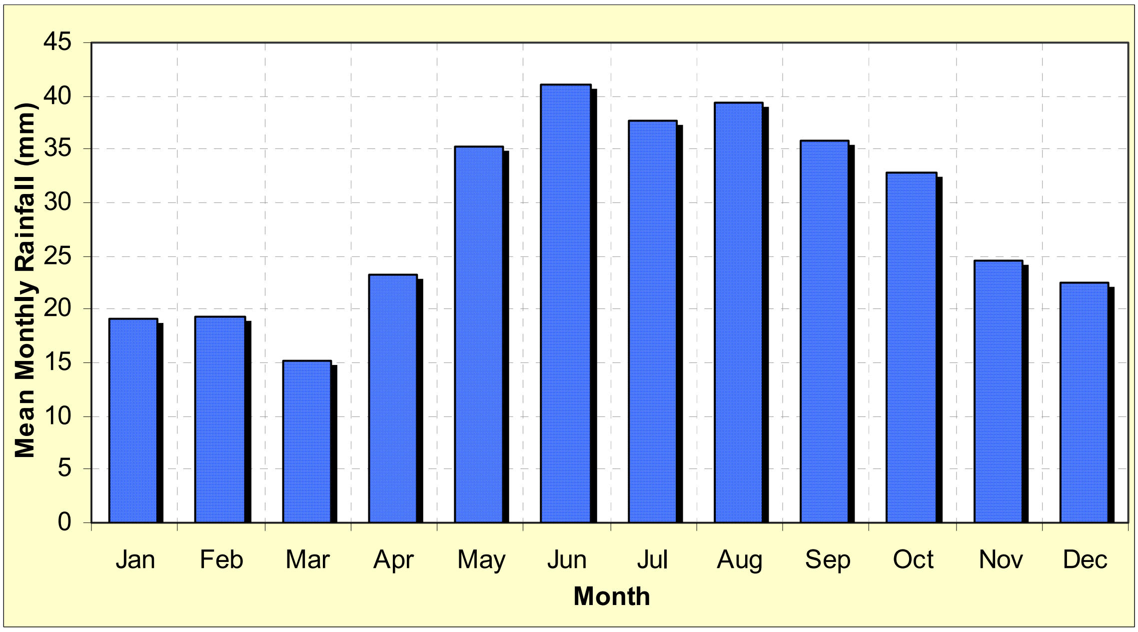


Figure 43. Booleroo Creek sub-catchment mean monthly rainfall

Rainfall in the region is predominately produced by southwesterly systems however; the higher mean monthly rainfall evident for January and February which exceeds that of March may be indicative of the northern monsoonal influence.

Farm dams

Based on data captured during 1987 and 1988 there are 128 farms dams within the sub-catchment. Table 20 below displays the runoff generated, dam storage capacity and the relative farm dam density of each sub-divided sub-catchments.

Table 20. Booleroo Creek sub-catchment farm dam density

No	Sub-Catchment	Area (SqKm)	Runoff (ML/Sqkm)	Volume Runoff Generated (ML)	Dam Capacity (ML)	Farm Dam Density (ML/Sqkm)
1	B1	6.8	6.2	42	0	0.0
2	B2	6.8	5.3	36	3	0.4
3	B3	49.7	5.3	263	61	1.2
4	B4	29.6	6.2	184	50	1.7
5	B5	36.6	6.5	239	91	2.5
6	B6	70.4	5.6	394	49	0.7
7	B7	69.1	0.0	0	37	0.5
8	B8	36.9	0.0	0	0	0.0
Total		**305.8**	**3.8**	**1158**	**291**	**1.0**

The farm dam density is low on the sub-catchment scale. The highest recorded farm dam density is 2.5 ML/km^2 in sub-division B5 which has a corresponding estimated runoff of 6.5 ML/ km^2 which are within sustainable development limits for an average rainfall year. Although there is a large number of dams within the catchment the majority of farm dams are off-stream dams and have a holding capacity less than 5 ML. While evaporative losses may be high, it is unlikely that the current development levels with the sub-divisions would cause major impact to downstream water users.

Water diversions

The majority of the sub-catchment area is undulating and unsuitable for flood irrigation. Aerial videography footage collected in June 2003 did not reveal in-stream structures.

Land use

The major land use in the Booleroo Creek sub-catchment is crop / grazing rotation and grazing modified pasture, which constitutes 94% of the total catchment area. The main use of water is to provide water for domestic stock. Figure 6 displays the land use of the sub-catchment.

Table 21. Booleroo Creek sub-catchment land use summary

Category	Landuse	Area (Sqkm)	Percentage
1	Crop/grazing rotation	173.64	56.76%
2	Grazing modified pastures	113.16	36.99%
3	Irrigated modified pastures		
4	Irrigated horticulure		
5	Livestock grazing (vegetation)	12.84	4.20%
6	Conservation Areas	0.07	0.02%
7	Intensive Animal Production		
8	Residential / Industrial	6.20	2.03%

Campbell Creek sub-catchment

Campbell Creek sub-catchment is 34.18 km^2. The catchment is located to the south of Mt Remarkable National Park and is steep with contours ranging from 950 m to 380 m. Campbell Creek is the main stream which drains in a northeasterly direction toward the Willochra Plain. The catchment has been divided into 5 sub-divisions based on topography, and the location of farm dams for the purpose of modelling. (see Figure 5).

Rainfall–runoff

Rainfall station M019024 Melrose Post Office has been used to represent the rainfall of Campbell Creek sub-catchment while the mean and median annual rainfall for the station is 598.1 mm and 578.4 mm respectively. The rainfall for each sub-divided sub-catchment has been estimated based on extrapolation of the annual rainfall isohyet data (Figure 7). Table 22 below shows the estimated rainfall of each sub-divided sub-catchment and its associated runoff in megalitres per square kilometre.

Table 22. Campbell Creek sub-catchment estimated rainfall and runoff

No	Sub Catchment	Area (SqKm)	Average Annual Rainfall (mm)	Runoff (ML/Sqkm)	Volume Runoff Generated (ML)
1	C1	8.0	570	29.2	234
2	C2	6.8	610	36.5	248
3	C3	4.1	560	27.5	114
4	C4	7.9	530	22.8	179
5	C5	7.4	550	25.9	191
Total		**34.2**	**564**	**28.2**	**965**

The estimated average annual rainfall for the Campbell Creek sub-catchment is 564 mm, which generates an average 28.2 mm of runoff. The runoff coefficient for the sub-catchment is 0.05, which is approximately 5% of the annual rainfall. In an average rainfall year the sub-catchment is capable of generating approximately 965 ML of surface water runoff.

Annual rainfall analysis

Figure 44 displays annual rainfall from 1889 to 2002. The highest annual rainfall occurred in 1889, 1890 and 1992 with 1083 mm, 989 mm and 989 mm respectively. The driest year recorded was 1982 with only 302.8 mm annual rainfall followed by 1914, 1959 and 1194 with less than 320 mm rainfall.

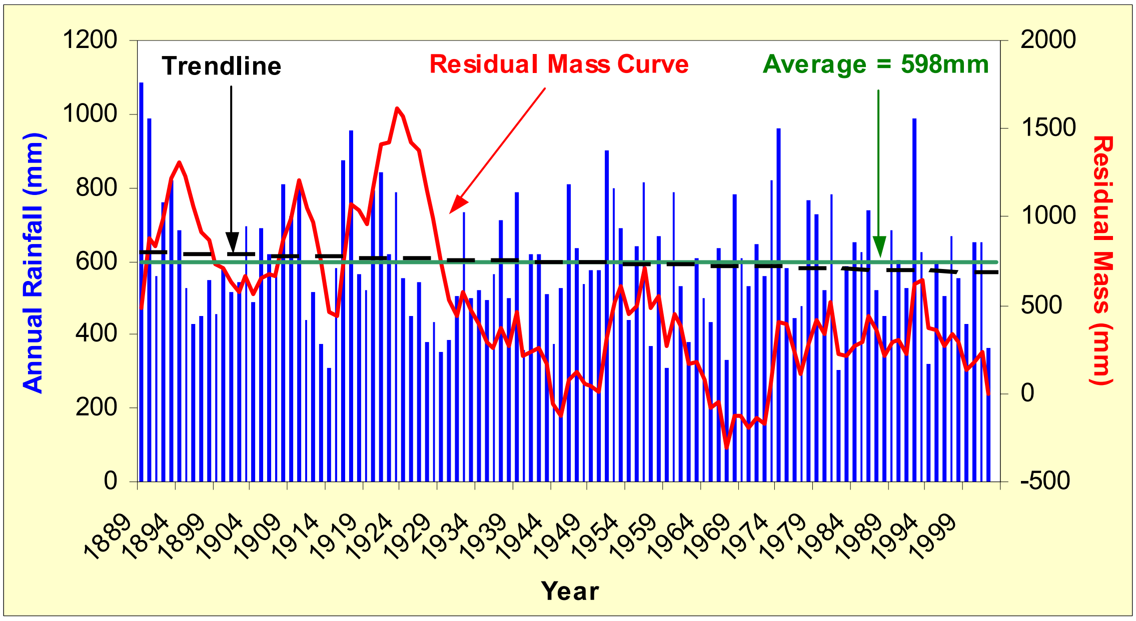


Figure 44. Campbell Creek sub-catchment long-term rainfall analysis

The residual mass curve indicates above or below average rainfall periods. A positive slope is representative of period of above average rainfall while a negative slope represents periods of below average rainfall. The chart shows since 1993 the region has experienced below average rainfall.

Decadal rainfall

The average decadal rainfall has been calculated for the period 1890 to 2000. The driest decade occurred during the 1940s. The wettest decade occurred during the 1970s and is evident from Figure 45.

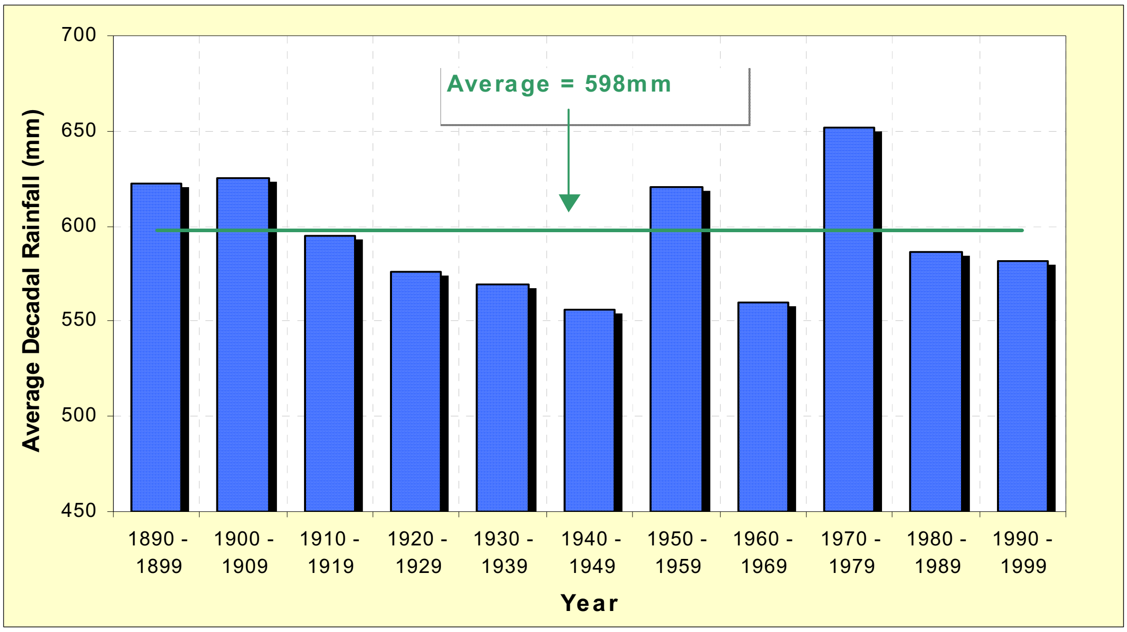


Figure 45. Campbell Creek sub-catchment mean decadal rainfall

Monthly rainfall

Based on data records from 1889 to 2002, June, July and August are the highest rainfall months followed by May and September. The lowest rainfall month is March. The mean monthly rainfall distribution is displayed below.

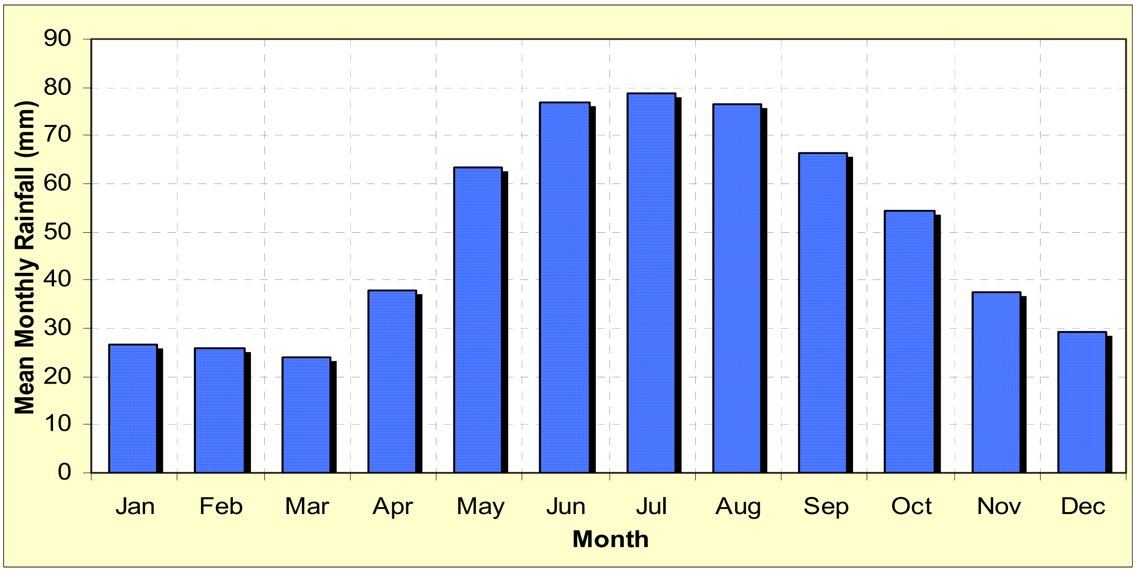


Figure 46. Campbell Creek sub-catchment mean monthly rainfall

Farm dams

Based on data captured during 1987 and 1988 there are 32 farms dams within the sub-catchment. Table 23 below displays the runoff generated, dam storage capacity and the relative farm dam density of each sub-divided sub-catchments.

Table 23. Campbell Creek sub-catchment farm dam density

No	Sub-Catchment	Area (SqKm)	Runoff (ML/Sqkm)	Volume Runoff Generated (ML)	Dam Capacity (ML)	Farm Dam Density (ML/Sqkm)
1	C1	8.0	29.2	234	4	1
2	C2	6.8	36.5	248	13	2
3	C3	4.1	27.5	114	0	0
4	C4	7.9	22.8	179	17	2
5	C5	7.4	25.9	191	0	0
Total		**34.2**	**28.2**	**965**	**34**	**1**

The farm dam density with in the sub-divided sub-catchments is low and two of the sub-catchments, C3 and C5 are free to flow catchments with no dams present (at the time the data was captured). The highest recorded farm dam density is 2.2 ML/km^2 in sub- catchment C4 that has a corresponding runoff of approximately 22.8 ML/km^2. All farm dams are less than 2 ML with the exception of 2 dams with a holding capacity less than 5 ML.

While the data in Table 23 indicates that the sub-catchment is well within its sustainable development limits (that is less than 50% of the runoff generated within the sub-catchment is captured) it has been reported that numerous small dams have been constructed in recent years to supplement diminishing spring supply for stock. A large irrigation dam has also recently been constructed apparently to the detriment of downstream water users. These dams are not represented in the current data set.

Water diversions

Due to the topographic relief of the sub-catchment flood irrigation and diversion of water is unsuitable.

Land use

The major land use in the Campbell Creek sub-catchment is grazing modified pasture, which constitutes 80% of the total catchment area followed by conservation areas the occupy 18% of the total area. Two vineyards exist within the catchment and occupy 0.35% (11.8 ha) of the catchment area. Figure 6 displays the land use of the sub-catchment.

Table 24. Campbell Creek sub-catchment land use summary

Category	Landuse	Area (Sqkm)	Percentage
1	Crop/grazing rotation		
2	Grazing modified pastures	27.46	80.32%
3	Irrigated modified pastures		
4	Irrigated horticulure	0.12	0.35%
5	Livestock grazing (vegetation)	0.12	0.35%
6	Conservation Areas	6.02	17.61%
7	Intensive Animal Production		
8	Residential / Industrial	0.47	1.37%

Irrigated horticulture (vineyards) is within sub-division C4 that also displays the highest farm dam density. It is assumed that irrigation is the major user of water in the sub-catchment.

Fullerville sub-catchment

Fullerville sub-catchment is 99.88 km^2. The catchment is located in the southeast region of the Willochra catchment, with undulating topography ranging from 310 m to 480 m altitude. The main stream drains from the southeast of the catchment in a northwesterly direction toward the Willochra Plain, discharging to Rotten Creek. The catchment has been divided into 4 sub-catchments based on topography, and the location of farm dams for the purpose of modelling (see Figure 5).

Rainfall–runoff

Rainfall station M019006 Booleroo Centre has been used to represent the rainfall of Fullerville sub-catchment. While the mean and median annual rainfall for the station is 398.4 mm and 395.2 mm respectively, the rainfall for each sub-divided sub-catchment has been estimated based on extrapolation of the annual rainfall isohyet data (Figure 7). Table 25 below shows the estimated rainfall of each sub-divided sub-catchment and its associated runoff in megalitres per square kilometre.

Table 25. Fullerville sub-catchment estimated rainfall and runoff

No	Sub Catchment	Area (SqKm)	Average Annual Rainfall (mm)	Runoff (ML/Sqkm)	Volume Runoff Generated (ML)
1	F1	34.8	420	10.0	347
2	F2	15.9	405	8.7	139
3	F3	21.8	385	7.2	157
4	F4	27.4	390	0.0	0
Total		**99.9**	**400**	**6.4**	**643**

The estimated average annual rainfall for the Fullerville sub-catchment is 400 mm, which generates an average 6.4 mm of runoff. The runoff coefficient for the sub-catchment is 0.02, which is approximately 2% of the annual rainfall. The runoff on the plains regions is negligible and it is assumed that sub-division F4 does not generate runoff. In an average rainfall year the sub-catchment is capable of generating approximately 640 ML of surface water runoff.

Annual rainfall analysis

Figure 47 displays annual rainfall from 1889 to 2002. The highest annual rainfall occurred in 1973 with 692.1 mm, followed by 1889 and 1992 with 681.8 and 681.0 mm. The driest year on record is 1940 with only 195.7 mm. Other years of low rainfall include 1895, 1967, 1913 and 2002, which all experienced annual rainfalls of less than 225 mm.

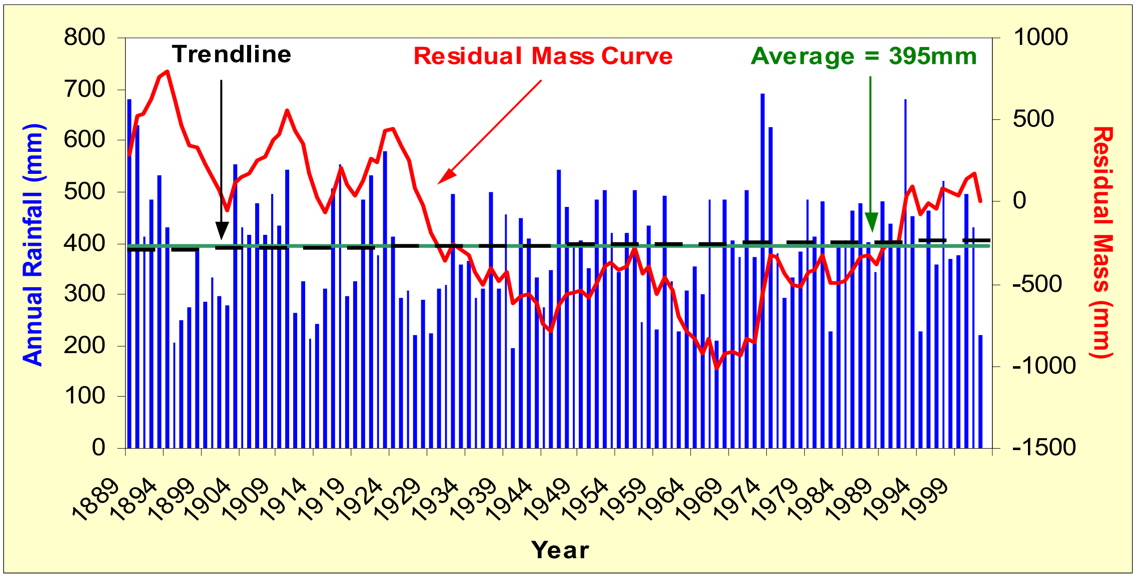


Figure 47. Fullerville sub-catchment long-term rainfall analysis

The residual mass curve indicates above or below average rainfall periods. A positive slope is representative of a period of above average rainfall while a negative slope represents periods of below average rainfall. For example from the 1920s to the late 1960s the region experienced below average rain. From the 1970s to 2001 the slope of the residual mass curve is increasing indicating an above average rainfall period.

Decadal rainfall

The average decadal rainfall has been calculated for the period 1890 to 2000. The driest decade occurred during 1910, this differs from sub-catchments on the western bounds of the Southern Willochra where the driest decade was often the 1930s and 1940s. The wettest decade occurred during the 1970s and that is consistent with all of the sub-catchments within the Southern Willochra, and is evident from Figure 48.

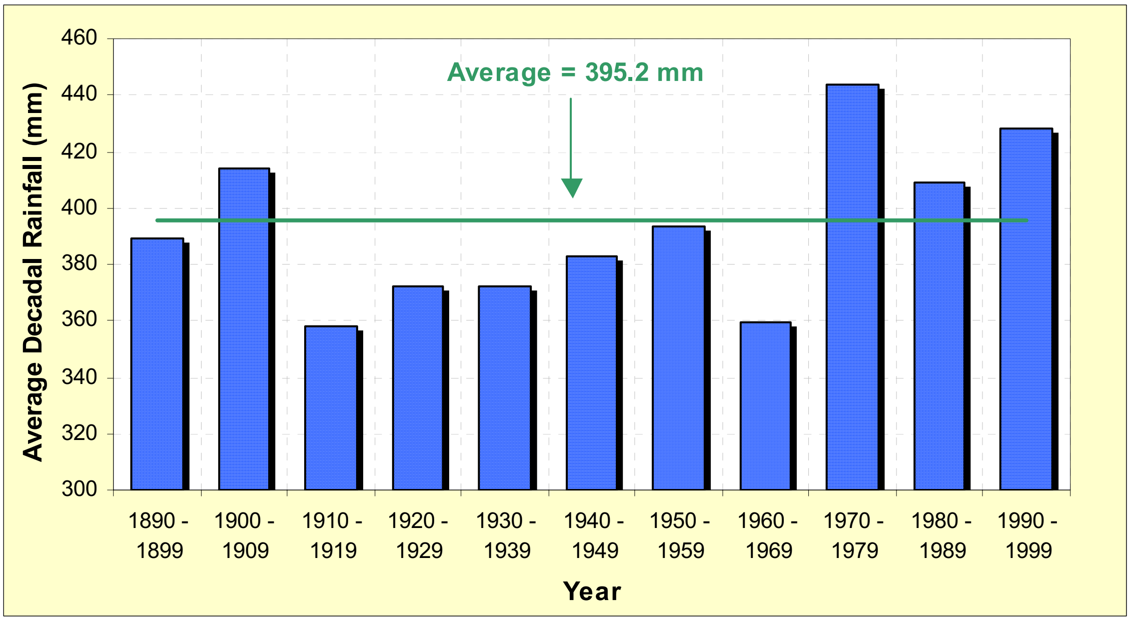


Figure 48. Fullerville sub-catchment mean decadal rainfall

Monthly rainfall

Based on the data records from 1889 to 2002, June, and August are the highest rainfall months followed by July and September. The lowest rainfall month is March. The mean monthly rainfall distribution is displayed below.

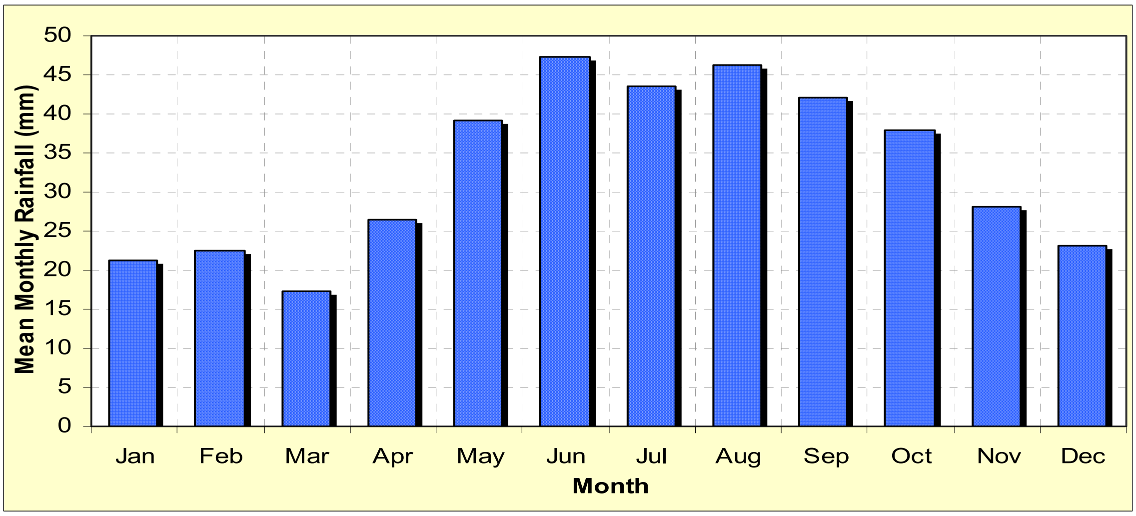


Figure 49. Fullerville sub-catchment mean monthly rainfall

Farm dams

Based on data captured during 1987 and 1988 there are 71 farms dams within the sub-catchment. Table 26 below displays the runoff generated, dam storage capacity and the relative farm dam density of each sub-divided sub-catchments.

Table 26. Fullerville sub-catchment farm dam density

No	Sub-Catchment	Area (SqKm)	Runoff (ML/Sqkm)	Volume Runoff Generated (ML)	Dam Capacity (ML)	Farm Dam Density (ML/Sqkm)
1	F1	34.8	10.0	347	60	2
2	F2	15.9	8.7	139	29	2
3	F3	21.8	7.2	157	48	2
4	F4	27.4	0.0	0	19	1
Total		**99.9**	**6.4**	**643**	**156**	**2**

The farm dam density within the sub-catchments is low. The highest recorded farm dam density is 2 ML/km^2 in sub-division F3; this figure is well below the sustainable development level of 50% of the estimated runoff that equates to 7.2 ML/km^2. Of the 7 dams only 5 dams have a holding capacity of greater than 5 ML and less than 10 ML, the remaining 66 dams are less than 5 ML.

Water diversions

Diversion of water for the purpose of flood irrigation has not been identified in this region.

Land use

The major land use in the Fullerville sub-catchment is crop/grazing rotation and grazing modified pasture, which constitutes 97% of the total catchment area. Intensive animal production accounts for 0.23% of the catchment area. Figure 6 displays the land use of the sub-catchment.

Table 27. Fullerville sub-catchment land use summary

Category	Landuse	Area (Sqkm)	Percentage
1	Crop/grazing rotation	64.84	64.92%
2	Grazing modified pastures	32.09	32.13%
3	Irrigated modified pastures		
4	Irrigated horticulure		
5	Livestock grazing (vegetation)	0.18	0.18%
6	Conservation Areas		
7	Intensive Animal Production	0.23	0.23%
8	Residential / Industrial	2.54	2.54%

Old Booleroo Creek sub-catchment

Old Booleroo Creek sub-catchment is 352.98 km2. The catchment is located in the southeast region of the Willochra catchment with topography varying from steep slopes on the southeastern bounds of the catchment to undulating then flattens towards the west. Elevation ranges from 280 m to 710 m altitude. The main streams that drain the catchment are Morchard Creek, Stokes Creek and Old Booleroo Creek that flow in a westerly direction toward the Willochra Plain. The catchment has been divided into 8 sub-divisions based on topography, and the location of farm dams for the purpose of modelling (see Figure 5).

Rainfall–runoff

Rainfall station M019007 Booleroo Whim has been used to represent the rainfall of Old Booleroo Creek sub-catchment. While the mean and median annual rainfall for the station is 345.9 mm and 342.2 mm respectively, the rainfall for each sub-divided sub-catchment has been estimated based on extrapolation of the annual rainfall isohyet data (Figure 7). Table 28 below shows the estimated rainfall of each sub-divided sub-catchment and its associated runoff in megalitres per square kilometre.

Table 28. Old Booleroo Creek sub-catchment estimated rainfall and runoff

No	Sub Catchment	Area (SqKm)	Average Annual Rainfall (mm)	Runoff (ML/Sqkm)	Volume Runoff Generated (ML)
1	OB1	13.2	352	5.1	67
2	OB2	12.8	345	4.7	61
3	OB3	20.2	345	4.7	96
4	OB4	30.6	338	4.4	134
5	OB5	97.6	347	4.8	473
6	OB6	69.9	335	4.2	295
7	OB7	68.7	326	0.0	0
8	OB8	40.1	360	0.0	0
Total		**353.0**	**344**	**3.2**	**1125**

Both sub-divisions OB7 and OB8 occupy plains regions of the Old Booleroo sub-catchment where runoff is negligible (with the exception of extreme rainfall events) therefore, it is assumed that no runoff is generated from these regions. The estimated average annual rainfall for the sub-catchment is 344 mm, and has a corresponding runoff of 3.2 mm, which is equivalent to 3.2 ML/km^2. While this figure is higher for the individual sub-divisions, the whole sub-catchments average is reduced as no runoff is being generated from the plains regions. The runoff coefficient for the sub-catchment is only 0.01, which is approximately 1% of the average annual rainfall.

Annual rainfall analysis

Figure 50 displays annual rainfall from 1889 to 2002. The highest annual rainfall occurred in 1973 and 1889 with 676 mm and 668 mm respectively. 1974 and 1890 were also wet years with recorded rainfall greater than 620 mm. The driest years was recorded in 1940 with 153.6 mm. 2002, 1994 and 1982 were the next driest years on record with an annual rainfall of less than 180 mm.

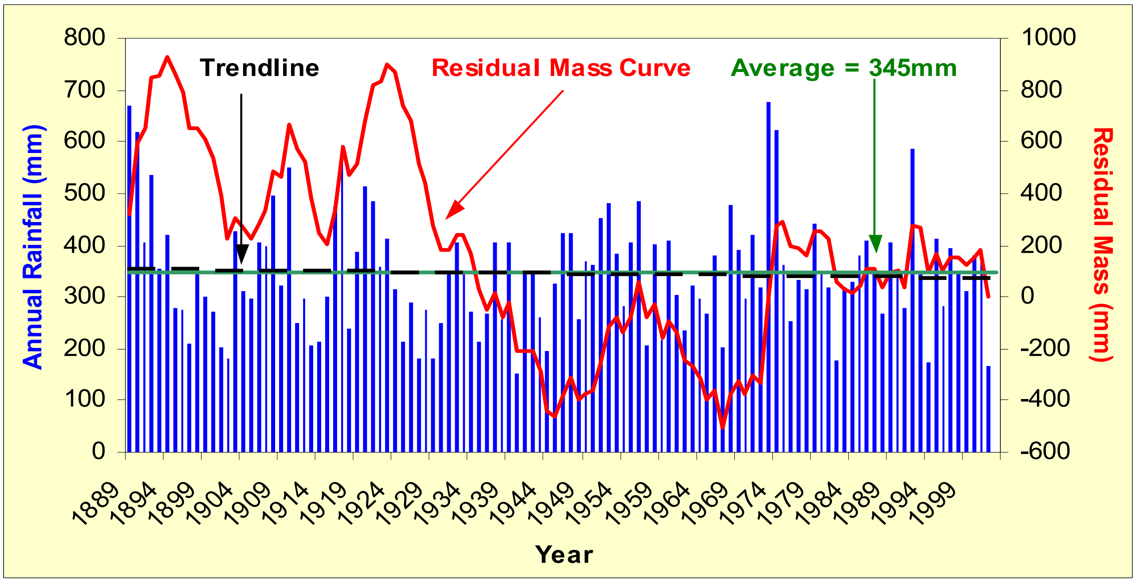


Figure 50 Old Booleroo Creek sub-catchment long-term rainfall analysis

The residual mass curve indicates above or below average rainfall periods. A positive slope is representative of period of above average rainfall while a negative slope represents periods of below average rainfall. Generally from the late 1970s to 2001 the residual mass curve exhibits no upward or downward trend, suggesting that the rainfall for the period was close to the average. Below average rainfall was experienced from the mid 1920s to the mid 1940s and above average rainfall is evident from the late 1960s to the late 1970s.

Decadal rainfall

The average decadal rainfall has been calculated for the period 1890–2000. The driest decade occurred during the 1940s. The wettest decade occurred during the 1970s and is evident from Figure 51 below. Six of the eleven decades have recorded below average rainfall.

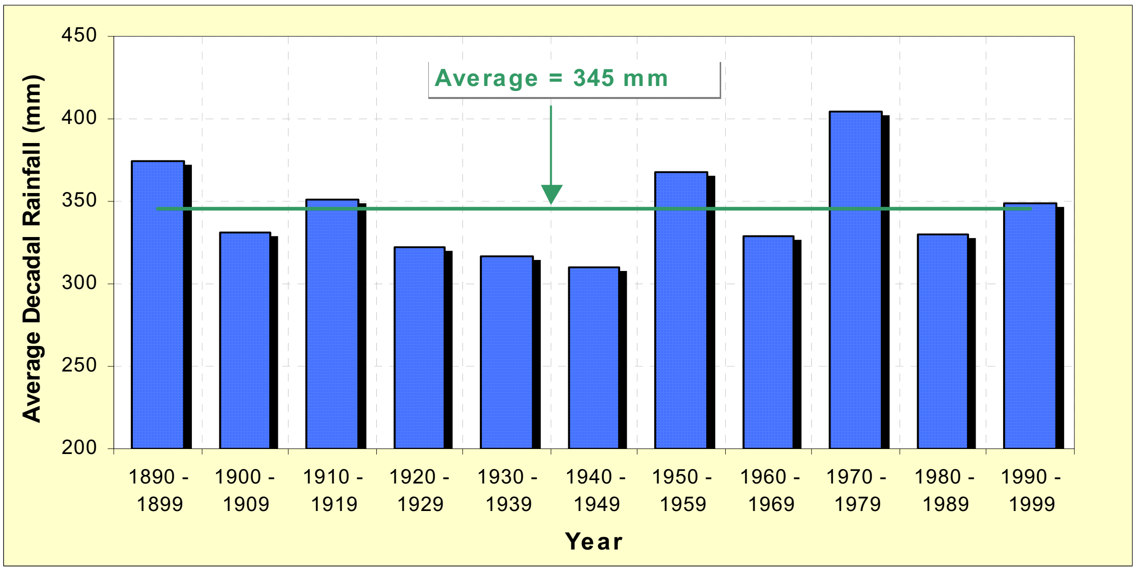


Figure 51. Old Booleroo Creek sub-catchment mean decadal rainfall

Monthly rainfall

Based on data collected from 1889 to 2002, June and August are the highest rainfall months followed by July and September. The lowest rainfall month is March. The mean monthly rainfall distribution is displayed below.

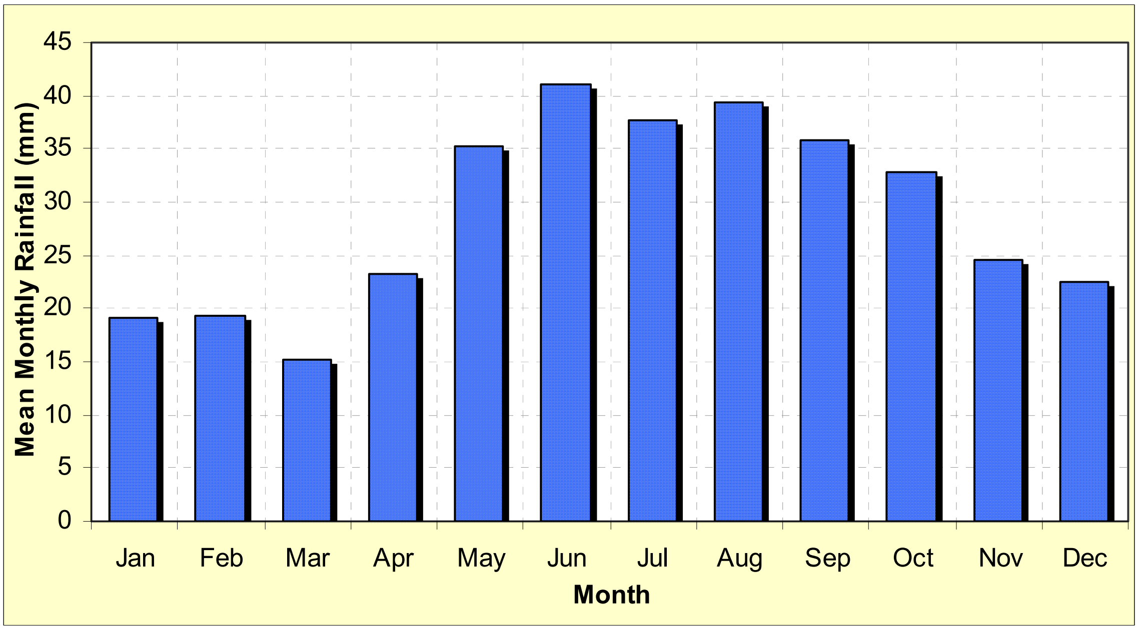


Figure 52. Old Booleroo Creek sub-catchment mean monthly rainfall

Farm dams

Based on data captured during 1987 and 1988 there are 122 farms dams within the sub-catchment. Table 29 below displays the runoff generated, dam storage capacity and the relative farm dam density of each sub-divided sub-catchments.

Table 29. Old Booleroo Creek sub-catchment farm dam density

No	Sub-Catchment	Area (SqKm)	Runoff (ML/Sqkm)	Volume Runoff Generated (ML)	Dam Capacity (ML)	Farm Dam Density (ML/Sqkm)
1	OB1	13.2	5.1	67	5	0.4
2	OB2	12.8	4.7	61	14	1.1
3	OB3	20.2	4.7	96	18	0.9
4	OB4	30.6	4.4	134	19	0.6
5	OB5	97.6	4.8	473	205	2.1
6	OB6	69.9	4.2	295	29	0.4
7	OB7	68.7	0.0	0	0	0.0
8	OB8	40.1	0.0	0	19	0.5
Total		**353.0**	**3.2**	**1125**	**308**	**0.9**

The farm dam density at the sub-catchments is low. The highest recorded farm dam density is 2.1 ML/km^2 in sub-catchment OB5 which has a corresponding estimated runoff of 4.8 ML/km^2 this sub-divisions is close to the sustainable development limit of 50% of the runoff and may actually exceed the limit which considers the median runoff and not mean (average) runoff. Of the 122 dams, 113 have a holding capacity less than 5 ML, 8 have a holding capacity less than 10 ML and the remaining dam has a holding capacity of 10.6 ML

Water diversions

Diversion of water for the purpose of flood irrigation has not been identified in this region.

Land use

The major land use in the Old Booleroo Creek sub-catchment is crop / grazing rotation, grazing modified pasture and grazing (vegetation), which constitutes 98% of the total catchment area. Figure 6 displays the land use of the sub-catchment.

Table 30. Old Booleroo Creek sub-catchment land use summary

Category	Landuse	Area (Sqkm)	Percentage
1	Crop/grazing rotation	178.54	50.58%
2	Grazing modified pastures	154.05	43.64%
3	Irrigated modified pastures		
4	Irrigated horticulure		
5	Livestock grazing (vegetation)	12.60	3.57%
6	Conservation Areas		
7	Intensive Animal Production		
8	Residential / Industrial	7.79	2.21%

Spring Creek sub-catchment

Spring Creek sub-catchment is 52.80 km^2. The catchment is located in the southwest region of the Willochra catchment, the topography is steep and the elevation ranges from 350 m to 950 m. The main streams which drains the catchment is Spring Creek which flows in a northerly direction on the western side of Mt Remarkable then trends easterly toward the Willochra Plain. The catchment has been divided into 4 sub-divisions based on topography, and the location of farm dams for the purpose of modelling (see Figure 5).

Rainfall–runoff

Rainfall station M019071 Alligator Gorge has been used to represent the rainfall of Spring Creek sub-catchment. While the mean and median annual rainfall for the station is 644.7 mm and 612.2 mm respectively, the rainfall for each sub-divided sub-catchment has been estimated based on extrapolation of the annual rainfall isohyet data (Figure 7). Table 31 below shows the estimated rainfall of each sub-divided sub-catchment and its associated runoff in megalitres per square kilometre.

Table 31. Spring Creek sub-catchment estimated rainfall and runoff

No	Sub Catchment	Area (SqKm)	Average Annual Rainfall (mm)	Runoff (ML/Sqkm)	Volume Runoff Generated (ML)
1	SP1	6.8	580	30.9	212
2	SP2	16.0	560	27.5	439
3	SP3	10.7	580	30.9	332
4	SP4	19.3	540	24.3	468
Total		**52.8**	**565**	**27.5**	**1450**

The estimated average annual rainfall for the Spring Creek sub-catchment is 565 mm, which generates approximately 27.5 mm of runoff, equating to 27.5 ML/km^2. The runoff coefficient for the sub-catchment is 0.05, which is 5% of the annual rainfall. In an average rainfall year the sub-catchment is capable of generating approximately 1450 ML of surface water runoff, this value is larger than the volume of water generated in Old Booleroo sub-catchment which is 300 km^2 larger than Spring Creek sub-catchment.

Annual rainfall analysis

Figure 53 displays annual rainfall from 1889 to 2002. The highest annual rainfall occurred in 1992 and 1974 with 1204.7 mm and 1194.3 mm respectively. 1889 and 1973 followed with an annual rainfall of 1181.7 mm and 1138.7 mm respectively. The driest year was recorded in 1929 with 281.1 mm. 1994 and 1982 were the following driest years on record with an annual rainfall of 327.8 mm and 328.5 mm, which is approximately one half of the long-term average.

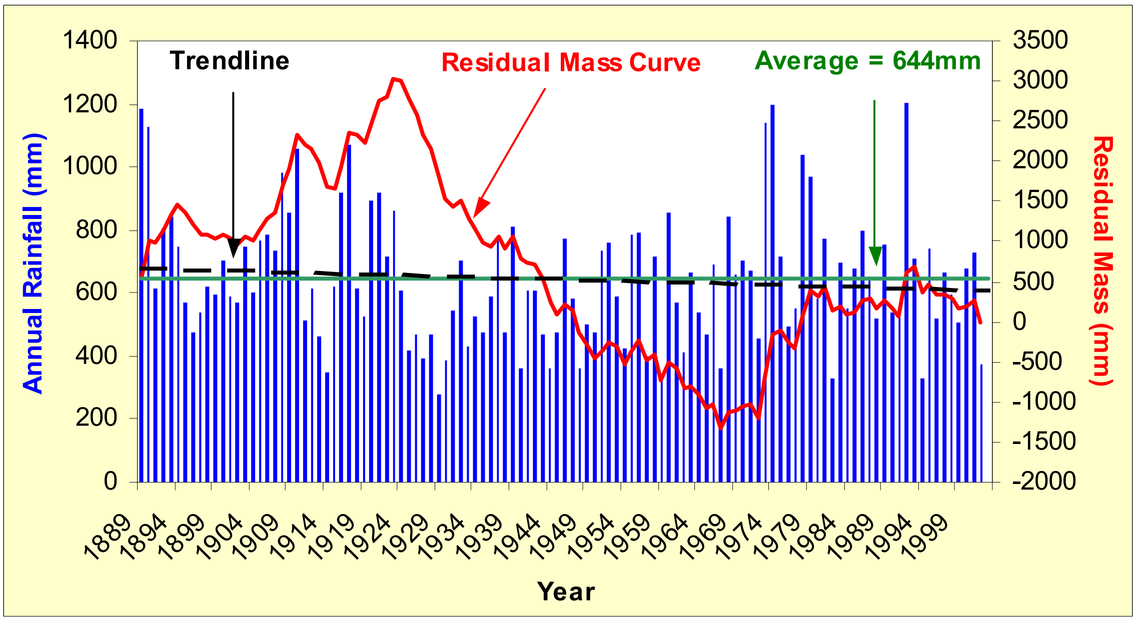


Figure 53. Spring Creek sub-catchment long-term rainfall analysis

The residual mass curve indicates above or below average rainfall periods. A positive slope is representative of periods of above average rainfall while a negative slope represents periods of below average rainfall. Above average rainfall was experienced from 1890 to mid 1920, followed by below average rainfall until late 1960. From early 1970 to mid 1990 the rainfall was above average and recently below average rainfall has been experienced.

Decadal rainfall

The average decadal rainfall has been calculated for the period 1890 to 2000. The driest decade occurred during the 1940s. The wettest decade occurred during the 1970s and is evident from Figure 54 below. While there exists some variation in the driest decade experienced between sub-catchments common with all sub-catchments is the wettest decade occurring during 1970.

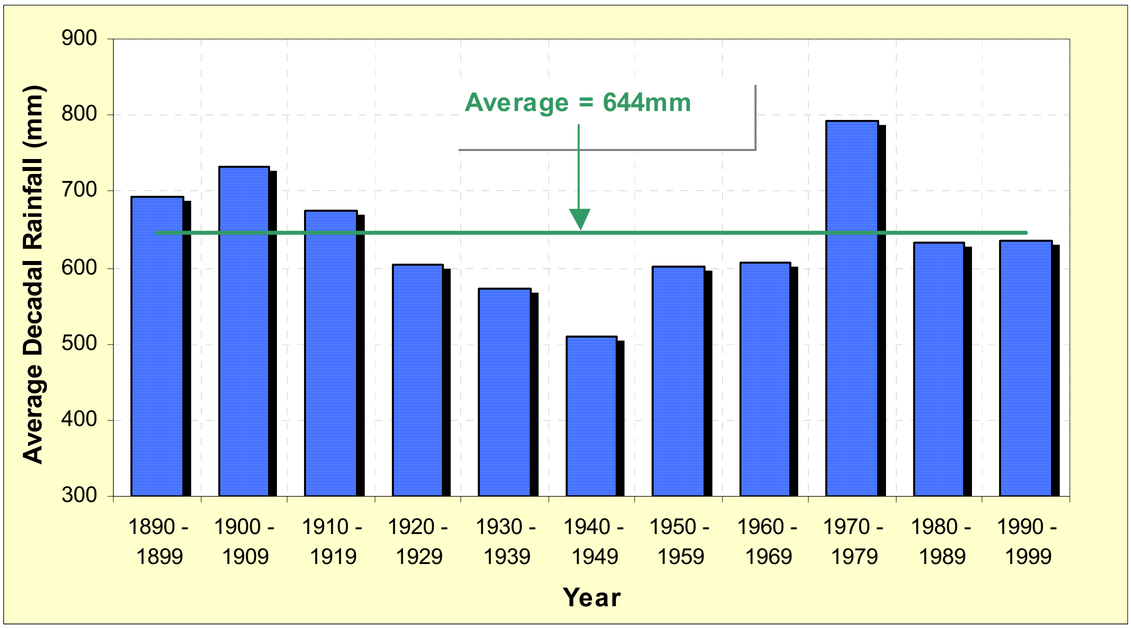


Figure 54 Spring Creek sub-catchment mean decadal rainfall

Figure 54 displays the past 2 decades close to the long-term average it is evident however, that many decades have been far drier than that experienced in recent times.

Monthly rainfall

Based on data collect from 1889 to 2002, June, July and August are the highest rainfall months followed by September. The lowest rainfall month is March. The mean monthly rainfall distribution is displayed below.

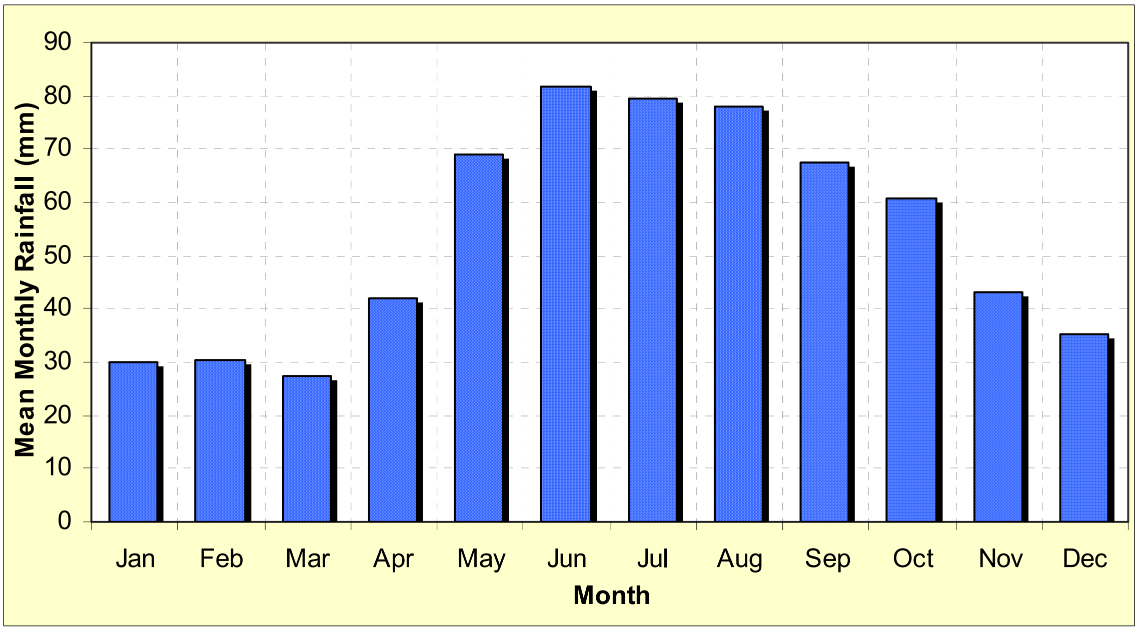


Figure 55. Spring Creek sub-catchment mean monthly rainfall

Farm dams

Based on data captured during 1987 and 1988 there are 8 farms dams within the catchment. Table 32 below displays the displays the runoff generated, dam storage capacity and the relative farm dam density of each sub-divided sub-catchments.

Table 32. Spring Creek sub-catchment farm dam density

No	Sub-Catchment	Area (SqKm)	Runoff (ML/Sqkm)	Volume Runoff Generated (ML)	Dam Capacity (ML)	Farm Dam Density (ML/Sqkm)
1	SP1	6.8	30.9	212	0	0.0
2	SP2	16.0	27.5	439	1	0.1
3	SP3	10.7	30.9	332	5	0.4
4	SP4	19.3	24.3	468	7	0.4
Total		**52.8**	**27.5**	**1450**	**13**	**0.2**

The farm dam density within the sub-catchment is low. Of the 8 dams 6 have a holding capacity less than 2 ML and 2 have a holding capacity of less than 5 ML. As evident from Table 32 the runoff greatly exceeds the farm dam density and the volume of runoff generated from each sub-division greatly exceeds the volume required to fill the farm dams.

Water diversions

Diversion of water for the purpose of flood irrigation has not been identified in this region and is unsuitable due to the topography of the sub-catchment.

Land use

The major land use in the Spring Creek sub-catchment is conservation areas that constitute 50% of the total catchment area, followed by grazing modified pasture. Figure 6 displays the land use of the sub-catchment.

Table 33. Spring Creek sub-catchment land use summary

Category	Landuse	Area (Sqkm)	Percentage
1	Crop/grazing rotation		
2	Grazing modified pastures	25.32	47.95%
3	Irrigated modified pastures		
4	Irrigated horticulure		
5	Livestock grazing (vegetation)	0.47	0.88%
6	Conservation Areas	26.36	49.93%
7	Intensive Animal Production		
8	Residential / Industrial	0.65	1.23%

Stony Creek sub-catchment

Stony Creek sub-catchment is 22.01 km^2, the catchment is located in the southwest region of the Willochra catchment, the topography is relatively steep and the elevation ranges from 340 m to 770 m. The main streams which drains the catchment is Stony Creek that flows in a northeasterly direction toward the Willochra Plain. The catchment has been divided into 4 sub-divisions based on topography, and the location of farm dams for the purpose of modelling (see Figure 5).

Rainfall–runoff

Rainfall station M019071 Alligator Gorge has been used to represent the rainfall of Stony Creek sub-catchment. While the mean and median annual rainfall for the station is 644.7 mm and 612.2 mm respectively, the rainfall for each sub-divided sub-catchment has been estimated based on extrapolation of the annual rainfall isohyet data (Figure 7). Table 34 below shows the estimated rainfall of each sub-divided sub-catchment and its associated runoff in megalitres per square kilometre.

Table 34. Stony Creek sub-catchment estimated rainfall and runoff

No	Sub Catchment	Area (SqKm)	Average Annual Rainfall (mm)	Runoff (ML/Sqkm)	Volume Runoff Generated (ML)
1	ST1	8.2	565	28.3	232
2	ST2	5.2	500	18.6	97
3	ST3	5.8	500	18.6	108
4	ST4	2.8	450	12.8	36
Total		**22.0**	**504**	**21.5**	**473**

The estimated average annual rainfall for the Stony Creek sub-catchment is 504 mm, which generates approximately 21.5 mm of runoff, equating to 21.5 ML/km^2. The runoff coefficient for the sub-catchment is 0.04, which is 4% of the annual rainfall. In an average rainfall year the sub-catchment is capable of generating approximately 470 ML of surface water runoff.

Annual rainfall analysis

Figure 56 displays annual rainfall from 1889 to 2002. The highest annual rainfall occurred in 1992 and 1974 with 1204.7 mm and 1194.3 mm respectively. 1889 and 1973 followed with an annual rainfall of 1181.7 mm and 1138.7 mm respectively. The driest year was recorded in 1929 with 281.1 mm. 1994 and 1982 were the following driest years on record with an annual rainfall of 327.8 mm and 328.5 mm.

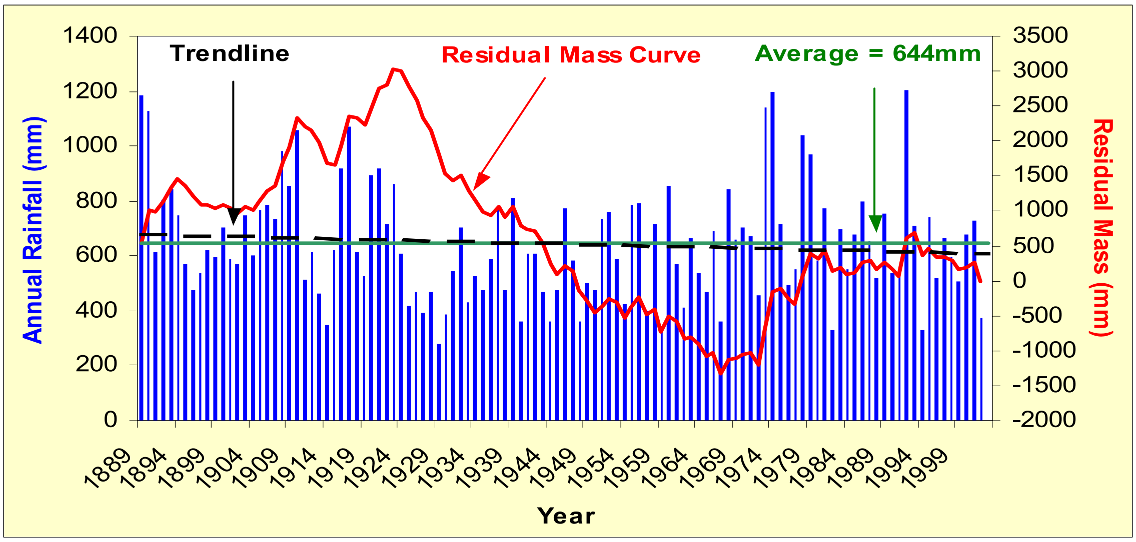


Figure 56. Stony Creek sub-catchment long-term rainfall analysis

The residual mass curve indicates above or below average rainfall periods. A positive slope is representative of period of above average rainfall while a negative slope represents periods of below average rainfall. Above average rainfall was experienced from 1890 to mid 1920, followed by below average rainfall until late 1960. From early 1970 to mid 1990 the rainfall was above average and recently below average rainfall has been experienced.

Decadal rainfall

The average decadal rainfall has been calculated for the period 1890 to 2000. The driest decade occurred during the 1940s. The wettest decade occurred during the 1970s and is evident from Figure 57 below. While there exists some variation in the driest decade experienced between sub-catchments common with all sub-catchments is the wettest decade occurring during 1970.

Figure 57 displays the past 2 decades close to the long-term average it is evident however, that many decades have been far drier than that experienced in recent times.

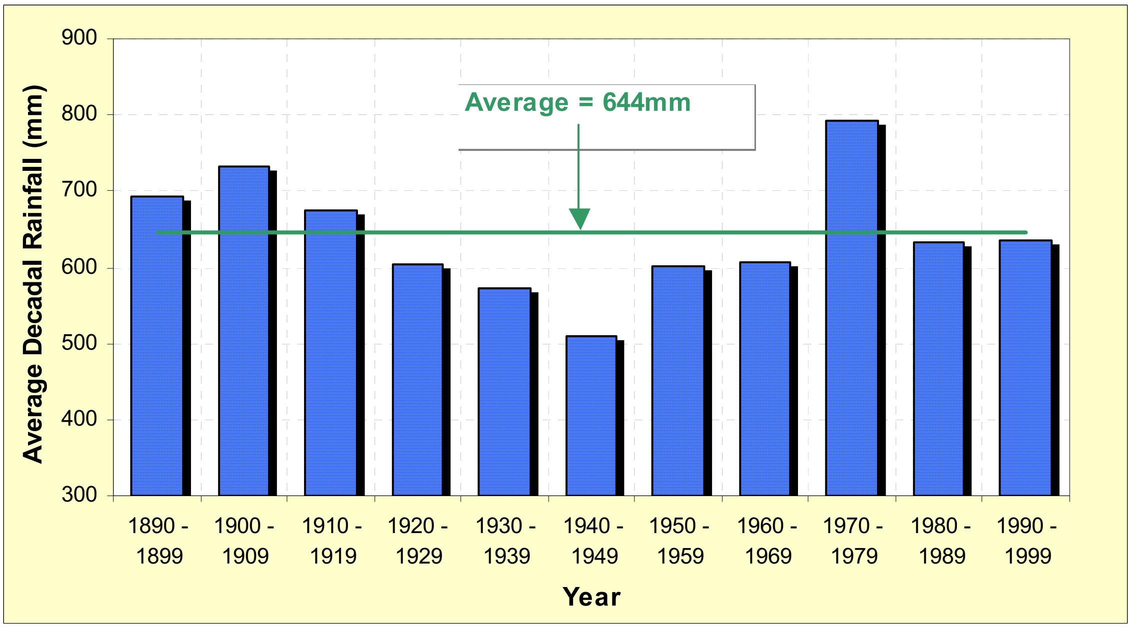


Figure 57. Stony Creek sub-catchment mean decadal rainfall

Monthly rainfall

Based on data collect from 1889 to 2002, June, July and August are the highest rainfall months followed by September. The lowest rainfall month is March. The mean monthly rainfall distribution is displayed below.

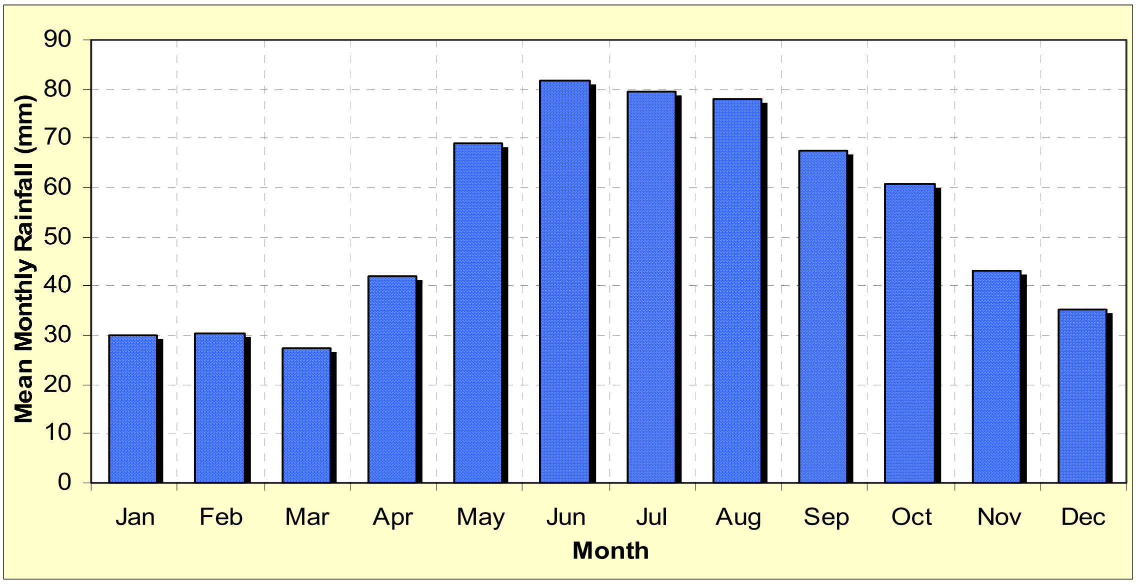


Figure 58. Stony Creek sub-catchment mean monthly rainfall

Farm dams

Based on data captured during 1987 and 1988 there are 8 farms dams within the sub-catchment. Table 35 below displays the runoff generated, dam storage capacity and the relative farm dam density of each sub-divided sub-catchments.

Table 35. Stony Creek sub-catchment farm dam density

No	Sub-Catchment	Area (SqKm)	Runoff (ML/Sqkm)	Volume Runoff Generated (ML)	Dam Capacity (ML)	Farm Dam Density (ML/Sqkm)
1	ST1	8.2	28.3	232	3	0.3
2	ST2	5.2	18.6	97	6	1.2
3	ST3	5.8	18.6	108	2	0.4
4	ST4	2.8	12.8	36	2	0.9
Total		**22.0**	**21.5**	**473**	**14**	**0.6**

The farm dam density within the sub-catchment is low. Of the 8 dams 6 have a holding capacity less than 2 ML and 2 have a holding capacity of less than 5 ML. All sub-divisions are far from the sustainable development limit, which in non-prescribed areas is 50% of the (median) runoff generated within a given area. Table 35 shows that the runoff generated (in ML/km^2) in each of the sub-catchments sub-divisions greatly exceeds the farm dam density (in ML/km^2)

Water diversions

Diversion of water for the purpose of flood irrigation has not been identified in this region and is unsuitable due to the topography of the sub-catchment.

Land use

The major land use in the Stony Creek sub-catchment is conservation areas that constitute 38% of the total catchment area, followed by livestock grazing (vegetation) with 30% of the catchment area. Figure 6 displays the land use of the sub-catchment.

Table 36. Stony Creek sub-catchment land use summary

Category	Landuse	Area (Sqkm)	Percentage
1	Crop/grazing rotation	2.76	12.53%
2	Grazing modified pastures	3.95	17.96%
3	Irrigated modified pastures		
4	Irrigated horticulure		
5	Livestock grazing (vegetation)	6.51	29.59%
6	Conservation Areas	8.26	37.56%
7	Intensive Animal Production		
8	Residential / Industrial	0.52	2.36%

Wild Dog Creek sub-catchment

Wild Dog Creek sub-catchment is 101.28 km^2, the catchment is located in the southern region of the Willochra catchment, the topography is undulating and the elevation ranges from 330 m to 530 m. The main streams that drain the catchment are Dog Trap Gully Creek, Pine Creek and Wild Dog Creek. The flow is in a northerly direction toward the Willochra Plain. The sub-catchment has been divided into 8 sub-divisions based on topography, and the location of farm dams for the purpose of modelling (see Figure 5).

Rainfall–runoff

Rainfall station M019011 Doughboy Creek has been used to represent the rainfall of Wild Dog Creek sub-catchment. While the mean and median annual rainfall for the station M019011 is 446.1 mm and 442.7 mm respectively, the rainfall for each sub-divided sub-catchment has been estimated based on extrapolation of the annual rainfall isohyet data (Figure 7). Table 37 below shows the estimated rainfall of each sub-divided sub-catchment and its associated runoff in megalitres per square kilometre.

Table 37. Wild Dog Creek sub-catchment estimated rainfall and runoff

No	Sub Catchment	Area (SqKm)	Average Annual Rainfall (mm)	Runoff (ML/Sqkm)	Volume Runoff Generated (ML)
1	WD1	17.5	470	15.0	262
2	WD2	17.0	445	12.3	210
3	WD3	7.2	470	15.0	107
4	WD4	4.1	475	15.6	63
5	WD5	3.2	475	15.6	50
6	WD6	0.8	475	15.6	12
7	WD7	26.7	450	12.8	343
8	WD8	24.9	448	12.6	314
Total		**101.3**	**464**	**13.4**	**1361**

T

The estimated average annual rainfall for the Wild Dog Creek sub-catchment is 564 mm, which generates approximately 13.4 mm of runoff, equating to 13.4 ML/km^2. The runoff coefficient for the sub-catchment is 0.03, which is 3% of the annual rainfall. In an average rainfall year the sub-catchment is capable of generating approximately 1360 ML of surface water runoff. Wild Dog Creek sub-catchment is the second largest water generating catchment within the Southern Willochra catchment.

Annual rainfall analysis

Figure 59 displays annual rainfall from 1889 to 2002. The highest annual rainfall occurred in 1992 with 884.4 mm. The driest year was recorded in 1914 with 212.2 mm.

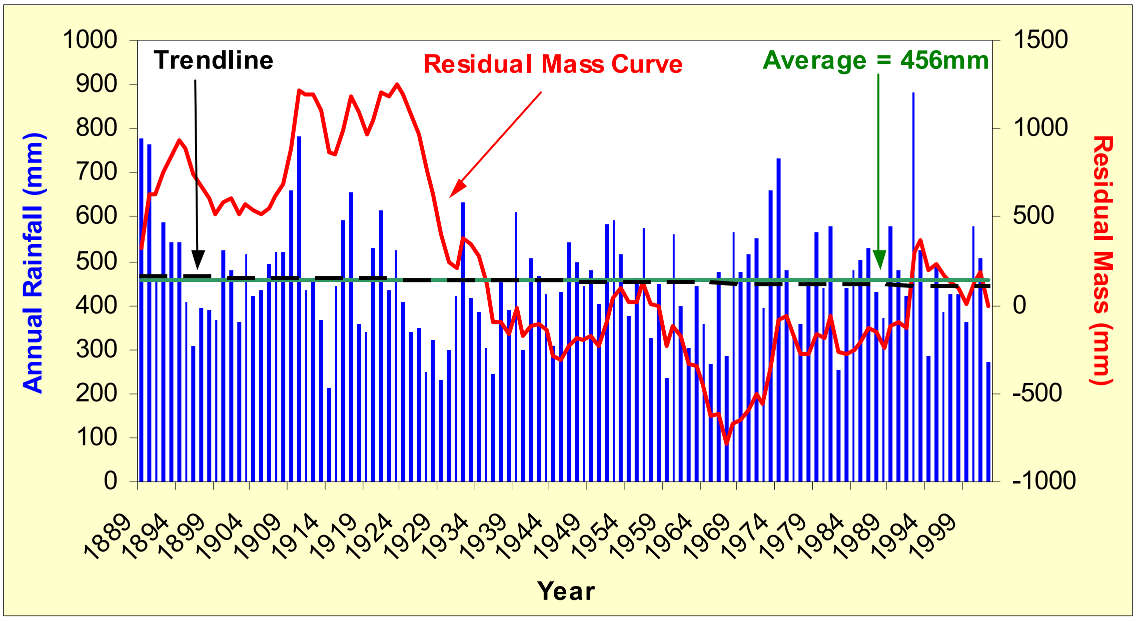


Figure 59. Wild Dog Creek sub-catchment long-term rainfall analysis

The residual mass curve indicates above or below average rainfall periods. A positive slope is representative of period of above average rainfall while a negative slope represents periods of below average rainfall. Generally above average rainfall is evident from 1890 to mid 1920 followed by below average rainfall from mid 1920 to late 1960. Above average rainfall is evident from early 1970 to early 1990, followed by below average from mid 1990 to 2002.

Decadal rainfall

The average decadal rainfall has been calculated for the period 1890 to 2000. The driest decade occurred during the 1920s, this period varies between the sub-catchments quite substantially, and it is interesting to note also that the largest flood event in the past 113 years occurred in 1921 however, due to the extreme below average rainfall years which followed the 1920s remained the driest decade in the sub-catchment region. The wettest decade occurred during the 1970s and is evident from Figure 60. While there exists some variation in the driest decade experienced between sub-catchments common with all sub-catchments is the wettest decade occurring during 1970.

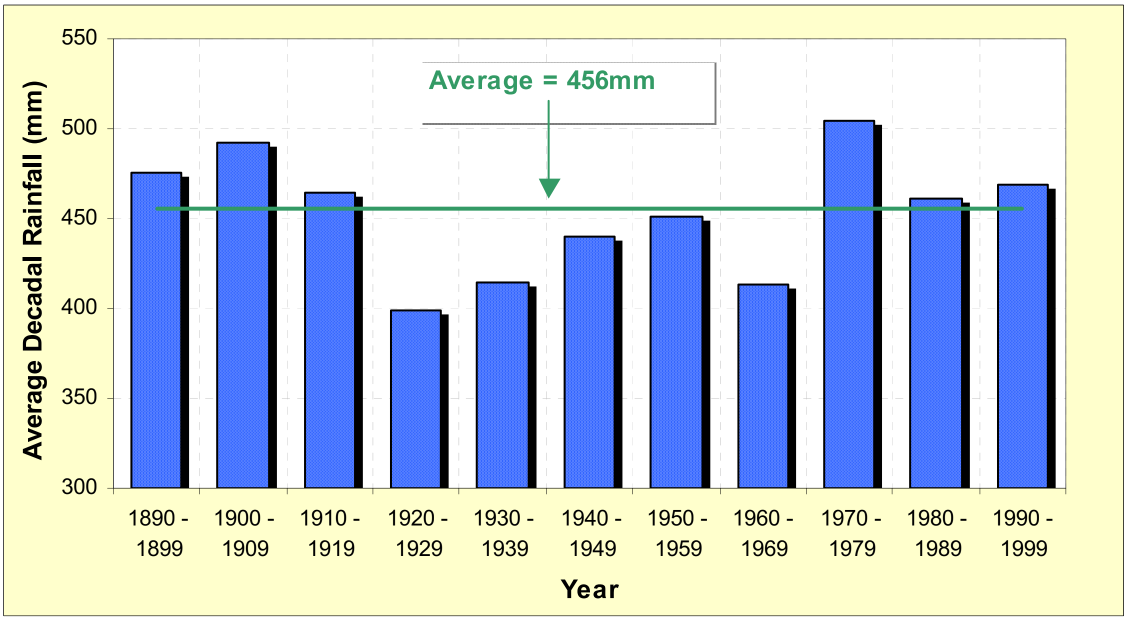


Figure 60. Wild Dog Creek sub-catchment mean decadal rainfall

Monthly rainfall

Based on data collect from 1889 to 2002, June, July and August are the highest rainfall months followed by September. The lowest rainfall month is March. The mean monthly rainfall distribution is displayed below.

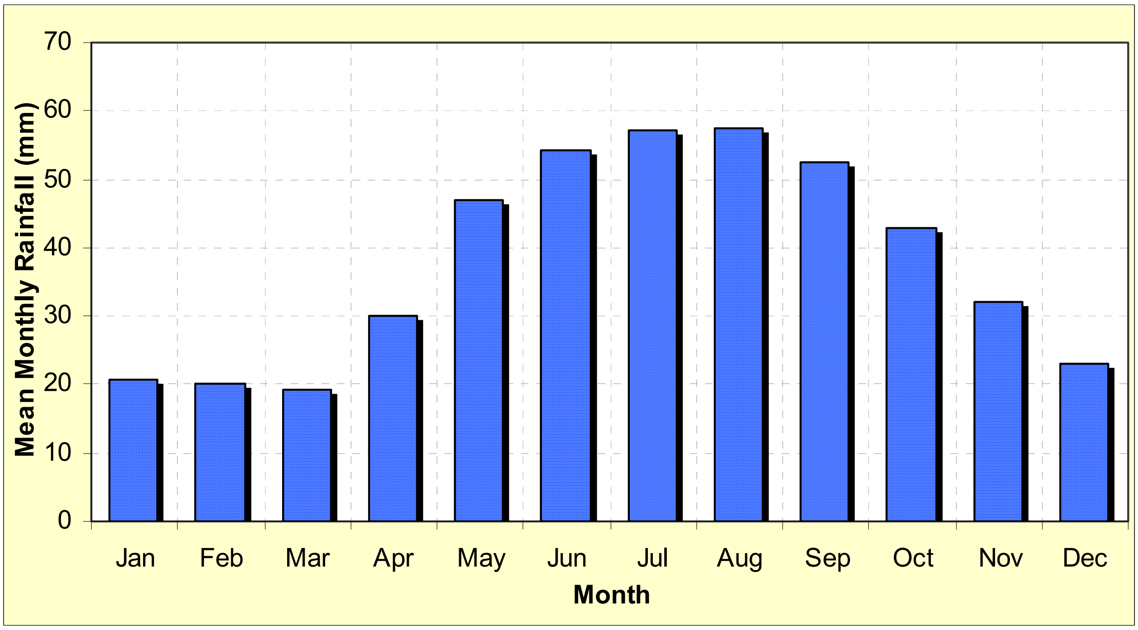


Figure 61. Wild Dog Creek sub-catchment mean monthly rainfall

Farm dams

Based on data captured during 1987 and 1988 there are 152 farms dams within the sub-catchment. Table 38 below displays the runoff generated, dam storage capacity and the relative farm dam density of each sub-divided sub-catchments.

Table 38. Wild Dog Creek sub-catchment farm dam density

No	Sub-Catchment	Area (SqKm)	Runoff (ML/Sqkm)	Volume Runoff Generated (ML)	Dam Capacity (ML)	Farm Dam Density (ML/Sqkm)
1	WD1	17.5	15.0	262	78	4
2	WD2	17.0	12.3	210	29	2
3	WD3	7.2	15.0	107	42	6
4	WD4	4.1	15.6	63	24	6
5	WD5	3.2	15.6	50	9	3
6	WD6	0.8	15.6	12	70	92
7	WD7	26.7	12.8	343	49	2
8	WD8	24.9	12.6	314	38	2
Total		**101.3**	**13.4**	**1361**	**341**	**3**

Of the 152 farm dams, 113 have a holding capacity of less than 2 ML, 32 farm dams have a holding capacity of less than 5 ML, and 5 have a holding capacity between 5 ML – 10 ML. The remaining 2 dams hold 11 ML and 68 ML. The 68 ML dam maybe incorrect and requires field investigation however, assuming the data is correct sub-division WD6 has the highest farm dam density of 92 ML/km^2, the corresponding runoff generated is 15.6 ML/km^2 consequently it is likely (if the data is correct) that all the water generated in this sub-catchment is captured.

Sub-divisions WD3 and WD4 have a farm dam density of 6 ML/km^2 and generate an estimated average runoff of 15.0 ML/km^2 and 15.6 ML/km^2 both of these sub-divisions are approaching their sustainable development limit which is 50% of the median runoff generated for the given area. The data in Table 38 is the estimated average runoff not the median that is generally less than the average. It may be possible that these sub-divisions are at or have exceeded their sustainable development limit.

The total farm dam density for the sub-catchment is 3 ML/km^2 with a corresponding runoff of 13.4 ML/km^2. On a sub-catchment scale the sustainable development limit is not exceeded however, one needs to consider the health of the sub-divisions within the sub-catchment.

Water diversions

Aerial videography conducted in June 2003 revealed in-stream diversion structures capable of diverting water for the purpose of flood irrigation. It has been conservatively estimated that approximately 50 ML to 90 ML of water is diverted from sub-division WD4. If this volume is added to the farm dam capacity then the total estimated water used within WD4 is between 70 to 110 ML, the corresponding runoff generated from WD4 is only 63 ML. The sustainable development limit for sub-division WD4 is clearly exceeded.

Land use

The major land use in the Wild Dog Creek sub-catchment is crop/grazing rotation and grazing modified pasture that constitutes 94% of the total catchment area. Figure 6 displays the land use of the sub-catchment.

Table 39. Wild Dog Creek sub-catchment land use summary

Category	Landuse	Area (Sqkm)	Percentage
1	Crop/grazing rotation	61.24	60.46%
2	Grazing modified pastures	34.25	33.82%
3	Irrigated modified pastures		
4	Irrigated horticulure		
5	Livestock grazing (vegetation)	2.86	2.82%
6	Conservation Areas		
7	Intensive Animal Production		
8	Residential / Industrial	2.93	2.90%

Willochra Creek sub-catchment

Willochra Creek sub-catchment is 165.82 km^2, the catchment is located in the south-central region of the Southern Willochra catchment, the topography varies considerably, and is steep on the western bound with elevation ranging from 950 m to 350 m. From the base of Mt Remarkable the land flattens and elevation ranges from 480 m to 270 m. The main streams within the catchment are Rotten Creek, Spring Creek and Willochra Creek. Willochra Creek flows in a northerly direction to the Willochra Plain. The sub-catchment has been divided into 7 sub-divisions based on topography, and the location of farm dams and diversion structures for the purpose of modelling (see Figure 5).

Rainfall–runoff

Rainfall station M019042 Melrose Para Gums has been used to represent the rainfall of Willochra Creek sub-catchment. While the mean and median annual rainfall for the station M019042 is 462.4 mm and 439.0 mm respectively, the rainfall for each sub-divided sub-catchment has been estimated based on extrapolation of the annual rainfall isohyet data (Figure 7). Table 40 below shows the estimated rainfall of each sub-divided sub-catchment and its associated runoff in mega litres per square kilometre.

Sub-divisions WC2, WC5, WC6 and WC7 occupy plains regions of the Willochra Creek sub-catchment where runoff is negligible (with the exception of extreme rainfall events) therefore, it is assumed that no runoff is generated from these regions. The estimated average annual rainfall for the Willochra Creek sub-catchment is 437 mm, which generates approximately 4.8 mm of runoff, equating to 4.8 ML/km^2. The runoff coefficient for the sub-catchment is low at 0.01, which is 1% of the annual rainfall. In an average rainfall year the sub-catchment is capable of generating approximately 800 ML of surface water runoff.

Table 40. Willochra Creek sub-catchment estimated rainfall and runoff

No	Sub Catchment	Area (SqKm)	Average Annual Rainfall (mm)	Runoff (ML/Sqkm)	Volume Runoff Generated (ML)
1	WC1	19.2	520	21.3	409
2	WC2	7.9	410	0.0	0
3	WC3	38.2	400	8.3	319
4	WC4	3.8	510	20.0	75
5	WC5	17.5	420	0.0	0
6	WC6	49.9	400	0.0	0
7	WC7	29.4	400	0.0	0
Total		**165.8**	**437**	**4.8**	**803**

Annual rainfall analysis

Figure 62 displays annual rainfall from 1889 to 2002. The highest annual rainfall occurred in 1974, 1973 and 1992 with 909.5 mm, 831.2 mm and 822.7 mm respectively. The driest year was recorded in 1929 with 224.7 mm. Of the 6 driest years on record, 3 occurred in the last 20 years and are 1982, 1994 and 2002 with 240.4 mm, 227.2 mm and 254.6 mm respectively.

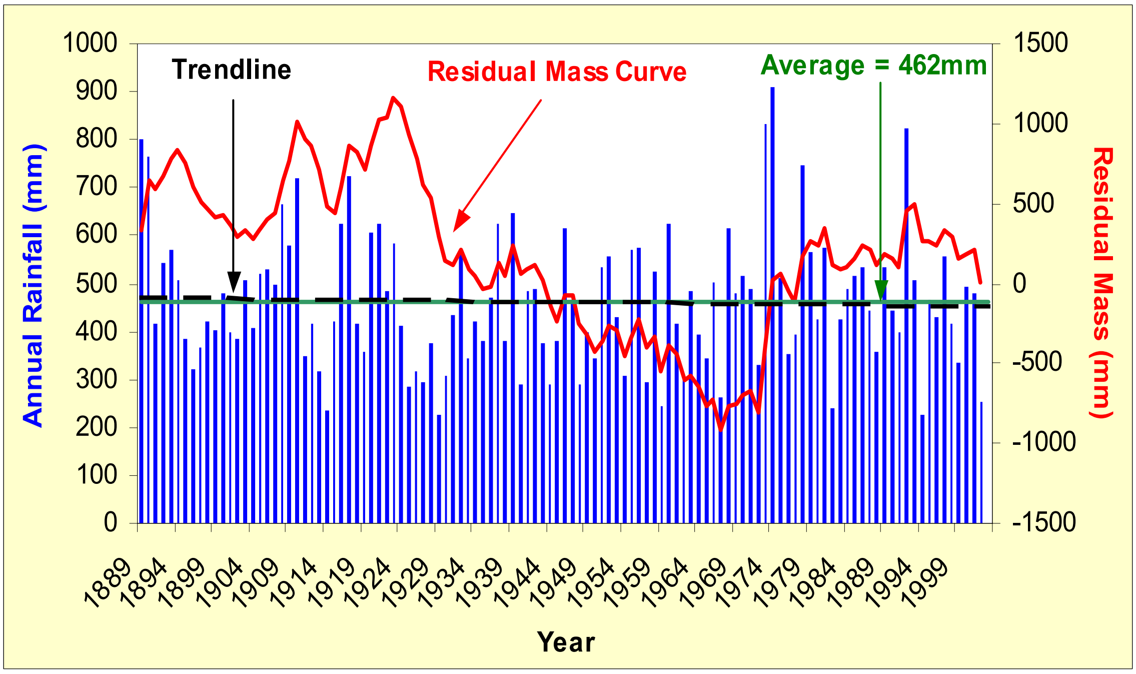


Figure 62. Willochra Creek sub-catchment long-term rainfall analysis

The residual mass curve indicates above or below average rainfall periods. A positive slope is representative of period of above average rainfall while a negative slope represents periods of below average rainfall. Generally above average rainfall is evident from 1890 to mid 1920, followed by below average rainfall until late 1960. From early 1970 to mid 1990 there is an upward trend in the rainfall and above average rainfall was experienced and since mid 1990 to 2002 the rainfall has been below average.

Decadal rainfall

The average decadal rainfall has been calculated for the period 1890 to 2000. The driest decade occurred during the 1940s. The wettest decade occurred during the 1970s and is evident from Figure 63. The last two decades where close to the long-term average, and are far from the direst conditions experienced within the sub-catchment.

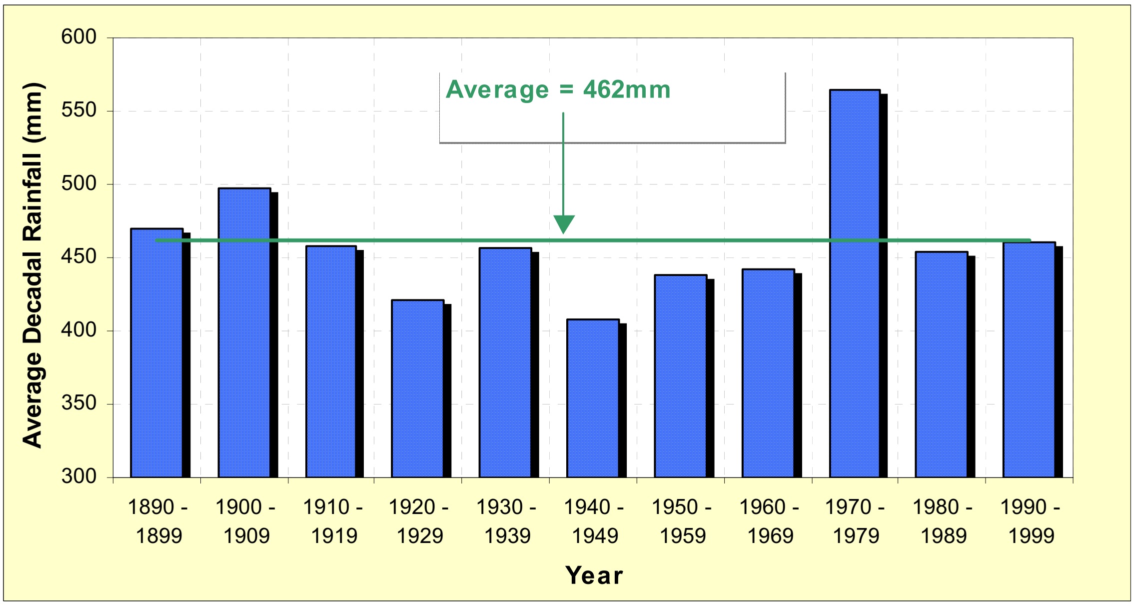


Figure 63. Willochra Creek sub-catchment mean decadal rainfall

Monthly rainfall

Based on data collect from 1889 to 2002, June, July and August are the highest rainfall months followed by September. The lowest rainfall month is March. The mean monthly rainfall distribution is displayed below.

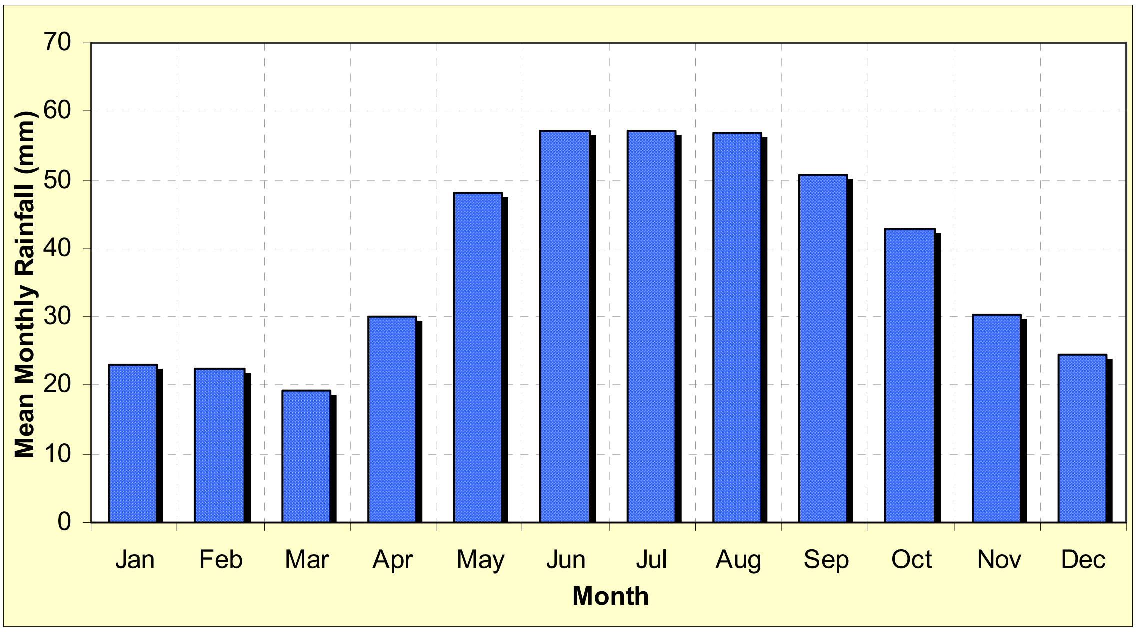


Figure 64. Willochra Creek sub-catchment mean monthly rainfall

Farm dams

Based on data captured during 1987 and 1988 there are 70 farms dams within the sub-catchment. Table 41 below displays the runoff generated, dam storage capacity and the relative farm dam density of each sub-divided sub-catchments.

Table 41. Willochra Creek sub-catchment farm dam density

No	Sub-Catchment	Area (SqKm)	Runoff (ML/Sqkm)	Volume Runoff Generated (ML)	Dam Capacity (ML)	Farm Dam Density (ML/Sqkm)
1	WC1	19.2	21.3	409	3	0.2
2	WC2	7.9	0.0	0	0	0.0
3	WC3	38.2	8.3	319	49	1.3
4	WC4	3.8	20.0	75	0	0.0
5	WC5	17.5	0.0	0	21	1.2
6	WC6	49.9	0.0	0	41	0.8
7	WC7	29.4	0.0	0	13	0.4
Total		**165.8**	**4.8**	**803**	**128**	**0.8**

The greatest developed sub-division within the sub-catchment is WC3 with a farm dam density of 1.2 ML/km^2 and corresponding runoff of 8.3 ML/km^2. The farm dam density with in the sub-catchment is low. Of the 70 dams 67 have a holding capacity less than 5 ML and the remaining 3 farm dams have a holding capacity of greater than 5 ML and less than 10 ML.

Water diversions

Aerial videography data captured in June 2003, and information provided by landholders confirmed that water is diverted from streams for the purpose of flood irrigation. A conservative estimate of the volume of water used for flood irrigation is approximately between 1800 ML and 2700 ML, with 700 ML to 1000 ML potentially diverted from sub-division WC5 and the remaining 1000 ML to 1500 ML potentially diverted from WC6. Appendix H details the methodology used for determining the volumes of water used for flood irrigation.

If the volume of water attributed to flood irrigation is added to the farm dam holding capacity then the relative farm dam density is around 15 ML/km^2 and is far greater than the runoff generated in the sub-catchment, which is only 4.8 ML/km^2. Clearly the water used for flood irrigation is sourced from sub-catchments that drain to the Willochra sub-catchment. If these sub-catchments were developed to their sustainable development limit the water used for flood irrigation would not be available. The farm dam density value of 15 ML/km^2 is comparable to that experienced in regions of the Mt Lofty Ranges which have greater runoff coefficients and higher rainfall.

If flood irrigation occurs annually and not opportunistically (when conditions are well above average) it is highly probable that no water will be available for downstream water users or the environment.

Land use

The major land use in the Willochra Creek sub-catchment is crop / grazing rotation and grazing modified pastures that constitute 82% of the total catchment area, followed by conservation areas that constitute almost 12% of the catchment area. Figure 6 displays the land use of the sub-catchment.

Table 42. Willochra Creek sub-catchment land use summary

Category	Landuse	Area (Sqkm)	Percentage
1	Crop/grazing rotation	71.26	42.97%
2	Grazing modified pastures	64.29	38.77%
3	Irrigated modified pastures	2.00	1.21%
4	Irrigated horticulure		
5	Livestock grazing (vegetation)	4.70	2.83%
6	Conservation Areas	19.06	11.49%
7	Intensive Animal Production		
8	Residential / Industrial	4.51	2.72%

Irrigated modified pasture is displayed to account for only 1.2% of the total catchment area, this is misleading as the land use data collected in 1999 failed to identify areas that are flood irrigated as irrigated modified pastures.

Yellowman Creek sub-catchment

Yellowman Creek sub-catchment is 23.1 km^2, the catchment is located in the southern region of the Willochra catchment, the topography is undulating and the elevation ranges from 600 m to 340 m. The main stream that drains the catchment is Yellowman Creek. The flow is in a northeasterly direction toward the Willochra Plain. The sub-catchment has been divided into 4 sub-divisions based on topography, and the location of farm dams for the purpose of modelling. (see Figure 5).

Rainfall–runoff

Rainfall station M019042 Melrose Para Gums has been used to represent the rainfall of Willochra Creek sub-catchment. While the mean and median annual rainfall for the station M019042 is 462.4 mm and 439.0 mm respectively, the rainfall for each sub-divided sub-catchment has been estimated based on extrapolation of the annual rainfall isohyet data (Figure 7). Table 43 below shows the estimated rainfall of each sub-divided sub-catchment and its associated runoff in mega litres per square kilometre.

Table 43. Yellowman Creek sub-catchment estimated rainfall and runoff

No	Sub Catchment	Area (SqKm)	Average Annual Rainfall (mm)	Runoff (ML/Sqkm)	Volume Runoff Generated (ML)
1	YM1	3.1	512	20.2	62
2	YM2	8.1	490	17.4	141
3	YM3	3.3	500	18.6	62
4	YM4	8.6	470	15.0	128
Total		**23.1**	**493**	**17.0**	**393**

The estimated average annual rainfall for the Yellowman Creek sub-catchment is 493 mm, which generates approximately 17.0 mm of runoff, equating to 17.0 ML/km^2. The runoff coefficient for the sub-catchment is 0.03, which is 3% of the annual rainfall. In an average rainfall year the sub-catchment is capable of generating approximately 390 ML of surface water runoff.

Annual rainfall analysis

Figure 65 displays annual rainfall from 1889 to 2002. The highest annual rainfall occurred in 1974, 1973 and 1992 with 909.5 mm, 831.2 mm and 822.7 mm respectively. The driest year was recorded in 1929 with 224.7 mm. Of the 6 driest years on record, 3 occurred in the last 20 years and are 1982, 1994 and 2002 with 240.4 mm, 227.2 mm and 254.6 mm respectively.

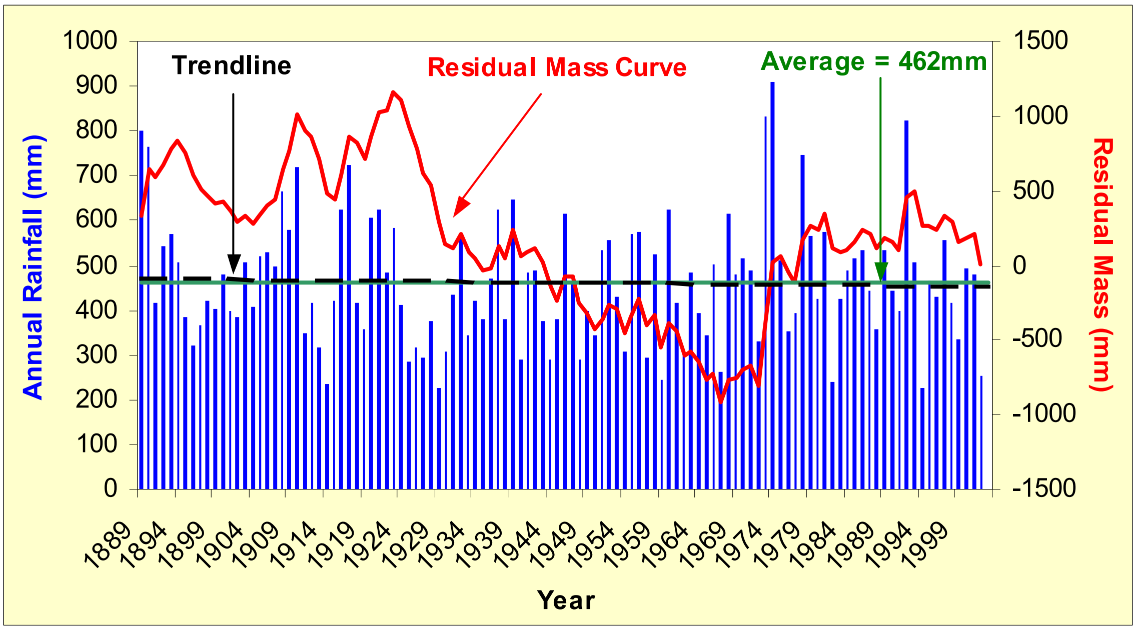


Figure 65. Yellowman Creek sub-catchment long-term rainfall analysis

The residual mass curve indicates above or below average rainfall periods. A positive slope is representative of period of above average rainfall while a negative slope represents periods of below average rainfall. Generally above average rainfall is evident from 1890 to mid 1920, followed by below average rainfall until late 1960. From early 1970 to mid 1990 there is an upward trend in the rainfall and above average rainfall was experienced and since mid 1990 to 2002 the rainfall has been below average.

Decadal rainfall

The average decadal rainfall has been calculated for the period 1890 to 2000. The driest decade occurred during the 1940s. The wettest decade occurred during the 1970s and is evident from Figure 66.

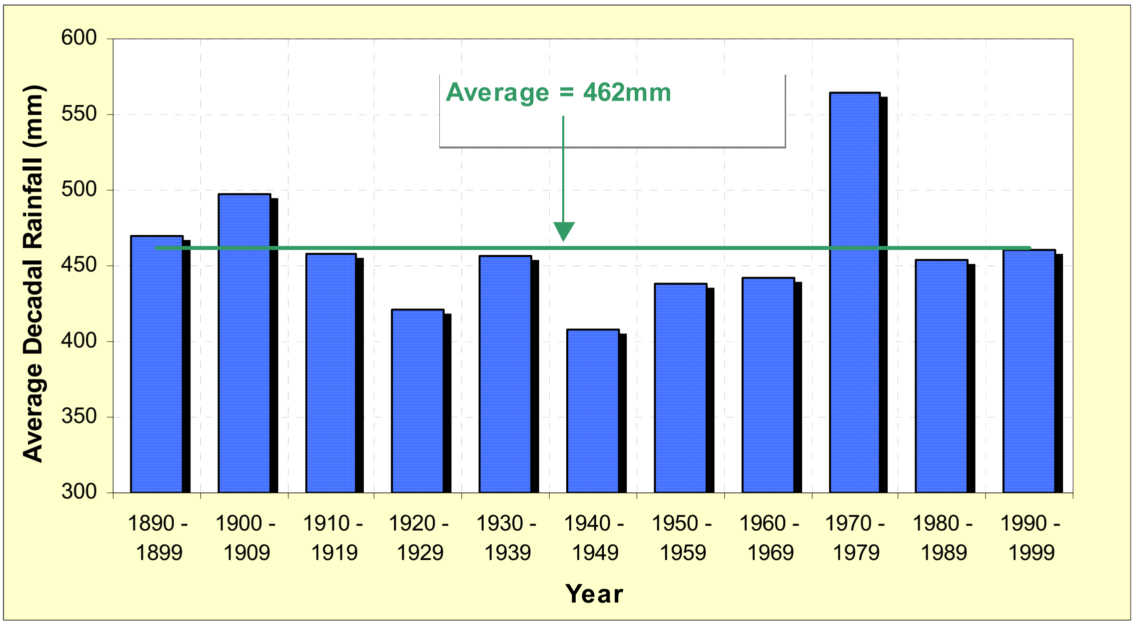


Figure 66. Yellowman Creek sub-catchment mean decadal rainfall

Monthly rainfall

Based on data collect from 1889 to 2002, June, July and August are the highest rainfall months followed by September. The lowest rainfall month is March. The mean monthly rainfall distribution is displayed below.

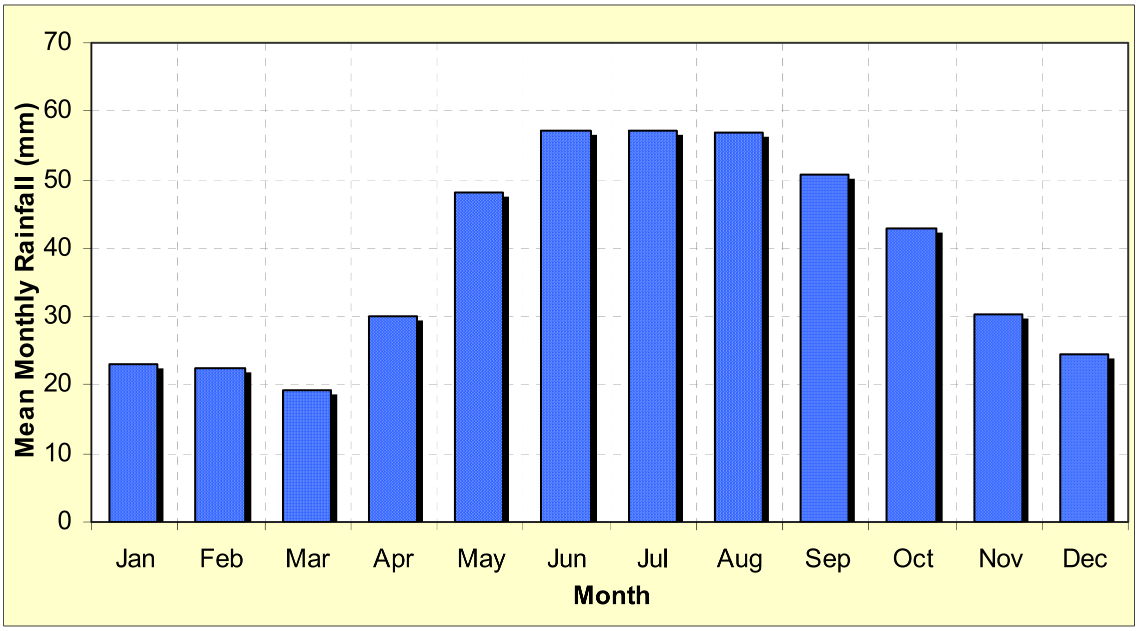


Figure 67. Yellowman Creek sub-catchment mean monthly rainfall

Farm dams

Based on data captured during 1987 and 1988 there are 33 farms dams within the sub-catchment. Table 44 below displays the runoff generated, dam storage capacity and the relative farm dam density of each sub-divided sub-catchments.

Table 44. Yellowman Creek sub-catchment farm dam density

No	Sub-Catchment	Area (SqKm)	Runoff (ML/Sqkm)	Volume Runoff Generated (ML)	Dam Capacity (ML)	Farm Dam Density (ML/Sqkm)
1	YM1	3.1	20.2	62	8	3
2	YM2	8.1	17.4	141	21	3
3	YM3	3.3	18.6	62	4	1
4	YM4	8.6	15.0	128	17	2
Total		**23.1**	**17.0**	**393**	**51**	**2**

Of the 33 farm dams, 26 have a holding capacity of less than 2 ML, 6 farm dams have a holding capacity of greater than 2 ML and less than 3 ML, and the remaining farm dam has a holding capacity 7.4 ML. The total farm dam density is 2 ML/km^2 and is relatively low and is within the sustainable development limit as the corresponding estimated sub-catchment runoff is 17.0 ML/km^2.

Water diversions

Diversion of water for the purpose of flood irrigation has not been identified within the sub-catchment.

Land use

The major land use in the Yellowman Creek sub-catchment is crop / grazing rotation and grazing modified pasture that constitutes 98% of the total catchment area. Figure 4 displays the land use of the sub-catchment.

Table 45. Yellowman Creek sub-catchment land use summary

Category	Landuse	Area (Sqkm)	Percentage
1	Crop/grazing rotation	6.68	28.99%
2	Grazing modified pastures	15.98	69.32%
3	Irrigated modified pastures		
4	Irrigated horticulure		
5	Livestock grazing (vegetation)		
6	Conservation Areas		
7	Intensive Animal Production		
8	Residential / Industrial	0.39	1.69%

APPENDIX F. ACTS AND SPECIFICATION FOR CONSTRUCTION AND MAINTENANCE OF WELLS

There are provisions within the *Water Resources Act 1997,* and the General Specifications for Well Construction, Modification and Abandonment in South Australia related to the construction and maintenance of wells and protection of the water resource from wastage, pollution, deterioration or undue depletion. The relevant sections of the *Specifications* and *Act* are detailed below:

- In accordance with section 1.4 of the General Specifications for Well Construction an appropriately licensed well driller must carry out well construction in accordance with sound well drilling practice to ensure the long-term economic production of groundwater of the best possible quality and the protection of the groundwater resource from wastage, pollution deterioration and undue depletion.

- In accordance with section 3.2 of the General Specifications for Well Construction the well driller shall ensure that the well is capped or equipped in such a way as to completely control artesian water.

- In accordance with section 1.5 of the General Specifications for Well Construction an inspector may by written notice to the well driller, delay construction of a well or direct the modification of an operation if the inspector is satisfied that the construction will not achieve the long-term economic production of groundwater of the best possible quality and will not protect the resource from wastage, pollution, deterioration or undue depletion.

- Pursuant to section 27 of the *Water Resources Act 1997,* the occupier of land on which a well is situated must ensure that the well (including the casing, lining, and screen of the well and the mechanism (if any) used to cap the well) are properly maintained.

- Pursuant to section 28 of the *Water Resources Act 1997* where the Minister is satisfied that the water of a well is likely to be degraded or wasted because - (c) there is no mechanism for capping the well or the mechanism for capping the well is inadequate or in need of maintenance, the Minister may, by notice served on the owner or occupier of the land on which the well is situated direct that the work or other action specified on the notice be carried out or taken to remedy the problem.

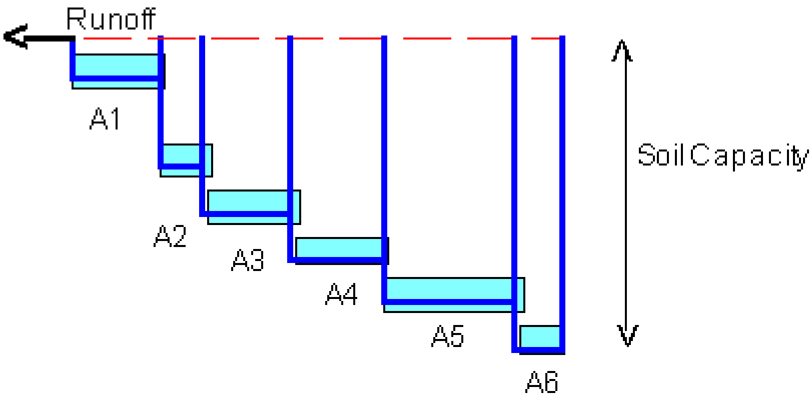
Further information regarding the *Water Resources Act 1997* is available from the following website: www.dwr.sa.gov.au/water/legislation/resource_act.html

APPENDIX G. WC1 MODEL DESCRIPTION (CRESSWELL 2002)

The following information was accessed on 30 December 2003 from website: www.waterselect.com.au/watercress/webhelp/webhelpstart.htm.

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

The model is based on the typical lumped parameter Boughton model using a partial area method. The idea for the model came from a paper " " written by Boughton in 19xx that described how the runoff process could be simulated by a number of storages of differing capacities and areas

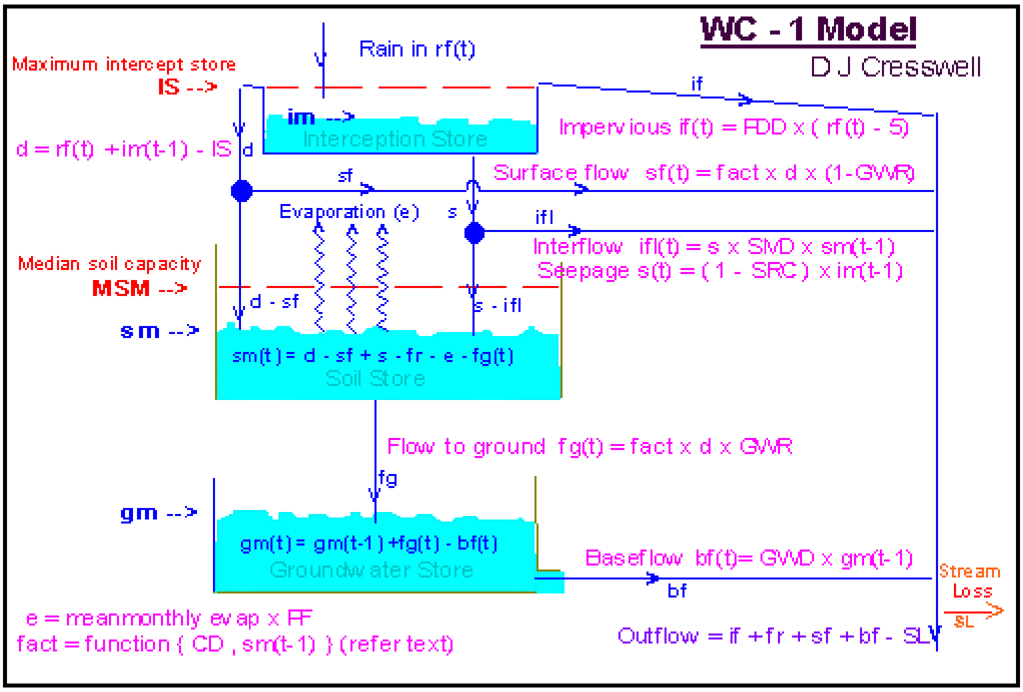


Another model AWBM, created by Boughton possibly about the same time also adopts this concept of variable storage across the catchment but handles it in a different way to WC-1. The AWBM model was not known to the author when WC was developed but it is considered that the concepts utilised by AWBM and WC-1 are likely to produce the best results for semi-arid catchments.

The two models utilise the principles in different ways and each offer advantages and disadvantages which are discussed within the description of the AWBM model.

Model concept

The model is a 10 parameter model using 3 storages as shown in Figure 6.1.2(b) to track interception, soil moisture and groundwater. The soil store is generally the main runoff producing component requiring 4 parameters for calibration.



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

By far the greatest proportion of surface flow is by calculating the saturated surface area of the catchment. To do this, rather than track numerous soil storages as shown in Figure 6.1.2(a) the model tracks just one and calculates the area saturated based on the assumption that the soil moisture holding capacity is normally distributed across the catchment. This is shown in Figure 6.1.2(c).

To calibrate such a model, two parameters are required, the median soil moisture of the catchment (MSM) and the catchment standard distribution (CD). Typically these values are found to lie between 150 to 250 mm (MSM) and 20 to 80 mm (CD).

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

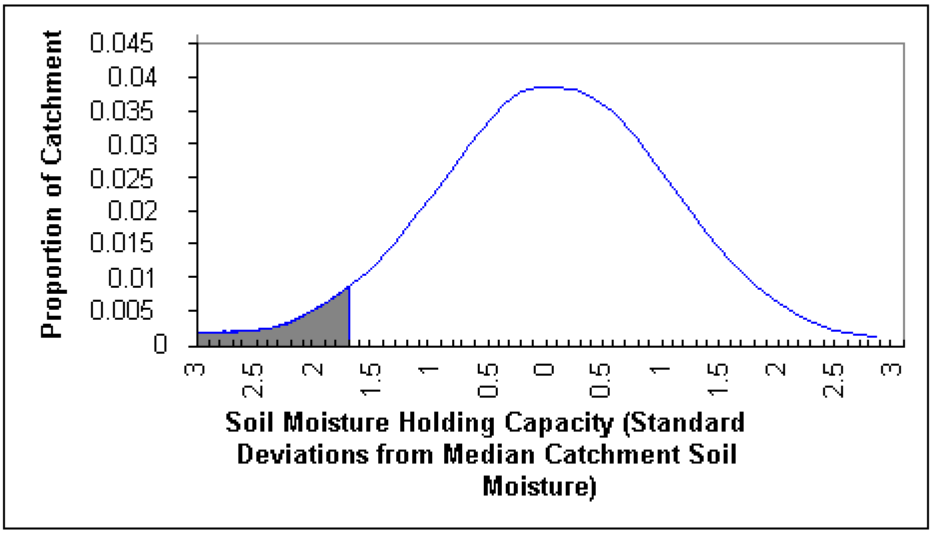


Figure 6.1.2(c) Contributing catchment calculated from Soil Moisture

When the soil moisture of the soil store reaches MSM – 1.6 x CD the area shaded is the proportion of the catchment contributing to the runoff. From normal distribution tables this is 5.5% of the catchment.

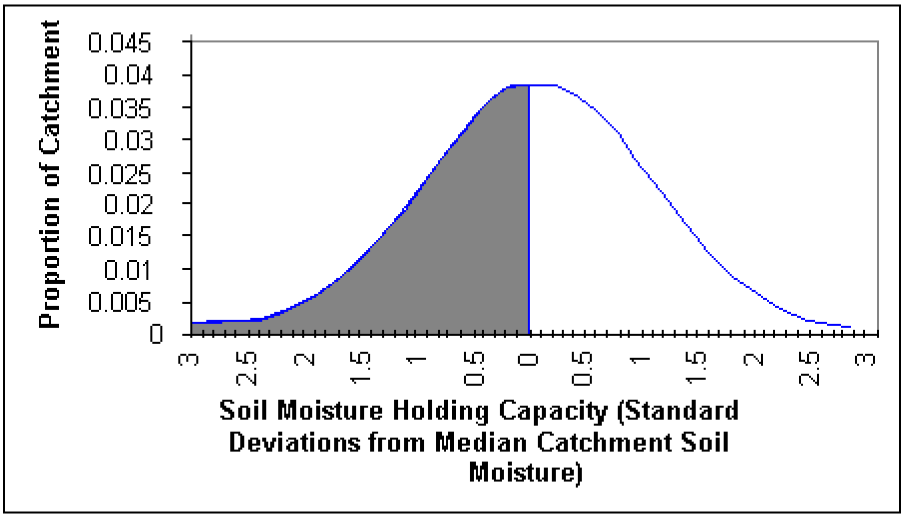
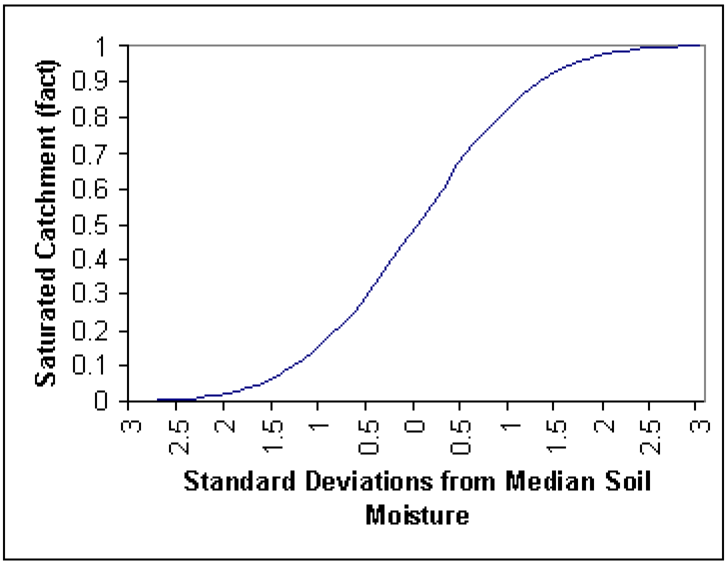


Figure 6.1.2(d) Contributing catchment calculated from Soil Moisture

When the median soil moisture is reached the catchment contributing is 50%

The shape of this relationship, (Figure 6.1.2(e)), is similar to a power curve but asymptotic to Y = 0 and Y = 1. Intuitively this is what is expected and overcomes the problem of the power curve that is required to be silled at 1.0.



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

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

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

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

- S = (1 – SWM) x im(t)

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

This interflow is assumed in the model to equal

- Ifl = s x SMD x sm(t)

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

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

Models use various formulas ranging from linear to power functions to estimate the moisture loss from soils. Experimentation with the linear model was not found to improve the estimate of runoff and was discarded for the simpler constant model. Here evapotranspiration is assumed to equal the pan factor times recorded daily evaporation. Typically a value of 0.6 to 0.7 is used for class A pan recordings.

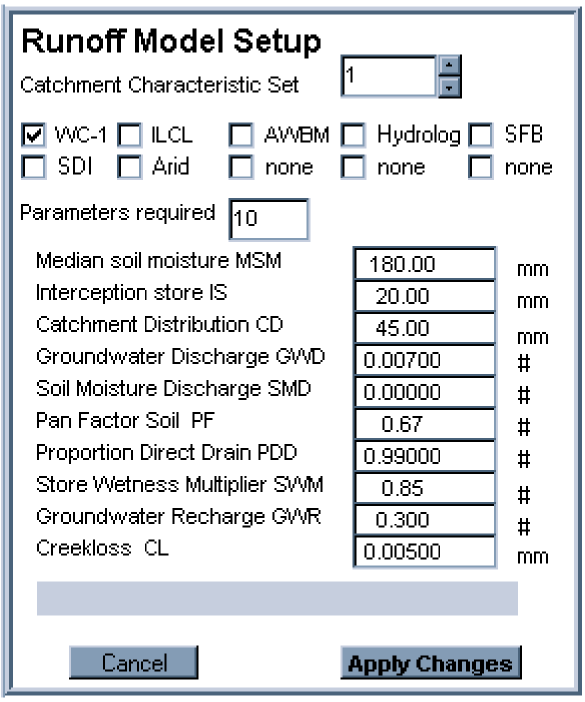
Groundwater is simulated within the model using two parameters GWR (recharge) and GWD (discharge). Both operate in a simple linear fashion.

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

The parameter GWF is used to define the proportion passing to ground and often this may be up to 20 to 30 percent.

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

Input Parameters



Medium soil moisture (MSM) - represents the field capacity of the soil. Usually in the range 150-300 mm. Increasing this value delays the early season initiation of runoff, decreases runoff by providing greater opportunity for evapotranspiration and assist in keeping late season groundwater flows up.

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

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

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

Baseflow = groundwater store x GWD

Usual values are small 0.001 to 0.0001

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

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

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

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

Groundwater Recharge (GWR) - is the proportion of rainfall that recharges the groundwater store. Usual values are 0.05 to 0.3 indicating that 5% to 30% of the flow running off the catchment is entering the groundwater system.

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

APPENDIX H. METHODOLOGY FOR DETERMINING VOLUMES OF WATER USED FOR FLOOD IRRIGATION

Without direct measurement of the volume of water used for the purpose of flood irrigation the volumes were estimated based on the methodology detailed below.

1. Consultation with landholders/irrigators and verification of information provided by landholders/irrigators with available data sets such as GIS land use data from the Bureau of Rural Science and Property Assist data provided by the Department of Environment and Heritage.

2. Where consultation was not available aerial videography was used to determine the location of diversion structures.

3. The location of diversion structures was imported into GIS ArcMap and was overlayed on the existing land use coverage. Where the land use was irrigation, attribute data from GIS ArcMap was used to determine the area of land that could potentially be subjected to flood irrigation.

4. Areas where it was not clear that the land use required irrigation but could potentially be irrigated, such as land adjacent diversion structure with a land use of either grazing/modified pasture or crop/grazing rotation, it was assumed that 40% of the land area was irrigated.

5. The assumption that 40% of the total area of land adjacent in-stream diversion structures could be potentially flood irrigated was established by landholder information where generally 40% of the land held by the landholder was flood irrigated. This assumption also takes into consideration topographic land features that prevent even distribution of flood irrigation waters (as currently the areas of land subject to flood irrigation have not been laser levelled). Furthermore the 40% assumption is a conservative figure in the absence of verbal conformation from all irrigators.

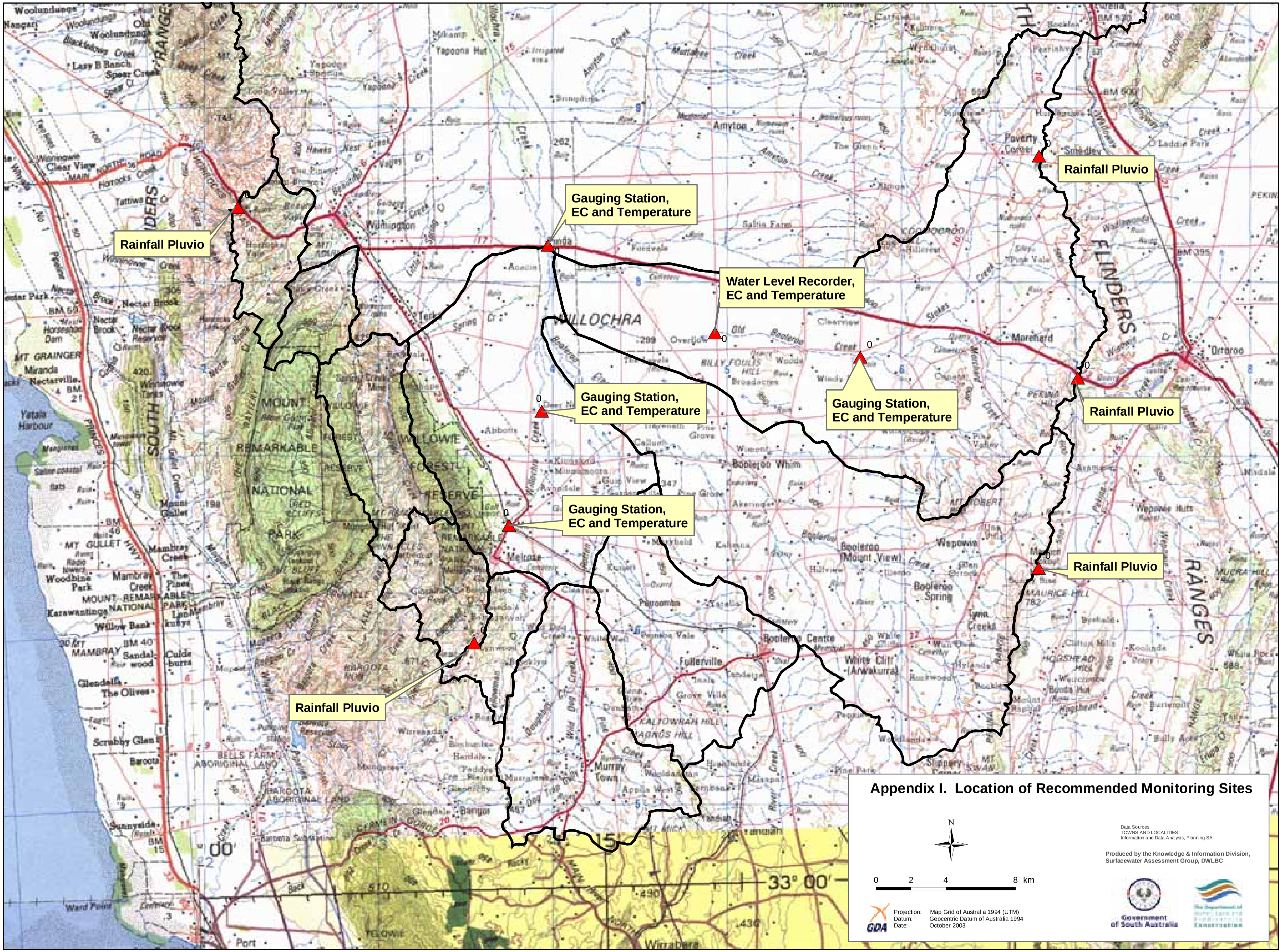
6. Once the area of land subjected to flood irrigation was estimated it was assumed that between 200 mm to 300 mm of water could potentially be distributed over the given area of land in order to establish a volume of water used for flood irrigation. The 200 mm to 300 mm assumption is a conservative assumption based on flood irrigation practices in the Murray Darling Basin, which range from 520 mm to 1030 mm for vines, which require substantially less water than pastures (Department of Agriculture 1985). Based of water requirements for optimum pasture yield in regions with rainfall equivalent to that experienced in the Willochra catchment up to 2375 mm of water is not unrealistic given the nature of flood irrigation. (Tony Thomson DWLBC pers. com., December 2003)

Table 46 displays the area of land subject to flood irrigation and associated volumes of water used in given sub-catchments.

Table 46. Estimates of volumes of water diverted for flood irrigation

Subcatchment	Node	Estimated Area Irrigated (ha)	Estimated Irrigation Depth (m)	Estimated Volume Water Diverted (ML)
Willochra Creek	WC5	20	0.2 - 0.3	40 - 60
Willochra Creek	WC5	50	0.2 - 0.3	100 - 150
Willochra Creek	WC5	50	0.2 - 0.3	100 - 150
Willochra Creek	WC5	80	0.2 - 0.3	150 - 230
Willochra Creek	WC5	80	0.2 - 0.3	160 - 240
Willochra Creek	WC5	60	0.2 - 0.3	120 - 180
Willochra Creek	WC5	40	0.2 - 0.3	90 - 140
Willochra Creek	WC6	10	0.2 - 0.3	20 - 30
Willochra Creek	WC6	70	0.2 - 0.3	140 - 210
Willochra Creek	WC6	400	0.2 - 0.3	800 - 1200
Willochra Creek	WC6	40	0.2 - 0.3	80 - 120
Wild Dog Creek	WD4	30	0.2 - 0.3	50 - 90
Estimated Diversion Volume		**900 ha**		**2000 - 3000 ML**

The information collated in Table 46 above is a guide to the order of the volumes of water diverted for flood irrigation and should <u>not</u> be considered to be an exact measurement.



Appendix I. Location of Recommended Monitoring Sites

N

0 2 4 8 km

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

Data Sources:
TOWNS AND LOCALITIES:
Information and Data Analysis, Planning SA

Produced by the Knowledge & Information Division, Surfacewater Assessment Group, DWLBC

Government of South Australia

The Department of Water, Land and Biodiversity Conservation

Section 2. Preliminary Ecological Assessment of Significant Water Dependent Ecosystems of the Willochra Catchment

Glen Scholz, Jason VanLaarhoven and David Deane

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

September 2003

Report DWLBC 2003/21

AIM

The Department of Water, Land and Biodiversity Conservation (DWLBC) undertook this study for the Northern and Yorke Agricultural District Integrated Natural Resource Management Committee (NYAD INRMC). The aim of the program is to investigate the sustainability of the water resource at current development levels within the Southern Willochra catchment.

This study provides a preliminary ecological assessment to identify the aquatic ecosystem assets within the Willochra catchment, gain insight into the potential threats to these assets and the resources required for further ecological studies and monitoring.

This assessment drew upon the results of the Willochra catchment hydrological assessment report (DWLBC 2003) to determine ecological assets that may be at risk through altered flow regimes.

STUDY AREA

The Willochra catchment is situated in the upper reaches of the Northern Agricultural District. The catchment is bound to the west by the Southern Flinders Ranges from Murray Town to Simmonston and to the east by the Pekina Ranges. The catchment area covers the Willochra Plain from Booleroo Centre in the south to Simmonston in the north. The Willochra river system is an ephemeral semi-arid to arid river that flows northward from Melrose, along the Willochra Plain, flows through the Southern Flinders Ranges and discharges into the Lake Torrens basin (Figure 69).

METHODOLOGY

The ecological survey had three separate stages.

- literature review
- aerial videography to record the presence of baseflow and pools, and the presence of several major vegetation types along the watercourses of the Willochra catchment
- more detailed on-ground surveys at sites within the Willochra catchment identified as being of high ecological value, which assessed representative aquatic ecosystems and the water dependent animals and plants associated with these areas.

Literature review

Current literature was reviewed to provide baseline information on the water dependent ecosystems within the Willochra catchment (Table 47).

Table 47. Literature review of the water dependent ecosystems in Willochra catchment

Component	Aspect of component	Source of information
Birds	Distribution	Birds Australia (2003) Bird Atlas of Australia: www.birdsaustralia.com.au/atlas/
	Habitat requirements	South Australian Aquatic Biota database (SAAB)
Fish	Distribution (historic)	South Australian Museum
		Landholder observations noted during community meetings (Appendix N)
	Habitat requirements and tolerances	Allen *et al,* 2002. Field guide to the freshwater fishes of Australia.
		Brandle, R. (Ed.) 2001. A Biological Survey of the Flinders Ranges, South Australia 1997-1999. Biodiversity Survey and Monitoring, National Parks and Wildlife, South Australia, Department for Environment and Heritage.
		McDowall, 1996. Freshwater fishes of south-eastern Australia.
		South Australian Aquatic Biota database (SAAB)
Macroinvertebrates	Distribution and composition	Australian Water Quality Centre (AWQC), unpublished data
	Assessment	EPA & AWQC. (2003) River Health in the Flinders Ranges. Fact sheet
Vegetation	General distribution	Neagle, 2003. An inventory of the biological resources of the rangelands of South Australia.
	Conservation status	DEH: Threatened Species Unit

Aerial videographic coding

Aerial videography was undertaken as a part of a hydrological study to capture key hydro-geomorphic features of the Willochra system. The streams surveyed were prioritised on the basis of hydrological criteria rather than highest ecological value (see Table 48; Figure 69). Aerial videographic imagery was captured on 16–17 June 2003, using a gyro-stabilised digital video camera mounted on the nose of a Bell Long Ranger Helicopter.

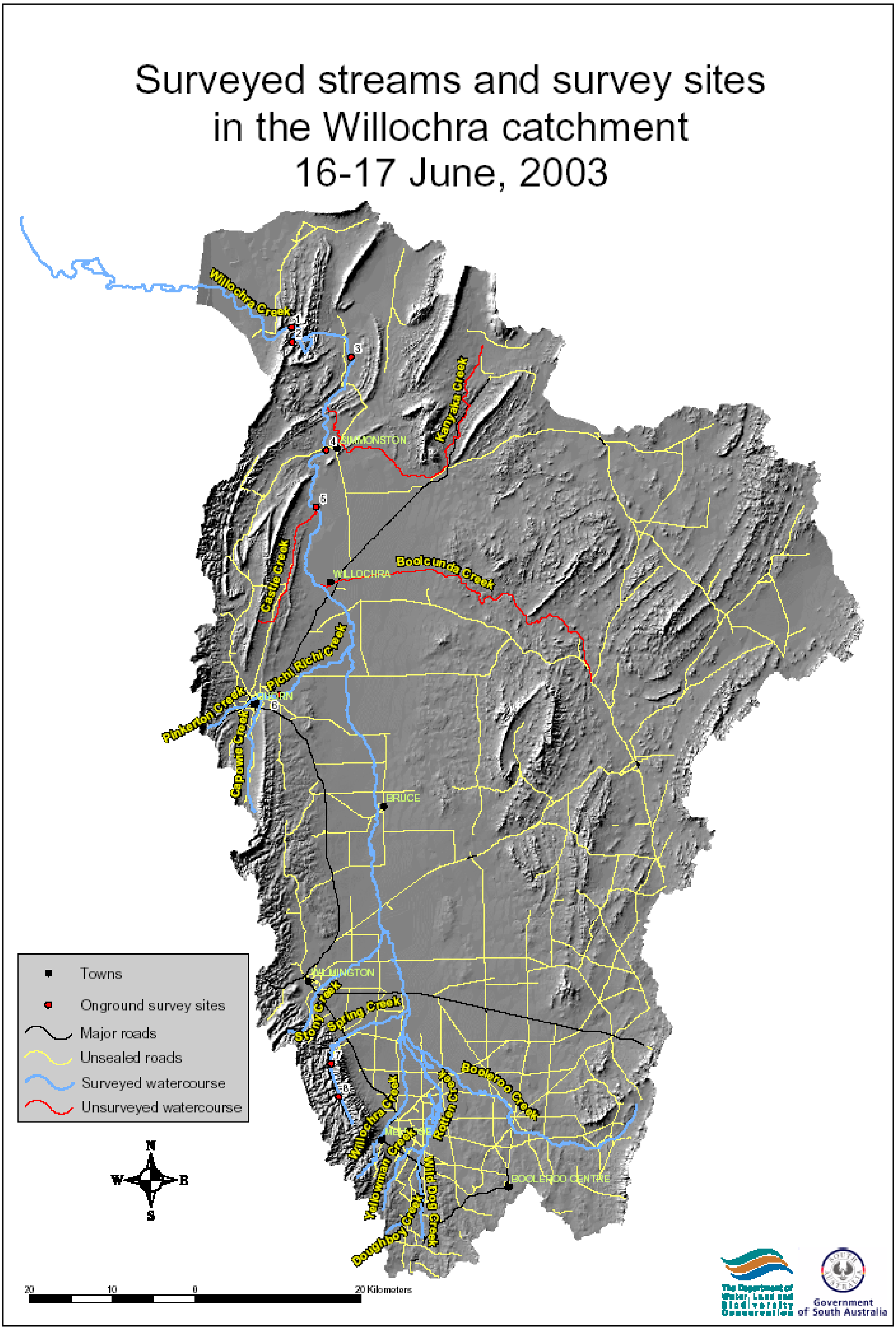


Figure 69. Surveyed steams and sites in the Willochra catchment

Table 48. Streams in the Willochra catchment captured by aerial videography

Stream	Selection criteria
Willochra Creek	Major watercourse of the catchment
Campbell Creek	Headwaters of Willochra, high rainfall area
Wild Dog Creek	Southern catchment, high rainfall & irrigation development
Yellowman Creek	Southern catchment, high rainfall & development
Rotten Creek	Southern catchment, high development
Booleroo Creek	Southeastern catchment, high development
Spring Creek	Southwestern catchment, high rainfall
Stony Creek	Southwestern catchment, high rainfall
Capowie Creek	Western catchment, high development
Pinkerton Creek	Western catchment, high development
Pichi Richi Creek	Middle of catchment, high development

Pools and baseflow

The videography was used to record the lengths of both pools and baseflow reaches onto a GIS map. As the survey was conducted after seasonal rainfall in June, it could not be certain that the recorded pools and baseflow were permanent. Therefore these features were coded as ‘wet season pool’ and ‘wet season baseflow’. Areas where the bed of watercourses could not be seen due to canopy cover were coded as ‘unobservable’.

Vegetation types

Broad vegetation categories were used to represent the major vegetation types found along the surveyed watercourses of the Willochra catchment. It was beyond the scope of the project to produce detailed vegetation associations. The classifications used were:

- Forest / woodland (Eucalypt)
- Shrubland (Acacia, Myoporum)
- Chenopod shrubland
- Pasture/cropping

On-ground surveys

Site selection

Once the surveys for the presence of water and vegetation types were completed, sites were selected for targeted on-ground surveys (Figure 69) based on the following criteria:

- Permanent water (high probability)
- Spatial distribution throughout the catchment to assess ecosystem connectivity

- Representation of aquatic habitat types.

Areas with permanent water (high probability) were selected, as these are more likely to contain the highest aquatic biodiversity and have greater significance as refuge sites from where biota can recolonise areas in favourable seasons. Selecting sites distributed throughout the catchment provides information on the distribution and connectivity of biota. This can be particularly important for fish species as they can be long lived and disperse widely. Sites representative of different habitat types were chosen to provide an indication of the diversity of biota, and their ecosystem characteristics.

Sites for on-ground surveys are shown in Figure 69 and listed in Table 49 below:

Table 49. Sites selected for on-ground surveys

Watercourse name	Site #	Site description
Willochra Creek	**1**	Warrakimbo gate
	2	Partacoona gauging station
	3	Partacoona
	4	Simmonston crossing
	5	Castle Creek junction
Pichi Richi Creek	**6**	Whitehead Road crossing
Spring Creek	**7**	Cannon Swamp
	8	Goat Rock Falls

On-ground surveys

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

- Ddate and time of survey
- Site photo
- GPS coordinates
- Physical features (i.e. the physical environment in which the site exists)
- Hydrological features
- Substrate types
- Habitat types
- Stream cover
- Vegetation cover
- Land use
- Water quality (salinity, temperature, pH, transparency)
- Fish sampling results

- Bird survey results.

The method used to conduct the bird surveys is that prescribed by the Birds Australia organisation, and involves observations over a 2 hectare area for 20 minutes (Birds Australia 2003).

RESULTS

Literature review

Literature was reviewed (Table 47) to provide information of relevance to this study. Information relating to aquatic biology of general interest to catchment managers in the region has been extracted and is included within the appendices. The reference material in Appendices C, D and E in particular can be used to assess the potential biodiversity value of various water dependent ecosystems, based on how well the various habitat and other requirements of the species concerned are being met.

Specific information presented in the appendices:

- A review of the South Australian museum records of fish distribution is presented in Appendix K
- The biological features of fish identified in the Willochra catchment are presented in Appendix L
- A list of bird records from the Willochra catchment area in Appendix M
- Waterbird habitat and feeding preferences can be found in Appendix N
- Landholder recollections on hydrology and ecology appear in Appendix O

EPA/AWQC macroinvertebrate data

The Australian Water Quality Centre (AWQC) and the Environmental Protection Authority (EPA) have conducted macroinvertebrate surveys in Flinders Ranges region to determine the ecological health of the river systems (EPA & AWQC 2003). Macroinvertebrate survey sites are distributed throughout the catchment (Figure 70). The location of two macroinvertebrate sites coincides with the on-ground survey sites 4 and 5.

The AUSRIVAS modelling program was used to evaluate watercourse health, according to macroinvertebrate composition (i.e. species richness). Watercourse health is measured by comparing the condition of a river to similar rivers of the same type in an undisturbed or unimpacted state (i.e. reference condition) (EPA & AWQC 2003).

The watercourses in the Willochra catchment were found to be in reference condition at: Willochra Creek, South of Partacoona; Willochra Creek, at the downstream junction of Castle Springs (coincident with on-ground survey site 5); Wild Dog Creek, Warren Gorge; Mt Arden Creek tributary (coincident with on-ground survey site 4); Kanyaka Creek at Kanyaka gauging station; and Coonatto Creek.

The sites located on Wirreanda, Beautiful Valley, and Campbell Creeks were all found to be significantly impaired. Sites located on Sugarloaf Creek, Willochra Creek at Quorn, and Willochra Creek at the Orroroo Road crossing were all found to be severely impaired.

Generally the report states that the tributary streams in the upper reaches of the Willochra catchment were in good (reference) condition and contained diverse biological communities. However, as the streams reach the Willochra Plain the ratings signified poorer watercourse condition due to the lower diversity of macroinvertebrates. Habitat disturbance and high salinity levels are thought to be the contributing processes to poorer condition ratings.

For further information on the macroinvertebrate species found at the sites within the Willochra catchment, contact the Australia Water Quality Centre, Bolivar Adelaide which holds and manages the State's macroinvertebrate data.

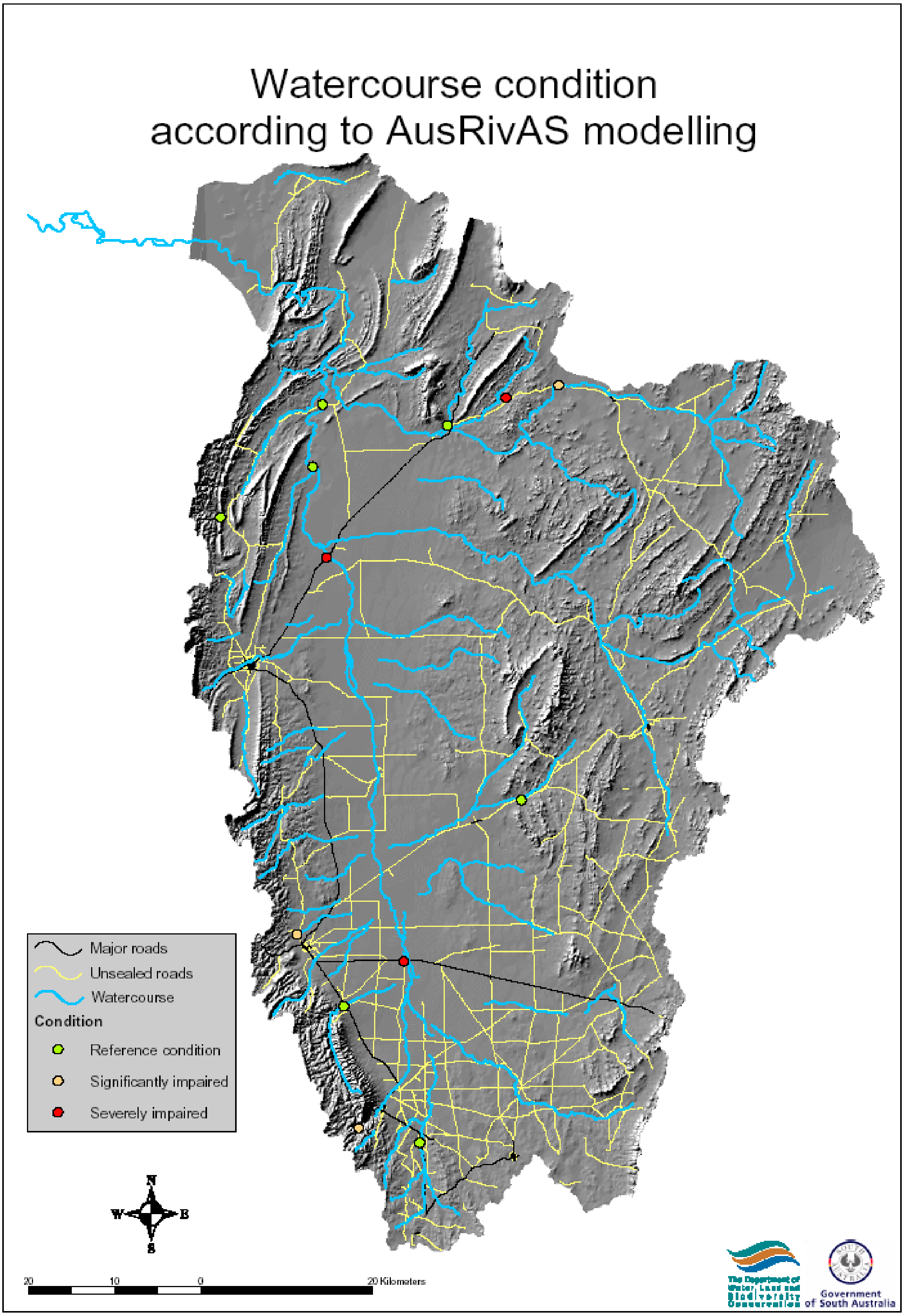


Figure 70. Watercourse condition according to AusRivAS modeling

Aerial videographic coding

Pools and baseflow

The distribution of wet season pools identified using aerial videography is displayed in Figure 71; the distribution of wet season baseflow in Figure 72. Areas that are most likely to contain permanent pools and or baseflow, are along the upper reaches of Spring Creek, and along the Willochra Creek from 10 km north of Willochra, through the rolling hills past Simmonston, to where the creek exits the Flinders Ranges at the edge of the Lake Torrens plain.

Pools observed using videography were concentrated to the west of the catchment in the upstream watercourses of the southern Flinders Ranges around Melrose; and the downstream rolling hills and gorges of the Flinders Ranges between Willochra and Yadlamulka Station. Pools were sparse to absent on the Willochra Plain, and the other flatter areas of the catchment.

Reaches identified as receiving baseflow were restricted to the upland reaches of Spring Creek near Melrose and in two reaches of the Willochra Creek within the rolling hills and gorges of the Flinders Ranges, upstream and downstream of Simmonston.

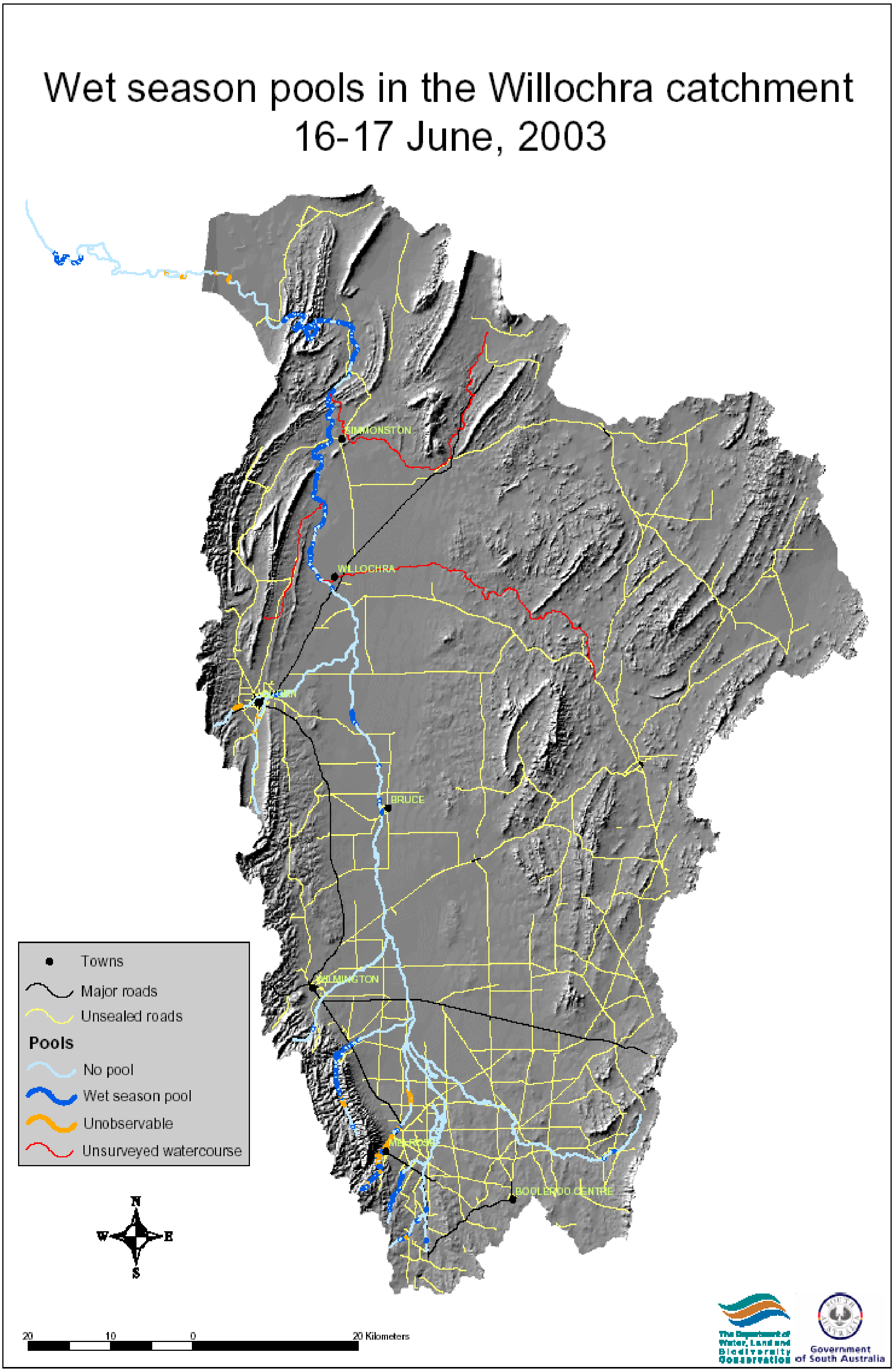


Figure 71. Wet season pools in the Willochra catchment

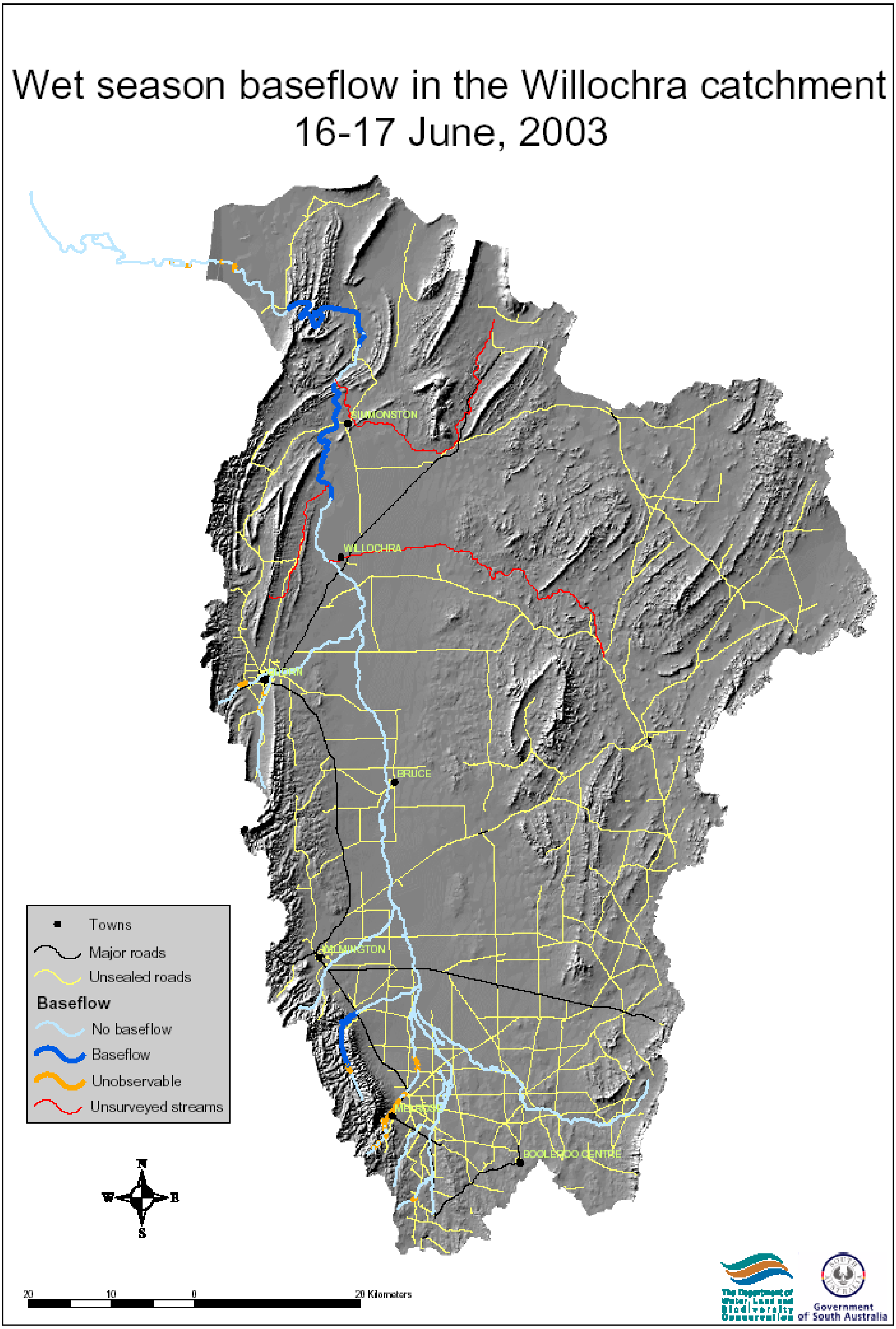


Figure 72. Wet season baseflow in the Willochra catchment

Vegetation type

The distribution of the major vegetation types identified through aerial videography can be seen in Figure 73. The riparian vegetation varied across the catchment, forming distinct associations following broad topographical and climatological patterns.

Shrublands (mostly dominated by *Acacia* spp.) were almost exclusively restricted to the gorge country in the downstream reaches of the Willochra, between Simmonston and Yadlamulka station.

Chenopod shrublands, dominated by blue bush (*Maireana*), saltbush (*Atriplex*) and copperburr (*Sclerolaena*) occurred across the Willochra Plains, and on the plains between the western foot slopes of the Southern Flinders Ranges and Lake Torrens.

Eucalypt forests, (dominated by river red gum, *Eucalyptus camaldulensis*) exist along the wetter, southern tributaries, as well as along Pichi Richi, Capowie and Pinkerton Creeks near Quorn. Areas of eucalypt forest also extend from near Wilmington, south along the lower Willochra and its tributaries. Small pockets of river red gum also occur along the Willochra Creek north of the Stony Creek junction (Wilmington).

Areas where pasture and cropping land extend to the edge of the watercourse, replacing natural riparian vegetation, are restricted to the southern reaches of the Willochra and the associated southern tributaries. Patches of remnant *Acacia* shrubland also exist within these reaches.

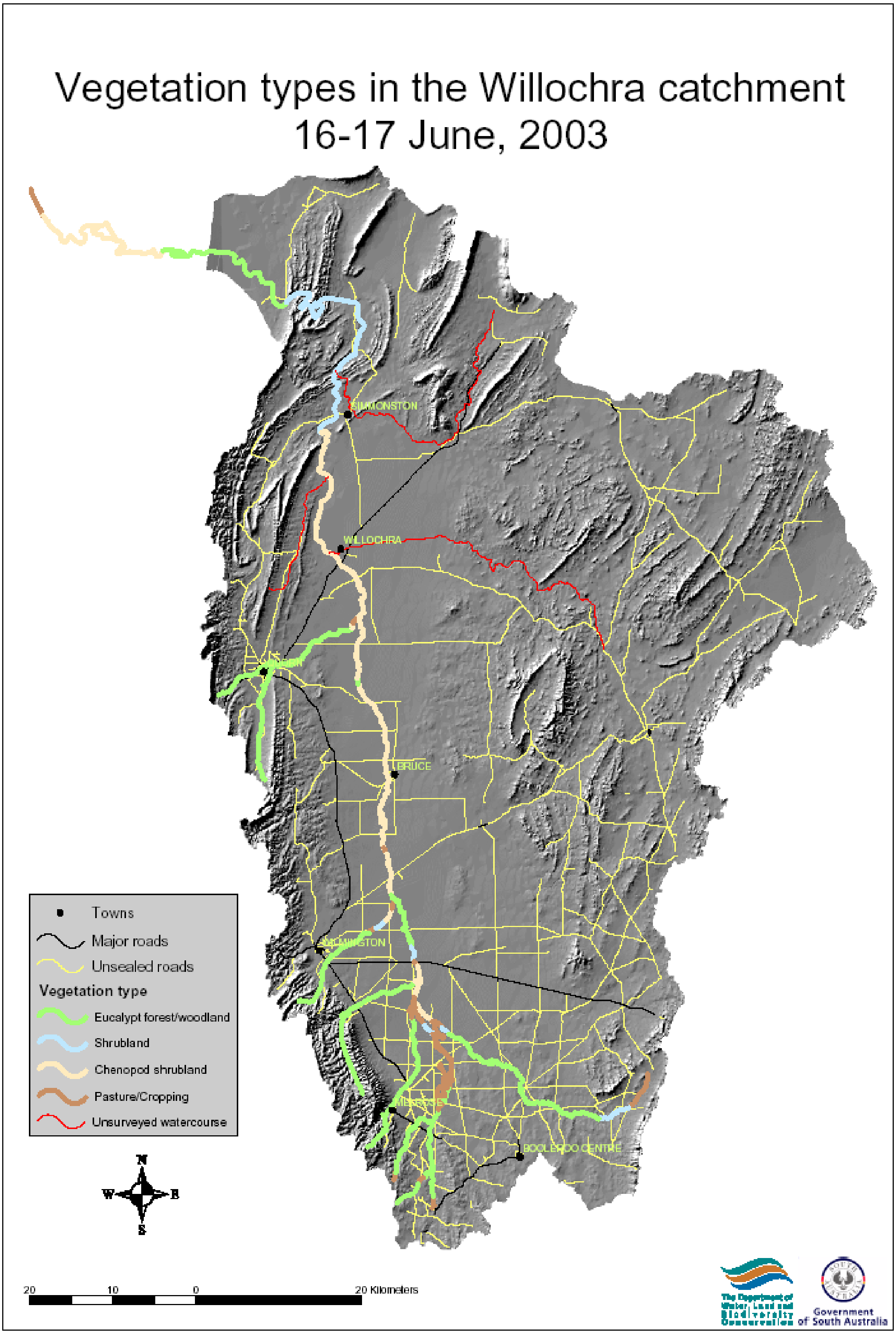


Figure 73. Vegetation types in the Willochra catchment

On-ground surveys

General character

Location of the survey sites is shown in Figure 69. Sites 1 and 2 were in a gorge environment. Sites 3 to 5 were permanent pools spread along rolling hills and lowlands before the lower Willochra enters the southern Flinders Ranges. Site 6 was in the upper catchment of Pitchie Ritchie Creek, a tributary to the Willochra draining the Flinders in the central-western Willochra Creek catchment. Sites 7 and 8, on Spring Creek, were chosen as representative of streams in the upper southern section of the Willochra catchment.

Sites were generally shallow with no site being deeper than 1.5 metres. Water at all sites surveyed was found to have a mild to moderately alkaline pH (as defined by ANZECC/ARMCANZ 2000). Readings taken during site surveys varied from pH 8.0 observed at site 3 (Partacoona) to above pH 9.2 found in the lower reaches of the Willochra Creek at sites 1 and 2 (Warrikimbo Gate and Partacoona gauging station).

Conductivity exhibited extremely high variation from 0.185 mS/cm in the upper catchment of Spring Creek (site 7) to greater than 31 mS/cm observed at sites 4 and 5 in the lower reaches of Willochra Creek between Simmonston and Partacoona. Generally salinity was very low in the southern catchment sites, intermediate in the gorge sites and very high in the hills/lowland sites.

Turbidity did not limit light penetration at the depths observed, with the exception of site 4 (see below) but water colouring, presumed to be tannins, was observed at sites 1, 2 and 8.

The diversity of fish species within the catchment was found to be very limited: only one species of native fish the Lake Eyre hardyhead, (*Craterocephalus eyresii* Figure 74) and one species of exotic fish eastern gambusia, (*Gambusia holbrookii* Figure 75) were recorded. These species can be easily distinguished by the tail – forked in the hardyhead and rounded in the gambusia.

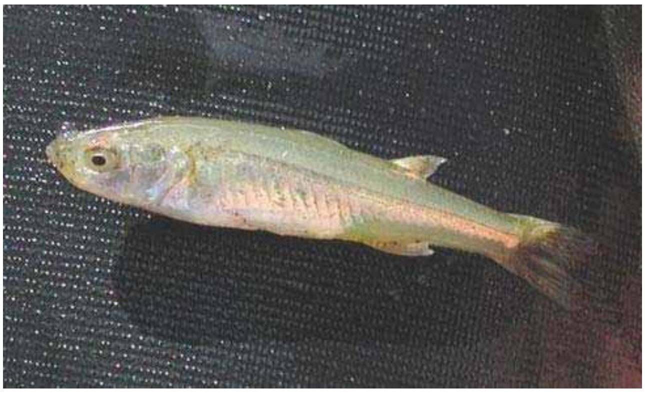


Figure 74 Lake Eyre hardyhead, average size 6–7cm (Photo: Jason VanLaarhoven)

Figure 75. Eastern Gambusia, female up to 6 cm, male 3.5 cm (Photo: David Morgan)

Summary of site findings

Gorge environment (sites 1 and 2)

These sites were small, relatively deep (1–1.5 m) rocky pools and had the highest pH found in the on-ground surveys. Salinity was relatively low at around 12 mS/cm in both pools.

The riparian areas were largely bare rock but some sedge and terrestrial vegetation was also present. Substrate type was largely bare rock but the aquatic plant genus *Isolepsis* was present.

Over 150 Lake Eyre hardyhead were recorded at site 1, but site 2 was restricted to a single gambusia individual.

Three species of waterbirds were observed in the area as follows:

Site 1. Rocky gorge – Acacia shrub land with open shallow water

- pacific black duck
- masked lapwing
- red kneed dotterel

Lower catchment rolling hills and lowlands (sites 3-5)

These sites were all long, narrow pools and backwaters, with depths of 0.3–1.5 m. The pH recorded was lower than the gorge environment but still alkaline, varying from 8.0 to 8.74. Salinity varied from 17.88 mS/cm at site 3 (also the shallowest pool) to around 31 mS/cm at sites 4 and 5 – the highest salinity recorded.

Riparian areas featured fairly continuous coverage of sedges and salt tolerant species but few woody shrubs were present. Aquatic sedges and reeds, including *Cyperus*, *Juncus* and *Phragmites* spp., were also variously present. Submerged vegetation consisted of *Isolepsis* sp. at site 3 and *Potamogeton pectinatus* at site 4 and 5 covered 20% of the stream area. This is despite the presence of colloidal clay at site 4 limiting transparency to 0.4 m.

Large numbers of Lake Eyre hardyheads were found at sites 3 (145), and 4 (100+ observed only), with limited numbers found at site 5 (14). A few gambusia were also caught at site 3 (3).

Six species of waterbird were observed in the area as follows:

Site 5. Rolling hills and lowlands – Salt marsh with open shallow and deep water

- pacific black duck
- white faced heron
- hoary headed grebe
- black winged stilt
- red necked avocet
- red kneed dotterel

Upper catchment sites (sites 6, 7 and 8)

These sites varied in morphology from long and narrow pools to almost circular waterfall plunge pools. Water depth was below 1 m at all sites. The pH showed little variation between sites, consistently around pH 8.5. Salinity varied to some degree but was consistently the lowest observed, particularly at the southern sites (7 and 8) where it was less than 0.5 mS/cm.

Riparian zones were relatively heavily vegetated, with *Eucalyptus camaldulensis* present at all sites, and understorey shrubs also present. Sedge communities also featured with *Cyperus* and *Juncus* spp. again represented at all sites. Reedbeds of *Typha* were found at site 7. Submerged vegetation was generally absent.

A variety of substrate type was identified, typically cobble and gravel. Leaf litter and woody debris was also present in stream.

A single waterbird survey was conducted with results as follows:

Site 7. Partly confined valley – Eucalypt forest with small pool/riffle sequence

- No waterbirds observed

DISCUSSION

Ecological character

The broad ecological character of the Willochra Creek and associated tributaries is that of a dryland ephemeral stream ecosystem. Ecosystems of this type are found throughout much of southern and inland Australia but vary greatly in their nature and form. Understanding of the ecological patterns and processes in these systems is an emerging science and significant work continues to provide understanding of how the ecology and hydrology of these systems interacts (e.g. Costelloe et al. 2004) and how best to assess their condition (e.g. CRL 2004).

In addition to vertical connectivity with soil and groundwater, it is generally accepted that ephemeral waterways rely heavily on permanent refugia pools and periodic lateral and longitudinal connectivity of these refuges for the maintenance of aquatic biodiversity (Costelloe et al. 2004; CRL 2004). Periods of high flow trigger ecological responses in many aquatic species, which results in movement both up and downstream as well as onto floodplain habitat where significant additional resources become available. These times of high connectivity and resource availability provide biological boom periods, allowing aquatic species to extend their range and numbers beyond those supported by refugia pools. This is a critical process for the maintenance of viable populations of aquatic species and has implications for other species, notably waterbird populations, which exploit the increased production.

The study area presents two regions of permanent or near permanent surface water habitat (refugia) in the upper and lower catchment, which are almost certainly entirely maintained by groundwater inflow. These areas are separated by the middle reaches, which are effectively terrestrial in nature, and apparently devoid of permanent surface water. Permanent pools represent key ecological assets as aquatic habitat refuge areas in dry spells and as a source for re-population establishment in favourable conditions. These are critical to the biology of the system as a whole.

Aquatic ecosystem assets

Most of the important aquatic habitat areas are associated with the valleys and gorges of the southern Flinders Ranges to the west of the catchment. This was determined during the aerial videographic coding. There is little permanent aquatic habitat within the reaches along the Willochra Plain and across the plain adjacent to Lake Torrens.

To confidently map permanent pool locations using videography, the imagery should ideally be captured at the end of the dry spell, which would mean autumn for the focus area. The aerial surveys were conducted during the start of winter in June and therefore some of the pools in the fringing areas may not be permanent and occur seasonally due to a rise in the groundwater table and localised rainfall events. The areas supporting aquatic habitat that were coded using videography provide an indication of the likely extent of the pool and baseflow areas. This provides both a baseline for the selection of monitoring sites and also a management tool to facilitate policy development with regard to activities likely to impact upon these assets.

While it is beyond the scope of this project to provide a definitive assessment of ecological patterns and processes, there is evidence that the among the permanent pool systems discussed, many are in quite good condition. The three broad habitat types all featured ecologically important characteristics. Pools surveyed in the gorge country, the lowland saline pools and wetlands and the upper catchment sites are all significant.

Gorge pools

Although these sites featured little riparian vegetation they still supported populations of true aquatic vegetation and fish. Features such as the lower salinity and shading from the surrounding Flinders Ranges providing temperature regulation differentiate this habitat from the saline pools.

Saline wetlands

The saline wetland ecosystems (as typified by sites 3–5) within the lower catchment are important ecological assets. These pools contain diverse habitat including the submerged aquatic macrophyte *Potamogeton pectinatus* not found elsewhere in the catchment. *Potamogeton* is capable of surviving saline conditions and seed dispersal is known to be facilitated by duck species (Romanowski 1998), which were observed at site 5.

Submerged vegetation provides habitat structural complexity and resources for aquatic biota including macroinvertebrates and fish. The AUSRIVAS modelling (Figure 70) classified two sites on the lower Willochra as reference condition, which supports the suggestion that a diverse macroinvertebrate population is present in the pools despite the high salinity.

These pools and wetlands are suited to wading birds and species that feed in shallow mud flats and nest in reedbeds, shrubs and grasslands. These species include some duck species, grebes, native waterfowl, lapwings, stilts, avocets, plovers and dotterels (Appendix N). It is less suited to those species that require trees and tree hollows for nesting, such as some duck species, herons and egrets as well as those that require fish as a main source of food i.e. cormorants. However, after high flow events these species may seasonally frequent these areas in large numbers due to an increase in food resources.

The pools are also important to fish species. Although the Lake Eyre hardyhead is a freshwater species that can tolerate salinity levels up to three times that of seawater (150 000 EC; 130 000 mg/L) (Ivantstoff and Crowley 1996), this level of salinity will preclude many other native fish from inhabiting these areas. Eastern gambusia is also able to tolerate high salinity levels and has been found in environments with salinity levels twice that of saltwater (Herbert pers. com. cited in Phipps 2000). Lake Eyre hardyheads are an important food source for many of the migratory waterbirds that frequent the catchment especially after flood events result in large population recruitment.

Mr Glen and Mrs Margaret Deer, formerly of Partacoona Station, recall permanent water located near the shearing shed, at Duck Pond near where Stevens Creek enters the Willochra. Mr Deer recalls that there was permanent water in the main stem of the Willochra down through Partacoona Station all the time. Mrs Deer told of three main pools that were very deep, and supported small minnow shaped fish (possibly Lake Eyre hardyheads). These recollections further support the conclusion that these are permanent refuge pools of ecological importance.

Upper catchment permanent pool refugia

In contrast with much of the lower rainfall areas of the catchment, riparian zones of the small streams draining the southern Flinders Ranges feature tree canopy and understorey species as well as aquatic macrophytes. Leaf litter from the riparian zone was observed and is an important energy input into upland streams where photosynthetic organisms are relatively absent. Woody debris input is also important in terms of habitat diversity.

In addition to diverse vegetation the geomorphology also provides a range of habitat important for macroinvertebrate communities such as riffles and cobbles. The AUSRIVAS modelling (EPA & AWQC 2003) rating for sites in the upper catchment of streams draining the southern Flinders within Willochra catchment was reference condition.

The Eucalypt open forest habitats such as those found in Spring Creek and Pichi Richi Creek are areas less suited to waders and wholly aquatic bird species due to the lack of open water and dense tree cover and are more suited to terrestrial bird species. This was reflected in the waterbird survey conducted at site 7 where no waterbirds were present.

Importance of groundwater

The presence of permanent surface water in the study area appears to be highly dependent upon groundwater. The persistence of waterhole refugia in the arid Lake Eyre Basin has been shown to depend only on the cease-to-flow depth following flood events (Costelloe et al. 2003). No pool visited during the on-ground surveys was deeper than 1.5 metres, suggesting that these are likely to be dependent upon groundwater surface expression to support the persistence of aquatic habitat through dry months.

Further evidence of this is provided by the location of permanent pools in gorge and hill country, high pH values found throughout the catchment, and observed salinity values that seem to follow known trends in groundwater quality and likely flow path lengths from likely recharge in the upland areas.

It appears that persistent pools in the middle reaches of Willochra Creek, which were evidently dependent on elevated groundwater tables, dried out in the 1960s and have never recovered (Reg Noll pers. com.). The pools may formerly have provided a link between refugia in the lower catchment/gorge country and the upper catchment pools.

The Willochra Lake Eyre hardyhead population

Recent genetic assessment of Lake Eyre hardyhead specimens has shown the population to be of higher conservation value than previously realised. The Lake Torrens drainage basin has been disconnected from the Lake Eyre hydrological system for a period long enough for the Lake Eyre hardyhead species to have evolved into a possible distinctive subspecies (M. Hammer pers. com. 2002) (Figure 76).

Crowley and Ivantsoff (1990) undertook genetic assessment on a range of populations previously known as the Lake Eyre hardyhead *(Craterocephalus eyresii)* and subsequently attributed them to four distinct species: *C. eyresii* within the Lake Eyre drainage system, *C.*

fluviatilis in the Upper Murray River system, and two new species, *C. centralis* from the Finke River system and *C. amniculus* from the upper Darling River system, Glennies Creek and Bowmans Creek. No populations from the Willochra catchment were included in that study.

Specimens of the Willochra population of the Lake Eyre hardyhead were collected in on-ground surveys conducted with this project, from sites 1 and 3, and they were subsequently genetically assessed by the South Australian Museum.

The study (Adams 2004) concluded that the:

- hardyheads in the Willochra catchment represent the southern-most population of the Lake Eyre hardyhead (*C. eyresii*) and the only population known outside of Lake Eyre Basin
- Willochra catchment sub-population warrants recognition as a “management unit” and is of special significance due to its ecogeographic uniqueness.

As the only native fish species present in the system collected so far, the ecological significance of the population was already high. As the only sub-population outside the Lake Eyre Basin, the Willochra Lake Eyre hardyhead should be considered of particular conservation significance. The new appreciation of the biodiversity conservation value of the populations warrants more extensive study and inclusion of the Willochra Lake Eyre hardyhead in community awareness and monitoring programs.

Historic specimens from the South Australian Museum suggest the Lake Eyre hardyhead distribution stretched from Beda Hill in Lake Torrens (15 km west of the mouth of the Willochra River), south to the Willochra bridge, north of Quorn. A specimen of Lake Eyre hardyhead was also recorded from a spring at the northern tip of Lake Torrens. The exact location and date of the record is unknown but the regional groundwater flow appears to converge and discharge around the northern end of Lake Torrens maintaining a few springs within the lake (Waterhouse et al. 2002). This isolated remnant population, if it still exists, is considered to be a significant asset worthy of further research, including genetic assessment, and protection.

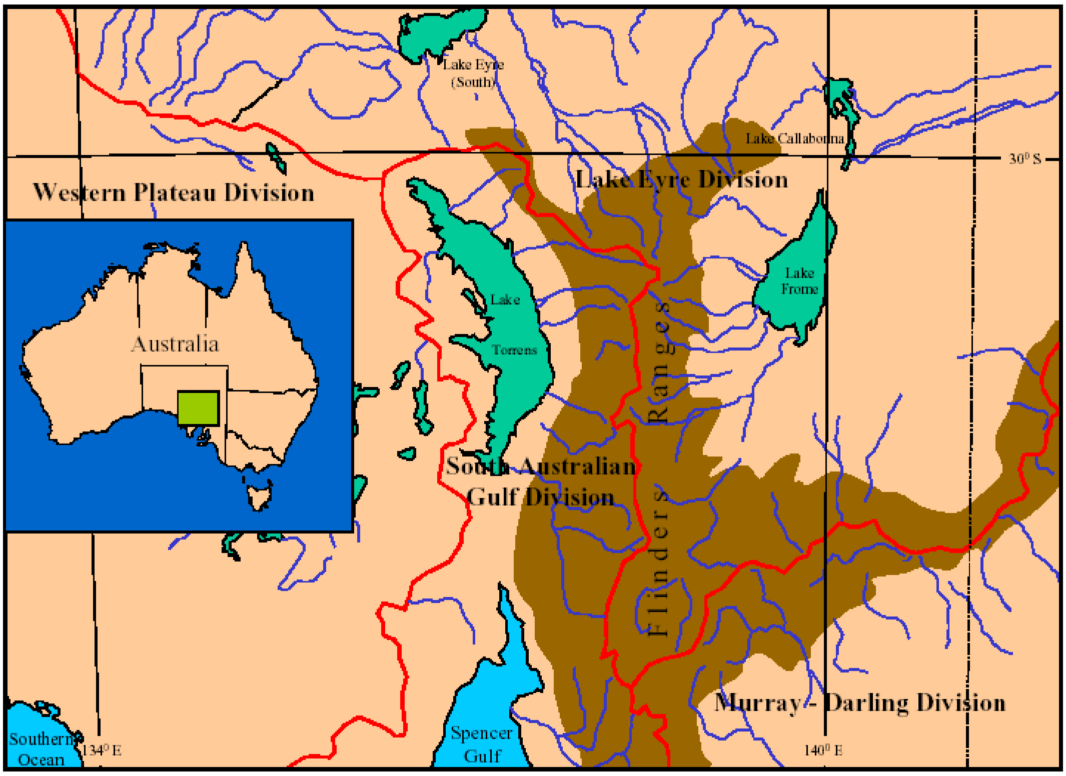


Figure 76. The South Australian Flinders Ranges and component meta-drainages
Source: Pierce et al. (2001)

Threats to the sustainability of the Willochra hardyhead population

Key threats to the species relate mainly to the loss of permanent pool refugia, specifically:

- habitat loss, degradation or contraction due to loss of hydrological connectivity, sedimentation; reduced water quality or quantity through groundwater water level lowering
- disturbance or loss of riparian or in-stream vegetation
- displacement or predation by other fish species.

The first two points are considered elsewhere in the discussion and the third will now be considered.

Eastern gambusia (*Gambusia holbrooki)* originates from southeastern North America; it is thought to have been introduced in the 1920s for use in aquariums, with subsequent releases into the wild as a potential mosquito control agent (McDowall 1996). The SA Museum records contain a specimen taken in 1994 from the Willochra Creek at the Simmonston to Proby Grave road crossing.

It is an aggressive and competitive species and poses a threat to native fish species that occupy a similar ecological niche. At high densities this species intimidates small native fish by fin nipping, and also eats their young and eggs (McDowall 1996). In Australia it has been implicated in the decline of a number of native fish species including hardyheads (Wagner and Jackson 1993).

Eastern gambusia was captured in the Willochra Creek at sites 2 and 3. The potential for direct competitive or predatory interactions between hardyheads and gambusia needs to be considered.

While only present in low numbers during this survey, life history of gambusia does, in theory present some threat to the Lake Eyre hardyhead. The hardyheads are thought to spawn among aquatic plants in late summer to early autumn (DWR 2001) although they are capable of opportunistic breeding in response to food and habitat availability (Ivantsoff and Crowley 1996).

Gambusia breeding is thought to peak during October, with the species producing up to nine broods of live young in a year. Given the generalist predatory nature of gambusia, potentially hardyhead eggs and larvae may be a food source.

Long-term hardyhead persistence is almost certainly dependent upon opportunistic breeding to greatly expand their numbers and distribution through flood or significant flow events. In the extended absence of such events, Gambusia populations may impact on hardyhead numbers and even possibly threaten populations at the pool scale.

Evidence of human influence on the ecology

Clearly the Willochra catchment has undergone significant changes over the past 200 years, including major changes to the hydrology (Section 1). There is the potential that these changes have affected natural ecological processes in a manner that may have at least *contributed* to a decline of the area concerned.

Information provided by the Willochra catchment hydrology assessment (Section 1) and personal communications with local landholders (Appendix O) suggests that over the last 100 years the water levels of shallow aquifers have reduced as have flow rates from springs and bores within the Willochra catchment. This may have resulted in a reduction of the distribution and extent of important aquatic habitat within the Willochra catchment.

The following sections discuss possible causes of habitat loss and apparent trajectories of the system.

Hydrology and geomorphology

Section 1 shows that the level of extraction is approaching or beyond the sustainable limits established under the *State Water Plan 2000.* Any reduction in flow is ecologically very significant for a dryland river; of equal or greater importance to the biota of the system are: aseasonal delays in flow onset; reduction in magnitude, duration and frequency of flow periods; loss of connectivity; and general loss of variability in flow volumes. It is an accepted 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 and Arthington 2002; Lloyd et al. 2004). Existing water extraction and management practice may well be impacting on the condition of the stream ecosystem as a whole by altering natural flow regimes.

Clearing of riparian vegetation and channel ploughing was identified in Section 1 (Conclusions – Channel Modifications) as a general risk to catchment condition. Apart from the loss of habitat and food resources, these practices potentially produce very large sediment export loads during flood events. Loss of riffle and other important habitat may occur through excess sediment load, decreasing habitat complexity.

Loss of permanent habitat and distribution of riparian vegetation

The condition of river red gum throughout the catchment is unknown, and warrants further investigation. Different biotic groups will respond to changed flow regimes on individual timescales and impacts may not become apparent at ecosystem level for decades (Lloyd et al. 2004). Based on landholder descriptions and the remnant patches and skeletons of river red gum evident from the vegetation mapping (Figure 73), it is possible that there has been some contraction of red gum distribution in the southern catchment.

Aerial videography within the zone north of the Willochra and Stony Creeks junction was reviewed to gain a preliminary appreciation of river red gum condition. The assessment showed that the majority age of skeletons was estimated to be greater than 100 years. It is therefore possible that the cause of death of these individuals was due to natural processes rather than recent human made alterations in flow regime. This is supported by landholder recollections that a loss of river red gums from the middle reaches has been occurring since before European settlement. Reduced flow frequencies could be accelerating or extending the spatial extent of natural successional changes in response to climatic cycles.

The most important step to successfully recruit to the adult population for red gums is not germination but seedling survival (Roberts and Marston 2000). While floods are not essential, spring–summer floods with summer recession provide ideal conditions. Seeds may germinate in winter during flood recession or under generally moist conditions but at a relatively low success rate. Survival of seedlings from winter germination then relies on a cool rainy summer following. Maintenance of red gum populations requires flood frequencies of between 1 and 3 years (Roberts and Marston 2000).

Whether the current river red gum populations are self sustaining was not assessed in this study. Self-sustaining populations must not only persist but regenerate. Young red gum trees of varying age were observed in some cropping areas, but were apparently absent from grazing land. This suggests either trampling or grazing pressure may be preventing regeneration on grazed land, but this requires further investigation.

It is probable that remnant patches of red gum are utilising groundwater rather than being reliant on inundation through overbank flows during flood events. It is possible that sub-lethal impacts of saline groundwater use by red gums has been exacerbated through reduced freshening following surface water flood events. This would potentially increase the stress on the remnant red gum patches.

River red gum and other riparian tree species have a profound influence on the ecology of any stream on which they are present. The ecological significance of riparian tree species on aquatic systems includes: provision of shade and shelter (regulating water temperatures and providing camouflage for fish species through light dappling); provision of significant substrate and habitat for aquatic flora and fauna via large woody debris from branch loss; improved bank and bed stability; and sources of food (terrestrial invertebrates, leaf litter).

Distribution of the Lake Eyre hardyhead

Although the number of surveys undertaken was small and did not include the entire catchment, a possible indicator of reduced connectivity resulting from changes to streamflow patterns, is the observed distribution of Lake Eyre hardyhead. While there appears to be permanent water along Spring Creek in the upstream reaches of the Willochra catchment that could theoretically support native fish populations, no fish were recorded in these areas.

The hardyhead has a life-cycle strategy that enables it to persist in ephemeral river systems. Under average or dry conditions they are not usually abundant, but during seasons of high rainfall and flooding episodes they are capable of opportunistic breeding, reaching peak abundances and dispersing rapidly, with enough of the population existing in refuge areas through dry seasons to ensure survival of the species (Ivantsoff and Crowley 1996). Re-colonisation from local extinctions has been known to occur from populations both upstream and downstream (Pierce et al. 2001).

Landholder observations suggest that historically the Lake Eyre hardyhead extended further upstream of the Willochra. Following the large flooding events in 1973 Jeff McCallum from a property on Rotten Creek south of Melrose observed “minnow like” fish, in Salt Creek (at the junction with the Willochra Creek) and within clay pans on the floodplain. The flooding event began in autumn and Mr McCallum observed these fish in spring. The fish disappeared as the pools became shallower and dried out in summer. Hardyheads were potentially sighted as far south as the junction between the Willochra and Rotten Creek (Jeff McCallum pers. com.).

Mr McCallum also observed the introduced species redfin and trout in Rotten Creek during the flooding events in 1997 and believes that these were sourced from locals stocking dams and permanent pools within the area. These species are often a significant threat to native fish populations.

Landholder evidence suggests that former aquatic refuges in the middle catchment may have been lost. Mr Reg Noll from a property near Wilmington recalled that in the Willochra Creek near the Hammond road bridge there existed small fishes approximately two inches long that looked similar to sardines. These fish have not been observed since 1950–1960 when the permanent waterholes in the mid reaches of the Willochra dried up. Locally it is acknowledged that during the period 1950–1960 the watertable in the Willochra Plain had lowered to the point where the groundwater no longer fed into these reaches of the Willochra Creek and the permanent pools dried up (Reg Noll pers. com.).

Loss of saline waterholes in the middle reaches provides a possible explanation for the apparent contraction of the Lake Eyre hardyhead to the lower reaches of the Willochra. The distances required to colonise upstream areas prior to flood recession and cease-to-flow during a single flood event may simply be too great for successful dispersal of biota. This would be exacerbated by the changes in flow regime. A lack of suitable habitat to support a staged migration through the middle reaches across multiple flow events, may prevent successful upstream migration and re-colonisation.

Any additional work to provide definitive indication of fish population dynamics needs to have a catchment wide focus. Further fish surveys would present an opportunity to test the above theories and should examine the distribution of hardyhead under drought and flood conditions across the entire catchment.

Adaptive management and monitoring

This study has collected, collated and reported information on key individual biological components and physical attributes of water-dependant ecosystems in the Willochra catchment. It is important that future work to answer the above questions be undertaken as part of an adaptive management regime for the entire catchment. This needs to be supported by effective and targeted monitoring and evaluation programs.

Due to the inherent variability of biological systems, it is not possible to obtain a comprehensive understanding of current condition based on a single survey. To confidently predict the status and trends in ecosystem patterns and processes requires conceptual models of ecosystem function, targeted monitoring of appropriate indicators and regular assessment of the findings over time. This is vital information to inform adaptive management practices and to ensure the system has an ecologically sustainable usage pattern.

Information collected during this study provides a good starting point to refine the indicator choices and other technical aspects of future programs. Most useful in this regard is the baseline mapping of the permanent pools, baseflow and riparian vegetation mapping. Design of an appropriate monitoring program requires a dedicated project to undertake follow up work on the preliminary findings presented here. This will also require additional research and assessment work, an outline of which is presented below.

Knowledge gaps

It should be acknowledged that this report applies only to the surveyed streams. Similar work is needed at a number of additional areas to provide a full catchment focus on the findings. Future work should include Kanyaka, Mt Arden, Castle and Boolcunda Creeks.

Some questions of interest for resource managers and the community raised by this study include:

(1) What is the condition of the river red gum population along the upper-middle reaches?

(2) Have human induced changes to flow or land-use contributed to:
   - loss of connectivity throughout the system
   - loss of semi-permanent or permanent aquatic habitat in the upper-middle reaches of the Willochra?

(3) What is the potential to ameliorate any impacts, through improved water resource management or on-ground works such as riparian re-vegetation?

(4) Where can re-vegetation of the southern reaches of the Willochra and tributaries be undertaken to achieve maximum biodiversity benefits?

(5) What is the catchment wide distribution of the Lake Eyre hardyhead under flood and drought conditions?

(6) What is its breeding and dispersal potential at the catchment scale during typical flood events under the current water regime and what impact might this be having on long-term sustainability?

(7) Does eastern gambusia pose a serious threat to Lake Eyre hardyhead populations at the pool scale, what conditions facilitate this and how can the risk be managed?
(8) What monitoring program design would be appropriate to guide an adaptive management approach within the catchment and provide a clear indication of ecosystem condition and trends?

Suggestions for further research

The following studies could be used to determine the health and condition of the Willochra Creek and tributaries.

(1) Geomorphic assessment of the Willochra watercourses:
  - Determine current physical condition of the watercourses and future trajectory of watercourse condition.
  - Determine watercourse reach rehabilitation potential and target condition.

(2) Impact of water use on riparian vegetation:
  - Baseline on-ground riparian vegetation association and floristic assessment.
  - The salinity levels in the downstream reaches of the catchment may be impacting upon the health of the vegetation in these areas. Salinity trends and vegetation health relationships should be investigated for these areas.
  - Many reaches in the southern part of the catchment have significant stands of river red gum that require flooding to regenerate and should be assessed to ensure that the river red gums populations are self-sustaining.
  - The riparian corridor may contain threatened and endangered vegetation species.

(3) Environmental water requirement assessment to determine sustainability of water dependant ecosystems:
  - Determine water requirements for water dependent ecosystems and target species to determine if current condition and/or future scenario are sustainable.
  - Significant areas of the catchment have not had an ecological or hydrological assessment (e.g. Boolcunda and Kanyaka Creeks).
  - A late summer survey is needed to determine the true dry season permanency of baseflow and pools within the assessed areas.
  - Identification of significant hyporheic zones within the catchment.

(4) A current condition and risk assessment of the water quality and quantity impacts in the Willochra catchment:
  - Geomorphic assessment as discussed in (1) above.
  - Assessment of watercourse health looking at bed and bank stability, channel disturbance; channelisation, levee banks, dams, sedimentation, cultivation.
  - Stream works type (e.g. weir, culvert, bridge) and stability (low, medium, high).
  - Groundwater and stream pumping structures.
  - Salinity trends and potable water supply.
  - Water pollution, septic tanks and water treatment, stock and wildlife sewage.

(5) To assess the risk from current water resource use on the ecological function of the Willochra system, a survey to assess fish distribution and habitat condition should be conducted. The distribution of fish both during and after a major flood event is of particular interest. This will help determine if the Willochra system still maintains the ecological

connectivity and functionality to support fish populations in the upper reaches of the catchment.

CONCLUSIONS

The aim of this report is to identify the main ecological assets within the Willochra Creek (and selected tributaries) and gain insight into the potential threats to these ecosystems. It should be acknowledged that further assets probably exist in unsurveyed areas of the catchment, and work should be undertaken to confirm this. While significant assets were found to exist in the lower catchment and upstream areas, these exist effectively in hydrological isolation and are likely to be almost entirely groundwater dependent for persistence.

Connectivity between the lower and upper reaches of the catchment is irregular due to the contributing impacts of the current climatic conditions, the number of farm dams in the catchment and the construction of large diversion banks along the main stem of Willochra Creek. These banks divert high flows onto the floodplain for flood irrigation purposes and thus a substantial volume of water has been removed from the watercourse by the time flows pass Wilmington.

The consequence of these practices is that the duration of dry spells within the wet/dry sequences of the lower reaches may also have increased, potentially causing a reduction in the frequency and duration of connectivity between upstream and downstream aquatic environments.

The key findings of the Willochra catchment hydrology assessment report (Section 1) indicate that there has been a substantial modification in the hydrological flow in the southern reaches of the Willochra catchment. Anecdotal evidence combined with the ecological assessment suggests that there has been a potential loss of aquatic habitat and fish within the upper and middle reaches of the Willochra catchment and a reduction in the number and duration of flow events suitable for recolonisation from downstream environments. This suggests that the ecological condition has declined, and the loss of connectivity during flow events is the major threat to the sustainability of water-dependent ecosystems in the study area.

Findings of the preliminary ecological study

- Loss of longitudinal and possibly lateral connectivity of the streams of the Willochra system has occurred
- This situation may have been compounded by the loss of permanent or semi-permanent aquatic habitat in the upper-middle reaches of the system
- Water extraction practices lead to reduced streamflow duration, and variability of flood events, with probable adverse impacts on the stream ecosystem
- Isolation has produced a sub-population of Lake Eyre hardyhead, of increased biodiversity value
- Reduced connectivity has possibly prevented system-wide dispersal of biota (e.g. fish) typical of ephemeral systems, increasing the potential for local extinctions, and may be contributing to the decline of riparian vegetation
- Significant areas of good aquatic habitat exist within the Flinders Ranges, which are likely to be dependent on groundwater for persistence. The baseflow and permanent pools maps in this report provide an indication of the potential spatial extent of this habitat.

- Important aquatic habitat areas in the upper and lower catchment warrant careful consideration regarding protection from threatening processes most notably, but not restricted to, reduced water levels and introduced species
- There is good potential to improve the condition of the system without necessarily requiring major reductions in water usage through an improved, coordinated and cooperative approach to water resource management practices. Targeted on-ground works and development of an adaptive management framework, informed by appropriate consultation, monitoring and evaluation programs, would support appropriate management for the longer term

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The plans of the relevant soil conservation boards will also likely contain useful information relating to the watercourses of the Willochra catchment.

APPENDIX J. RESULTS OF ON-GROUND SURVEYS

Site Number: 1 **Site Name:** Warrikimbo Gate

Site Location: 54H**:** N – 225891: E – 6462751
Assessment Officer: Glen Scholz Senior Ecologist DWLBC
Assistant: Lyz Risby Hydrologist DWLBC
Date / Time Assessment: 27/5/03 - 4:00pm
Site Photos: Lyz Risby

Warrikimbo site looking upstream

Warrikimbo site looking downstream

Site Physical Features:
Gorge environment
Series of rocky uplift with disjointed small pools
Surveyed site is a small rocky pool

- **Pool dimensions (m) -** 15 x 12
- **Pool depth (m) -** 1

Site Hydrological Features:
Area fed by a moderate baseflow. Site believed to dry up in dryer years (pers. com. Geoff Whatstall Partacoona stn.)

Substrate type: Rock and silt

Site Habitat:
Rocky gorge
Submerged vegetation: *Isolepis sp*.
Other vegetation: *Cymbopogon ambiguus, Cyperus gymnocaulos*

Stream cover: 60% rock, 10% *Isolepis*.

Vegetation condition / Land use: Light pastoral grazing

Water Quality:

- **Conductivity (mS/cm) –** 12.41
- **Temperature (c) –** 15.4
- **Transparency (m) -** >1
- **PH –** 9.25
- **Other –** Water body contains light tannins

Method of Sampling:

- Fish traps 5 x 1hr
- Trap depth average 0.4m

Fish species recorded:

Fish Species	Trap 1	Trap 2	Trap 3	Trap 4	Trap 5
Craterocephalus eyresii – Lake Eyre Hardyhead	1	8	75	69	4

Lake Eyre Hardyhead: (Photo Jason VanLaarhoven)

Date / Time of 'water bird ' assessment: 30/7/03 – 12:30pm

Method of 'water bird' survey:
20 minute observation over 1ha

Assessment Officer: Glen Scholz Senior, Ecologist, DWLBC
Assessment Officer: Jason VanLaarhoven, Ecologist, DWLBC

Results of 'water bird' survey:

- Pacific black Duck
- Masked Lapwing
- Red kneed Dotterel

Site Number: 2 **Site Name:** Partacoona gauging station

Site Location: 54H: N – 0225929: E – 6460973
Assessment Officer: Glen Scholz Senior Ecologist DWLBC
Assistant: Lyz Risby Hydrologist DWLBC
Date / Time Assessment: 27/5/03 – 4:30pm
Site Photos: Lyz Risby

Partacoona gauging stn looking up stream

Partacoona gauging stn looking down stream

Site Physical Features:

Gorge environment.

Series of rocky uplift with areas of gravel beds (riffles) and bars.

Stream unincised.

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

- **Pool dimensions (m) -** 70 x 15
- **Depth (m) –** 1 – 1.5

Site Hydrological Features:

Area fed by a slow – to moderate baseflow.

Substrate type: Rock bottom with silt / clay and some cobbles and gravel at the start of the pool.

Site Habitat:

Rocky gorge

Submerged vegetation: *Isolepis sp.*

Other vegetation: *Sclerostegia tenuis, Cyperus gymnocaulos, Maireana brevifolia, Juncus sp.*

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

Vegetation condition / Land use: Light pastoral grazing

Water Quality:

- **Conductivity (mS/cm) –** 11.27
- **Temperature (c) –** 14.3
- **Transparency (m) -** 1.5m
- **PH** – 9.27
- **Other-** Tannins present

Method of Sampling:

- Fish traps 5 x 1hr
- Trap depth average 0.4m

Fish species recorded:

Fish Species	**Trap 1**	**Trap 2**	**Trap 3**	**Trap 4**	**Trap 5**
Gambusia holbrooki – Eastern Gambusia	0	0	0	1	0

Site Number: 3 **Site Name:** Partacoona

Site Location: 54H: N – 0233092: E – 6459164
Assessment Officer: Glen Scholz Senior Ecologist DWLBC
Assistant: Lyz Risby Hydrologist DWLBC
Date / Time Assessment: 27/5/03 – 10:30am
Site Photos: Glen Scholz

Partacoona site looking upstream fish located in foreground backwater

Partacoona site looking down stream

Site Physical Features:

Rolling hills

Meandering stream with a long continuous run and larger shallow pools. Stream unincised with a shallow bank slope.

Surveyed site is a low flow backwater channel

- **Backwater dimensions (m) -** 60 x 2
- **Depth (m) –** 0.3m

Site Hydrological Features:

Area fed by a low baseflow, currently at near permanent flow level. Pools in this zone have never been recorded as dry (pers. com. Geoff Whatstall Partacoona stn.)

Substrate type: Silt / clay bottom covered with an algal mat with some cobbles and gravel

Site Habitat:

Saline wetland

Submerged vegetation: *Isolepis sp.*

Other vegetation: *Sclerostegia tenuis, Arthrocnemum halocnemoides, Juncus sp., Nitraria billardierei, Myoporum montanum, Atriplex lindleyi*

Stream cover: 5% Juncus, 2% submerged vegetation, 1% cobbles, 1% bank overhang

Vegetation condition / Land use: Light pastoral grazing

Water Quality:

- **Conductivity (mS/cm) –** 17.88
- **Temperature (c) –** 13.3
- **Transparency (m) -** >0.3m
- **PH** – 8
- **Other-** no tannins observed

Method of Sampling:

- Seine net over area 2x4m
- Depth average 0.2m

Fish species recorded:

Fish Species	**Seine1**
Craterocephalus eyresii – Lake Eyre Hardyhead	145
Gambusia holbrooki – Eastern Gambusia	3

Site Number: 4 **Site Name:** Simmonston crossing (upstream)

Site Location: 54H: N – 0230102: E – 6447881
Assessment Officer: Glen Scholz Senior Ecologist DWLBC
Assessment Officer: Jason VanLaarhoven Ecologist DWLBC
Date / Time Assessment: 30/7/03 – 3:30pm
Site Photos: Glen Scholz

Simmonston crossing (upstream) site looking upstream

Simmonston crossing (upstream) site looking downstream

Site Physical Features:
Rolling hills
Shallow pool and riffle sequence, with bedrock riffles. Stream unincised with a shallow bank slope.

- **Pool length (m) -** 150 x 6
- **Depth (m) –** 1.5

Site hydrological features:
Area fed by a low baseflow, currently at near permanent flow level.

Substrate type: Silt / clay bottom bedrock and cobbles

Site Habitat:
Saline wetland
Submerged vegetation: *Potamogeton pectinatus*
Other vegetation: *Juncus sp., Sclerostegia tenuis, Arthrocnemum halocnemoides, Cyperus gymnocaulos, Nitraria billardierei, Maireana pyramidata, Maireana brevifolia, Acacia victoriae, Myoporum montanum, Phragmites australis*

Stream cover: 30% *Juncus sp*, 30% *Phragmites australis*, 20% *Potamogeton pectinatus*

Vegetation condition / Land use: pastoral cattle grazing.
Moderate grazing on *Phragmites australis*, *Cyperus gymnocaulos* and *Myoporum montanum*.

Water Quality:
- **Conductivity (mS/cm) –** 31.2
- **Temperature (c) –** 13.1
- **Transparency (m) -** >1
- **PH –** 8.74

Method of Fish Sampling:
- No fish sampling occurred
- Site observation found a small school (>100 fish) along the edge of *Potamogeton pectinatus*. Behaviour and appearance suggest the species to be *Craterocephalus eyresii* – Lake Eyre Hardyhead.

Site Number: 5 **Site Name:** Castle Creek Junction

Site Location: 54H: N – 0228899: E – 6440986
Assessment Officer: Glen Scholz Senior Ecologist DWLBC
Assessment Officer: Jason VanLaarhoven Ecologist DWLBC
Date / Time Assessment: 30/7/03 – 12:00pm
Site Photos: Jason VanLaarhoven

Castle Creek Junction site looking upstream

Castle Creek Junction site looking downstream

Site Physical Features:

Rolling hills and lowlands

Meandering stream with a long shallow pools and interconnecting riffles and runs. Stream unincised with a shallow bank slope.

- **Pool dimensions (m) -** 250 x 10
- **Depth (m) –** From 0.1m to 1m

Site Hydrological Features:

Area fed by a low baseflow, currently at near permanent flow level.

Substrate type: Silt / clay bottom covered with in-stream submerged vegetation

Site Habitat:

Saline wetland

Submerged vegetation: *Potamogeton pectinatus*

Other vegetation: *Sclerostegia tenuis, Arthrocnemum halocnemoides, Nitraria billardierei, Maireana pyramidata, Maireana brevifolia, Acacia victoriae, Cyperus vaginatus.*

Stream cover: 30% deep pools, 50% shallow pools, 20% submerged vegetation

Vegetation condition / Land use: Light pastoral grazing.

Historically site heavily grazed, noted by density and extent of *Nitraria billardierei* and *Maireana pyramidata*.

Water Quality:

- **Conductivity (mS/cm) –** 31
- **Temperature (c) –** 12.9
- **Transparency (m) -** >1
- **PH –** 8.99

Method of Fish Sampling:

1. Fish traps 10 x 1hr
   - Trap depth average 0.4m

Fish species recorded:

Fish Species	Trap 1	Trap 2	Trap 3	Trap 4	Trap 5	Trap 6	Trap 7	Trap 8	Trap 9	Trap 10
None recorded	-	-	-	-	-	-	-	-	-	-

2. Small seine net 3 x 50m

Fish species recorded:

Fish Species	1	2	3
Craterocephalus eyresii – Lake Eyre Hardyhead	3	2	3

3. Large seine net 1 x 50m

Fish species recorded:

Fish Species	1
Craterocephalus eyresii – Lake Eyre Hardyhead	6

- Fish size range: From 16mm to 52mm

Method of 'water bird' sampling:
20 minute observation over 1ha.

- Pacific black Duck
- White faced Heron
- Hoary headed Grebe
- Black winged Stilt
- Red necked Avocet
- Red kneed Dotterel

Site Number: 6 **Site Name:** Pichie Richie Creek, Whitehead Rd crossing

Site Location: 54H: N – 224385: E – 6418253
Assessment Officer: Glen Scholz Senior Ecologist DWLBC
Assistant: Lyz Risby Hydrologist DWLBC
Date / Time Assessment: 28/5/03 - 10:45am
Site Photos: Glen Scholz

Pichie Richie Creek site looking upstream

Pichie Richie Creek site looking downstream

Site Physical Features:

Lowland plains

Cobble based stream with cobble riffles and shallow pools

Surveyed site is a small rocky pool

- **Pool dimensions (m) -** 25 x 10
- **Pool depth (m) –** 0.6

Site Hydrological Features:

Site may be at close proximity to the watertable, the site appears to be influenced by a recent surface flow event.

Substrate type: cobbles and clay

Site Habitat:

Eucalyptus open forest

Shallow cobble based stream

Vegetation: *Juncus sp., Eucalyptus camaldulensis, Cyperus gymnocaulos, Myoporum montanum*

Stream cover: 70% Cobble, 10% *Eucalyptus camaldulensis*, 5% *Juncus sp*., 5% snags.

Vegetation condition / Land use: Pastoral grazing. Moderate level has allowed regeneration of *E. camaldulensis* and *M. montanum*.

Water Quality:

- **Conductivity (mS/cm) –** 5.32
- **Temperature (c) –** 11.3
- **Transparency (m) –** 0.4
- **PH –** 8.49
- **Other –** Water body contains clay colloids

Method of Sampling:

- Fish traps 5 x 1hr
- Trap depth average 0.4m

Fish species recorded:

Fish Species	**Trap 1**	**Trap 2**	**Trap 3**	**Trap 4**	**Trap 5**
None recorded	-	-	-	-	-

Site Number: 7 **Site Name**: Spring Creek**,** Cannon Swamp

Site Location: 54H**:** N – 0230690: E – 6373643
Assessment Officer: Glen Scholz Senior Ecologist DWLBC
Assistant: Jason VanLaarhoven Ecologist DWLBC
Date / Time Assessment: 29/7/03 - 2:00pm
Site Photos: Glen Scholz

Cannon Swamp site looking upstream

Cannon Swamp site looking downstream

Site Physical Features:
Partly confined valley with discontinuous floodplains.
A pool and riffle sequence

- **Pool dimensions (m) –** 80 x 2
- **Pool depth (m) –** 0.25 – 0.8

Site Hydrological Features:
Area fed by a moderate baseflow. Site contains Typha, which suggests site is maintained by groundwater or permanent baseflow. Stream unincised.

Substrate type: Cobble, pebble and gravel

Site Habitat:
Eucalyptus open forest
Valley in good natural condition, well vegetated.
Vegetation: *Eucalyptus camaldulensis, Typha domingensis, Cyperus vaginatus, Nitraria billardierei, Juncus sp., Dodonaea sp.,* floating vegetation.
Exotic species: *Rosa sp*., (Wild Rose)

Stream cover: 60% *Typha domingensis*, 35% rock / cobble

Vegetation condition / Land use: Conservation and light pastoral grazing.

Water Quality:

- **Conductivity (mS/cm) –** 0.5
- **Temperature (c) –** 10.4
- **Transparency (m) -** >1
- **PH –** 8.5

Method of Sampling:

- Fish traps 3 x 1hr
- Trap depth average 0.4m

Fish species recorded:

Fish Species	Trap 1	Trap 2	Trap 3
None recorded	-	-	-

Method of 'water bird' sampling:
20 minute observation over 1ha

Assessment Officer: Glen Scholz Senior Ecologist DWLBC
Assessment Officer: Jason VanLaarhoven Ecologist DWLBC
Date / Time Assessment: 29/7/03 – 2:30pm

- No water birds observed

Site Number: 8 **Site Name**: Spring Creek, Goat Rock Falls

Site Location: 54H: N – 0231586: E – 6369637
Assessment Officer: Glen Scholz Senior Ecologist DWLBC
Assistant: Jason VanLaarhoven Ecologist DWLBC
Date / Time Assessment: 29/7/03 - 3:30pm
Site Photos: Glen Scholz

Goat Rock Falls site looking upstream

Goat Rock Falls site looking downstream

Site Physical Features:

Gorge plunge pool

- **Pool dimensions (m) –** 20 x 15
- **Pool depth (m) –** 0.5 – 1

Site Hydrological Features:

Area fed by a strong consistent flow. Site appears to be maintained by some baseflow all year round. Stream unincised.

Substrate type: Cobble, pebble and gravel

Site Habitat:

Valley gorge.

Vegetation: *Eucalyptus camaldulensis, Cyperus vaginatus, Nitraria billardierei, Dodonaea sp., Dianella revoluta*

Stream cover: 90% Cobbles / pebbles, 10% branches and leaf litter.

Vegetation condition / Land use: Conservation area, historically moderate pastoral grazing.

Water Quality:

- **Conductivity (mS/cm) –** 0.185
- **Temperature (c) –** 8.1
- **Transparency (m) -** >1
- **PH –** 8.5
- **Other:** contains some tannins

Method of Sampling:

No sampling, site observations did not indicate the presence of any fish species

APPENDIX K. MUSEUM FISH RECORDS

A review of historic South Australian Museum records produced the following results.

Species	Coll Date	Nearest Named Place		# fish
Craterocephalus eyresii	12-Oct-61	Willochra Creek	10 miles west of Gordon	many
Craterocephalus eyresii	9-Aug-76	Kanyaka Creek	Between Quorn & Hawker (Quorn-Hawker Road?)	1
Craterocephalus eyresii	23-Aug-76	Willochra Creek	North Of Quorn	7
Craterocephalus eyresii	8-May-81	Willochra Creek	Near Quorn	40
Craterocephalus eyresii	31-Jan-90	West Beda Hill	Lake Torrens	1
Craterocephalus eyresii	28-May-94	Willochra Creek	Mawson Trail (Probys Grave Road near Simmonston)	1
Gambusia holbrooki	28-May-94	Willochra Creek	Mawson Trail (Probys Grave Road near Simmonston)	1
Craterocephalus eyresii	Unknown	Lake Torrens	Mound springs on northern tip of Lake Torrens	3

APPENDIX L. BIOLOGICAL FEATURES OF FISH IDENTIFIED IN THE WILLOCHRA CATCHMENT

(Source: DWR 2001: South Australian Aquatic Biota Database)

Species:	Craterocephalus eyresii	***Order:***	Atheriniformes
Common Name:	Lake Eyre hardyhead, smelt minnow, whitebait	***Family:***	Atherinidae

Endemicity:	Native
Population Status:	This fish is not usually abundant but is capable of opportunistic breeding and peak abundances under favourable conditions, with enough animals surviving dry seasons in refuge areas to ensure continuation of the species (Ivantsoff and Crowley 1996).
Conservation Status:	No formal conservation concerns within S.A. (Robinson et al. 2000).
Distribution Patterns:	Range in 1989 included the Lake Eyre drainage of S.A. and the N.T. as well as the Murray-Darling system of S.A., northern Victoria, and western N.S.W. (Allen 1989). It has also been reported to occur (on the basis of a single specimen) east of the Great Dividing Range in the Hunter River, N.S.W. (Allen 1989).
Observed Locations:	Restricted to a small part of South Australia, being present in the Lake Eyre drainage west of the Flinders Ranges; also in the Frome River, springs and man-made bores around Lake Eyre (Ivantsoff and Crowley 1996).
Significance / Utility:	No commercial value and although easy to maintain in captivity it is fairly inconspicuous and therefore not generally used as an aquarium fish (Ivantsoff and Crowley 1996). Its primary importance is as a food source for piscivorous waterbirds during times of flooding in Lake Eyre (Ivantsoff and
Size:	It rarely attains a maximum size of 80 mm SL, but in general the largest fish do not exceed 60 mm SL (Allen 1989); can reach 96 mm but typically between 60-70 mm in length (Ivantsoff and Crowley
Longevity:	Can survive for a long time in captivity (Ivantsoff and Crowley 1996).
Migratory Behaviour:	Freshwater
Dispersal Capacity:	Able to opportunistically breed and disperse rapidly during rainy seasons and flooding episodes at Lake Eyre (Ivantsoff and Crowley 1996).
Migration:	No information.
Movement:	See 'Migration'.
Migratory Triggers:	No information.
Fecundity:	Females produce between 73-144 large ova (>0.9 mm in diameter) and 1,132-1,701 (Llewellyn 1979).
Egg Description:	Ova range from 0.1-1.9 mm in diameter (Llewellyn 1979). Eggs are about 1mm in diameter (Ivantsoff and Crowley 1996). Eggs more than 1 mm in diameter Llewellyn 1983).
Breeding:	Breeding may be opportunistic according to water and food availability, with peak breeding and dispersal occurring during rainy seasons or in times of flooding at Lake Eyre (Ivantsoff and Crowley 1996). Breeding season is thought to be from late summer through to early autumn (Cadwallader and Backhouse 1983); from January to March (Llewellyn 1983); eggs develop between January and March

(Ivantsoff and Crowley 1996). The spawning site is generally among aquatic plants (Cadwallader and Backhouse 1983).

Diet: May be a generalist feeder.

Habitat: Larvae: specific habitat preferences unknown. Juveniles and adults: inhabits fresh and highly saline water in streams, lakes and lagoons (Allen 1989), bores, springs and rivers (Ivantsoff and Crowley 1996); often associated with weeds or occurring over gravel beds in slow flowing sections of rivers or streams (Lloyd and Walker 1986, Allen 1989, Ivantsoff and Crowley 1996); found at river edges and in backwaters (Lloyd and Walker 1986). Spawning habitat: amongst aquatic weeds (Cadwallader and

Behaviour: Larvae: little known. Juveniles and adults: inconspicuous; tends to be benthic when observed in captivity, keeping close to the bottom of the tank (Ivantsoff and Crowley 1996); schooling species (Cadwallader and Backhouse 1983). Numbers peak during breeding flushes associated with flood and rainy season conditions, then rapidly fall in response to evaporation and increasing salinity as water levels subside and conditions are less favourable; enough animals survive dry seasons by utilising refuge areas to enable the species to persist (Ivantsoff and Crowley 1996).

Competitors: No information.

Predators: Important food source for pelicans, cormorants and whiskered terns when Lake Eyre is in flood (Ivantsoff and Crowley 1996).

Parasites: No information.

Diseases: No information.

Flow Responses: Requires flooding or rain season conditions (when associated with sufficient food) to breed; generally favour areas of low flow within a waterway (Ivantsoff and Crowley 1996). Require refuge areas (with adequate water, food and appropriate physico-chemical conditions) to survive periods of drought (Ivantsoff and Crowley 1996).

FISH

Threats: Loss of refuge areas, the persistence of prolonged drought conditions, and water salinities in excess of 100 ppt.

Physico Chemical Tolerances: Salinity: found in fresh and saline waters (Cadwallader and Backhouse 1983); can withstand salinities as high as 100 ppt (three times the salinity of sea water) (Merrick and Schmida 1984, Ivantsoff and Crowley 1996); tolerant of pure fresh to highly saline waters (possibly up to 100 ppt) (Allen 1989); can tolerate salinities of 30.9 ppt (Chessman and Williams 1974) and 61.9 ppt (Bayly and Williams 1966). Oxygen: since this species can survive in lakes and refuge areas during times of drought it is possibly tolerant to hypoxic conditions although the limits of its tolerances are unknown. Turbidity: occurs in both turbid and clear water (Allen 1989). Velocity: most frequently associated with slow velocity water (Allen 1989, Ivantsoff and Crowley 1996); also found in lakes (Allen 1989) where there would be an absence of unidirectional flow. Temperature: tolerant of water temperatures between 10-37oC (Merrick and Schmida 1984)

Comments:

Environmental Provinces:	***Drainage Basins:***
Flinders Ranges	
Northern Arid	

FISH

Species:	Gambusia holbrooki	***Order:***	Atheriniformes
Common Name:	eastern gambusia, plague minnow, mosquitofish	***Family:***	Poeciliidae

Endemicity: Introduced

Population Status: Populations secure (Watts 1990); exists as reproducing population(s) in S.A. (Pierce in prep).

Conservation Status: Not applicable.

Distribution Patterns: Native to rivers draining into the Gulf of Mexico. It has been introduced into many countries, including Australia; probably the most widely distributed freshwater fish in the world (Lloyd et al. 1986). Introduction to Australia is not well documented, thought to have occurred in the 1920s for use in aquaria, with subsequent release into the wild as a potential mosquito control agent (McDowall 1996a). Has been established in the wild in Australia since 1925 (Lloyd et al. 1986). It is now widespread and common throughout New South Wales, South Australia and Victoria, occurring in both inland and coastal drainages, and is also present in the coastal drainages of Queensland, and in parts of the Northern Territory and Western Australia (McDowall 1996a).

Observed Locations: Found in the Gawler catchment (Hicks and Sheldon 1999).

Significance / Utility: Although released in the wild to control malarial and other mosquitoes, it is probably of no more value in this capacity than the range of Australian native freshwater insectivorous fishes. Probably a threat to native species of fish which occupy a similar ecological niche. Are easy to keep in aquaria but is best kept alone due to its tendency to attack other fish and nip their fins (McDowall 1996a).

Size: The species displays sexual dimorphism in relation to size, with females capable of reaching a total length (TL) of 60 mm, and males about 35 mm (McDowall 1996a).

Longevity: No information.

Migratory Behaviour: Freshwater

Dispersal Capacity: Due to its high range of physico-chemical tolerances and generalist life style this species has rapidly invaded and become established in Australia. Its rapid maturation, overall relatively high fecundity and the mode of reproduction (giving birth to live young with a relatively high conversion of young to adults) has contributed to its spread throughout parts of this country.

Migration: Is not known to migrate as part of its life cycle.

Movement: See 'Migration'.

Migratory Triggers: No information.

Fecundity: Gives birth to live young. Fecundity averages about 50, but can be as high as 100, with as many as 300 young being reported in one female (McDowall 1996a).

Egg Description: No information.

Breeding: The males anal fin is thickened and elongated to form the gonopodium, which are used to facilitate internal fertilisation of eggs in the female. The male deposits the sperm at the mouth of the females genital opening using the gonopodium. The internal development of the young takes between 3-4 weeks, and they are produced throughout the warmer months (McDowall 1996a). The peak reproductive activity occurs in spring (mainly October), and up to 9 broods can be produced in one year. The new born young are small (a few millimetres long) but grow rapidly and females may achieve sexual maturity in under two months (and about 21 mm long). The breeding season is probably much longer in northern, warmer waters, with one southern Queensland population being found to have an extended season lasting from October to April (McDowall 1996a).

Diet: This is an adaptable generalist predator, able to change its diet in response to food availability. It feeds on a range of aquatic and terrestrial organisms, particularly terrestrial insects such as ants and flies, as well as aquatic bugs and beetles(McDowall 1996a). This fish is believed to be a visual predator (see Reddy 1975, Booth 1980, Bence and Murdock 1986); food recognition seems to occur after an item has been captured, with fish attacking items outside the range of sizes they could handle (Watt 1990). Lloyd (1987) describes the species as an opportunistic omnivore which feeds from all parts of the water column. When in high densities this species eats the young and eggs of other small native fish (McDowall 1996a); and it also preys on small anuran larvae (e.g. Crinia and Litoria spp.) (Blyth 1994, Morgan and Buttemer 1996) and probably the eggs of anurans (Blyth 1994). This species is classified in trophic group 4 (microphagic carnivores) by Harris (1995), but could be classified in trophic group 3 according to feeding information in Lloyd (1987).

Habitat: Typically inhabits the shallow margins of streams and the edges of aquatic vegetation beds, in warm waters (preferably between 25-38oC) with low flow velocities (e.g. gently flowing or still waters). This species can survive well under degraded conditions (McDowall 1996a). Gambusia is reported to favour permanent rather than temporary waters, unlike many native fish species (IFRP 1989); a finding which is supported by the field work of Wedderburn (2000) who found an association between this species and permanent lagoons with a high sedimentary organic content (Wedderburn 2000).

FISH

Behaviour: At high densities intimidates small native fish by fin nipping, and also eats their young and eggs (McDowall 1996a). Primarily a pelagic species.

Competitors: Competes with small native fish for habitat and resources. Its aggressive and intimidatory behaviour with other fish (e.g. fin nipping which leaves damaged fish more susceptible to infection), combined with its tendency to prey on the young and eggs of other fish and its adaptable generalist predatory strategy, makes this a competitively superior species, able to outcompete the majority of native fish (McDowall 1996a). Its ability to do well in degraded habitats also favours this fish over native species with which it co-occurs.

Predators: Probably a food source for introduced trout (McDowall 1996a). Purple spotted gudgeon are known to prey on young mosquito fish (Phipps 2000).

Parasites: Mosquito fish have been found to be infected by the Asian fish tapeworm (the cestode) Bothriocephalus acheilognathi (Dove et al. 1997). Compared to native fish species G. holbrooki carries a relatively light parasite load in Australian waters (Lloyd 1990).

Diseases: No information.

Flow Responses: Shallow slow flowing (and preferably warm) margins of streams.

Threats: This species poses a serious potential threat to all native fish (Lloyd et al. 1986, Lloyd 1989, Rupp 1996) and has been shown experimentally to negatively impact on the growth and reproduction of Pacific blue-eye (Pseudomugil signifer) (Howe et al. 1997); it is a significant major threat to native fish with which it co-occurs and competes; along with brown trout appears to be the introduced species of most threat to native fishes (Wagner and Jackson 1993). It is an extremely successful invader of new aquatic habitats due to its aggressive nature, high reproductive capacity (in combination with a short generation time), wide environmental tolerances and high genetic variability (Walter and Meffe 1989). It has been shown to target anuran eggs and larvae (Blyth 1994, Morgan and Buttemer 1996, Webb and Joss 1997), its spread has been linked to the decline of frog populations in N.S.W., and it is thought to be responsible for the decline of 35 species of fish world wide (Phipps 2000). In Australia it has been implicated in the decline of Ambassis, Chlamydogobius, Craterocephalus, Galaxias, Melanotaenia, Mogurnda, Pseudomugil, Retropinna and Scaturiginichthys species (Wagner and Jackson 1993). In S.A. it has been linked to the decline of the purple spotted gudgeon in the Murray Valley (where it is now believed to be extinct) (Phipps 2000). Mosquito fish have been found to be infected by the Asian tapeworm (B. acheilognathi). This cestode has recently been found to infect Hypseleotris klunzingeri, and it may infect other native fish species, which is significant in view of the high pathogenicity associated with infection in other known hosts (Dove et al. 1997). Its relatively light parasite burden in Australian waters compared to native species may contribute to growth of populations of this species at the expense of native fish populations (Lloyd 1990). Has been associated with decreased zooplankton and littoral invertebrate diversity in N.S.W. lakes, particularly coastal lakes with abundant alien vegetation (Timms 1992).

Physico Chemical Tolerances: Salinity: tolerant of a wide range of salinities, from freshwater to full marine salinities or higher (McDowall 1996a); found in Noora evaporation basin in water twice as saline as the sea (Herbert pers. comm, cited in Phipps 2000). Temperature: tolerant of extreme temperatures (0-400C), surviving at temperatures as high as 44oC and even surviving iced-over waters. It is similarly able to survive very low oxygen tensions (McDowall 1996a).

Comments:

Environmental Provinces: ***Drainage Basins:***

Adelaide Plains

Eastern Pastoral

Flinders Ranges

Mt Lofty Ranges

Murray Mallee

Northern Arid

South East

Western Pastoral

Yorke Peninsula

APPENDIX M. BIRD RECORDS FOR WILLOCHRA CATCHMENT

A review of Bird Atlas of Australia (www.birdsaustralia.com.au/atlas/) records produced the following results for the Willochra catchment area. Waterbirds and are highlighted yellow, those in green are those that are dependent upon aquatic habitat.

Emu	Sharp-tailed Sandpiper	Blue-breasted Fairy-wren	Rufous Whistler
Stubble Quail	Curlew Sandpiper	White-winged Fairy-wren	Grey Shrike-thrush
Brown Quail	Black-winged Stilt	Striated Grasswren	Restless Flycatcher
Freckled Duck	Banded Stilt	Spotted Pardalote	Magpie-Lark
Black Swan	Red-necked Avocet	Striated Pardalote	Grey Fantail
Australian Shelduck	Red-capped Plover	Chestnut-rumped	Willie Wagtail
Australian Wood Duck	Inland Dotterel	Rufous Fieldwren	Black-faced Cuckoo-Shrike
Mallard	Black-fronted Dotterel	Redthroat	Ground Cuckoo-Shrike
Pacific Black Duck	Red-kneed Dotterel	Weebill	White-winged Triller
Australasian Shoveler	Banded Lapwing	Inland Thornbill	Masked Woodswallow
Grey Teal	Masked Lapwing	Chestnut-rumped Thornbill	White-browed
Chestnut Teal	Australian Pratincole	Buff-rumped Thornbill	Black-faced Woodswallow
Pink-eared Duck	Silver Gull	Yellow-rumped Thornbill	Dusky Woodswallow
Hardhead	Whiskered Tern	Yellow Thornbill	Little Woodswallow
Australasian Grebe	Rock Dove	Southern Whiteface	Grey Butcherbird
Hoary-headed Grebe	Spotted Turtle-Dove	Red Wattlebird	Pied Butcherbird
Little Pied Cormorant	Common Bronzewing	Little Wattlebird	Australian Magpie
Pied Cormorant	Crested Pigeon	Spiny-cheeked Honeyeater	Grey Currawong
Little Black Cormorant	Diamond Dove	Striped Honeyeater	Australian Raven
Great Cormorant	Peaceful Dove	Noisy Miner	Little Raven
White-faced Heron	Galah	Yellow-throated Miner	Little Crow
White-necked Heron	Little Corella	Yellow-faced Honeyeater	White-winged Chough
Great Egret	Sulphur-crested Cockatoo	Singing Honeyeater	Apostlebird
Cattle Egret	Cockatiel	White-eared Honeyeater	Singing Bushlark
Australian White Ibis	Rainbow Lorikeet	Purple-gaped Honeyeater	Skylark
Royal Spoonbill	Purple-crowned Lorikeet	Yellow-plumed Honeyeater	Richard's Pipit
Yellow-billed Spoonbill	Crimson Rosella	Grey-fronted Honeyeater	House Sparrow
Black-shouldered Kite	Australian Ringneck	White-plumed Honeyeater	Zebra Finch
Black Kite	Blue Bonnet	Brown-headed Honeyeater	Diamond Firetail
Whistling Kite	Red-rumped Parrot	New Holland Honeyeater	Mistletoebird
Spotted Harrier	Mulga Parrot	White-fronted Honeyeater	White-backed Swallow
Brown Goshawk	Budgerigar	Tawny-crowned	Welcome Swallow
Collared Sparrowhawk	Elegant Parrot	Eastern Spinebill	Tree Martin
Wedge-tailed Eagle	Pallid Cuckoo	Black Honeyeater	Fairy Martin
Little Eagle	Fan-tailed Cuckoo	Pied Honeyeater	Clamorous Reed-Warbler
Brown Falcon	Black-eared Cuckoo	Crimson Chat	Little Grassbird
Australian Hobby	Horsfield's Bronze-Cuckoo	Orange Chat	Rufous Songlark
Grey Falcon	Shining Bronze-Cuckoo	White-fronted Chat	Brown Songlark
Black Falcon	Southern Boobook	Jacky Winter	Silvereye
Peregrine Falcon	Barn Owl	Scarlet Robin	Bassian Thrush
Nankeen Kestrel	Tawny Frogmouth	Red-capped Robin	Common Blackbird
Australian Spotted Crake	Australian Owlet-nightjar	Hooded Robin	Common Starling
Dusky Moorhen	Fork-tailed Swift	White-browed Babbler	Crow and Raven spp.
Black-tailed Native-hen	Laughing Kookaburra	Chestnut-crowned Babbler	Snipe spp.
Eurasian Coot	Red-backed Kingfisher	Chirruping Wedgebill	
Little Button-quail	Sacred Kingfisher	Varied Sittella	
Painted Button-quail	Rainbow Bee-eater	Crested Shrike-tit	
Marsh Sandpiper	Brown Treecreeper	Crested Bellbird	
Common Greenshank	Splendid Fairy-wren	Gilbert's Whistler	
Red-necked Stint	Variegated Fairy-wren	Golden Whistler	

APPENDIX N. HABITAT AND FEEDING PREFERENCES, WATERBIRDS OF INLAND SOUTH AUSTRALIA

NOTE: The information provided in these tables has been condensed from material, sourced from the South Australian Aquatic Biota Database (DWR 2001).

Key: MH – Migration Habits; D – dispersive, S – sedentary, M – migratory

Common Name	MH	Habitat Preference	Nesting preference	Diet	Feeding
Australian Pelican	**D**	Large open water	Low islands or sand spits,	Carnivore, fish mostly, also insects and crustaceans	Herding fish into shallows to feed
Black Swan		Large open water permanent not specific	Not specific, on islands, in reeds, or among shrubs	Herbivore, mostly leaves and shoots of aquatic plants also grasses	Can secure food only to depth of 1m
Australian Wood Duck	**D**	Grasslands and pasture associated near wetlands (terrestrial)	Tree hollows	Herbivore, mostly grasses, also grains and insects	Mostly grazing on land
Pacific Black Duck	**S**	Open water with dense fringing vegetation, not specific	Often in tree hollows, less on the ground amongst bushes	Omnivore, mostly seeds and vegetative material, sedges smartweeds and grasses	Not specific, dabble water surface, sift mud, strip seeds
Australian Shelduck	**M** **S**	Large open water, along the shoreline of shallow habitats (prefer salt affected wetlands)	Often in tree hollows, less on the ground amongst bushes and rabbit burrows	Omnivore, mostly vegetation and invertebrates, some molluscs	Not specific, dabble water surface, sift mud, strip seeds
Grey Teal	**D**	Large shallow inland waters, not specific	Often in tree hollows, less on the ground amongst bushes and reeds	Omnivore, mostly seeds and vegetative material, sedges smartweeds and grasses	Not specific, dabble water surface, sift mud, strip seeds
Pink Eared Duck	**D**	Large shallow inland waters, (aquatic)	Usually over water in trees, cane grass, lignum, chenopods	Omnivore, mostly invertebrates also algae and floating seeds	Filter feeder limited to water and sifting mud
Hardhead	**D**	Open deep water with dense fringing vegetation, (aquatic) (uncommon on salt affect. wetlands)	In dense reeds, on islands and lignum, melaleuca	Omnivore, mostly aquatic plants also molluscs and crustaceans	Mostly from diving also dabbling and strip seeds

Common Name	---	Habitat Preference	Nesting preference	Diet	Feeding
Blue-billed Duck	**M**	Large open water permanent with fringing vegetation (aquatic)	In dense vegetation, reeds, lignum, melaleuca, occasionally	Omnivore, plant material and insects also molluscs and crustaceans	Mostly from diving also surface of the water and strip seeds
Australasian Shoveller		Large open water permanent with fringing vegetation (aquatic)	On the ground in grassy sites usually close to waters edge	Omnivore, mostly insects also seeds	Feed off the surface of the water
Pacific (white necked) Heron	**D**	Shallow inland waters and flooded lands, with sparse grasses, herbs, sedges, rushes, elocharis. Not specific	Nest on limbs in trees	Carnivore, small aquatic and terrestrial animals (rarely fish) also molluscs and crustaceans	Standing, stalking and striking prey. Feed in shallow water <7 cm and steep banked waters.
White-faced Heron	**N**	Not specific, river systems, floodplains, swamps, fresh and saline	Nest in trees not necessarily near water	Carnivore, a wide range of vertebrates and invertebrates also crustaceans	Standing, stalking and striking prey in shallow waters.
Great Egret		Open shallow floodplain waterbodies permanent, not specific	Nest in upper parts of trees standing in water 7-15m above ground	Carnivore, mostly fish also insects, crustaceans, molluscs and birds	Standing, stalking and striking prey in shallow waters. Forage in shallow waters <30cm deep
Little Egret		Open shallow floodplain waterbodies, with abundant aquatic veg. and little to no emergent veg.	Nest on limbs in trees from water level to 7m above	Carnivore, mostly fish (mainly <2cm) also insects, crustaceans	Standing, stalking and striking prey in shallow waters. Forage in shallow waters <10 –15cm deep
Nankeen Night Heron	**N**	Open shallow floodplain waterbodies permanent, with wooded edges and / or tall sedges and reeds	Nest in trees, on top of shrubs, lignum and s	Carnivore, mostly fish also animals, insects and crustaceans	Nocturnal. Standing, stalking and striking prey in shallow waters and pursue prey on land.
Glossy Ibis	**M**	Floodplain waterbodies, along the shoreline of shallow habitats with abundant aquatic flora. (Prefer freshwater, avoid dry ground)	Nest on top and in lignum at 10-50 cm above water level	Carnivore, mostly aquatic invertebrates, also molluscs, crustaceans and insects	Slowly walking sifting mud, water surface and from grasses

Common Name	---	Habitat Preference	Nesting preference	Diet	Feeding
Straw-necked Ibis		Shallow wetlands, grasslands with trees, shrubs and reeds	Nest amongst lignum, reeds and sedges, on islands or over water<1m deep	Omnivore, mostly a wide range of vertebrates and invertebrates also crustaceans, molluscs some seeds and plant material	Feed by probing into ground or vegetation into shallow water
Royal Spoonbill		Not specific, wetlands, grasslands along shallow margins	In trees, lignum, reeds and rushes usually over water 0.5 to 1.5m deep in trees 1 to 15m high or reeds 0.5 to 1.5m high.	Omnivore, mostly fish also crustaceans, aquatic insects and vegetable matter	Wading sweeping, probing, grabbing in shallow water <40cm. Substrate of sand, mud and clay
Yellow-billed Spoonbill		Shallow wetlands, with abundant aquatic flora with sparse or low vegetation	Nest often in tree side branches 2 – 8m high over water	Carnivore, mostly aquatic insects also crustaceans and fish	Wading sweeping, probing, grabbing in shallow water <40cm. Substrate of sand, mud and clay
Brolga	**S**	Near open shallow wetlands (swamps and marshes) <2m deep	Prefer nesting in marshes <50cm deep and meadows <30cm deep, on the ground or small island, sedge and rushes, grasses or cane grass and lignum, occasionally floating nests	Omnivore, mostly tubers of sedges (particularly elocharis) and pasture, also insects molluscs and crustaceans	Slowly walking grazing and digging, also striking prey
Great Cormorant	**N** **D**	Deep open lakes / marshes and major rivers, permanent	Not specific, trees, bushes, lignum, rocks, on-ground near water	Carnivore, predominantly fish also crustaceans and insects	Most taken by pursuit diving, also wading in shallows
Pied Cormorant	**S**	Deep open lakes / marshes and major rivers, permanent, with fringing trees and islands	In trees and dense shrubs (lignum)	Carnivore, predominantly fish also insects	All food taken by pursuit diving
Little Black Cormorant	**D**	Deep open lakes / marshes and major rivers, permanent >1m deep, 90% on wetlands >100ha	Flooded trees away from land in vegetated swamps and lakes	Carnivore, predominantly fish also crustaceans	Most taken by pursuit diving
Little Pied Cormorant	**D**	Open lakes / marshes and major rivers, use smaller wetlands than other cormorant sp.	In trees, bushes, lignum and snags around 2.8m above water	Carnivore, prey on crustaceans more and take fish taken less often than other cormorants	Food taken by a succession of dives taking more sedentary prey in shallow waters

Australian Darter		Open lakes / marshes and major rivers, permanent smooth water >50cm deep	In branches of flooded trees around 3.5m above water	Omnivore, predominantly fish also insects and occasionally vegetable matter	All food taken by pursuit diving
Hoary-headed Grebe	**D**	Open lakes / marshes and major rivers, 100-500m wide and 0.5 –3m deep with submerged veg. (avoid dense waterweeds)	Off shore in floating waterweeds or amongst sedges, saltmarsh, lignum and canegrass	Carnivore, primarily aquatic arthropods also fish	Most taken by deep diving pecking inverts from sediments and vegetation
Australasian Grebe	**D**	Shallow wetlands, along steep gradient shoreline with fringing reeds and submerged vegetation	In shallow water among emergent plants and bushes or attached to overhanging branches	Omnivore, aquatic arthropods, fish, molluscs, vegetable matter and seeds	Wide range of methods, diving, picking from surface water, snatching insects from emergent veg.
Dusky Moorhen		Open waterbodies permanent, with fringing emergent and submerged vegetation also adjacent grassed areas	In dense vegetation, lignum, cane grass, reedbeds, rushes and sedges	Omnivore, vegetable matter, seeds, molluscs, insects, carrion	Feed on land and shallow water (up to 30cm deep) amongst floating veg. or in open water 100m from cover
Purple Swamphen		Not specific, around the margins of wetlands and adjacent grasslands	In reedbeds and rushes	Omnivore, mainly aquatic veg. also seeds, insects, fish animals	Feed in dense reedbeds gleaning insects and seeds, dig roots and rhizomes also graze grass
Black-tailed Native-hen	**D**	Open shallow wetlands to more saline conditions, not specific	Near water in swamps of red gum, lignum, cane grass, chenopod shrubs, grasses and small islets	Omnivore, seeds, vegetable and insects	Gleans from ground and water surface
Eurasian Coot	**D**	Open shallow wetlands with fringing emergent and submerged vegetation, often with open deep water >2m	In lignum, sword grass, rushes and forks of shrubs (melaleuca)	Herbivorous, mainly aquatic veg. seeds and grasses.	Graze on land and glean from water surface, dive for shoots and scrape algae
Australian Spotted Crake		Not specific, around the margins of wetlands (<5cm water) with dense fringing vegetation	In dense vegetation, bushes, lignum, rushes, sedges and grass	Omnivore, seeds (sedges, chenopods, legumes), also insects, molluscs and crustaceans	Foraging on the ground, wading, gleaning and probing

Common Name	---	Habitat Preference	Nesting preference	Diet	Feeding
Spotless Crake		Not specific, around the margins of wetlands with dense fringing vegetation	Usually over water in dense vegetation, reeds, rushes, grass tussocks and bushes	Omnivore, seeds, grasses, insects, molluscs and crustaceans	Mostly foraging on the ground, gleaning mudflats, reedbeds, shallow water
Ballion's Crake	**M**	Not specific, around the margins of wetlands with dense fringing vegetation and abundant floating vegetation (may prefer fluctuating water levels)	In dense vegetation above shallow water within 20m of waters edge	Omnivore, mostly aquatic insects also seeds, molluscs and crustaceans	Gleans among floating veg. reeds and marshy ground
Masked Lapwing	**S**	Open shallow wetlands, with short grassed areas at the margins, also adjacent open plains	Nest on-ground in short grass (<12cm) or stony ground also on small islands and floating reeds	Omnivore, molluscs, worms, insects, crustaceans and occasionally seeds	Stalk, run, glean and probe
Banded Lapwing		Not specific, near water open plains and margins of dry swamps	On-ground in a range of open dry habitats	Omnivore, seeds, leaves, molluscs, worms, insects	Stalk, run, glean and probe, seldom wade in shallow water
Red-Kneed Dotterel		Open floodplain wetlands along the open shallow margins, avoid tree lined and/ or the more saline wetlands	Not specific, on-ground along the shore or islets where samphire and shrubs can conceal nests	Omnivore, seeds, molluscs, worms, insects	Glean and probe and tremble feet to disturb prey in wet sand / mud
Black-Fronted Dotterel	**S**	Open floodplain wetlands along the shallow margins	Nest on-ground in stony areas or stone strewn sand	Omnivore, worms, molluscs, and crustaceans also insects, occasionally seeds	Forage at waters edge glean and probe into mud
Red-capped Plover		Saline wetlands along the open shallow mudflats with sparse fringing vegetation	Not specific, on-ground along the shore or islets, usually near water >40m	Omnivore, worms, molluscs, and crustaceans also insects, and vegetable matter	Forage stop-run-peck, seldom wade in shallow water
Black-winged Stilt	**D**	Open shallow wetlands, with short grassed areas, not specific	Not specific, on-ground	Omnivore, mainly invertebrates, also molluscs and crustaceans, occasionally vegetable material and seeds	Diurnal and nocturnal wide range of foraging, pecking, pursuit, filtering, probing and raking

Branded Stilt	**D**	Saline wetlands along the open shallow mudflats	On-ground on small islands in salt lakes with scattered samphire, occasionally on sand spits 1-1.5m above water level and besides shallow water 10-60cm deep	Omnivore, mainly crustaceans, also molluscs insects, vegetation matter and seeds	Forage at waters edge wading, pecking, scything and probe into mud
Red-necked Avocet	**D**	Saline wetlands along the open shallow mudflats, not specific	Not specific, on-ground along the shore or islets of salt lakes above water level	Omnivore, invertebrates, molluscs and crustaceans, occasionally vegetable material and seeds	Wading in shallow water scything, gleaning from water surface

APPENDIX O. LANDHOLDER ENVIRONMENTAL INFORMATION

Gary Wright

- Eucalypts dying in Willowie Forest, likely due to decreasing groundwater levels. NPWS looking into cause.

Jeff McCallum (flood irrigator from Rotten Creek)

- Jeff is aware of “minnow like” fish which he often finds in clay pans following flooding. He said he has also come across redfin and trout. He believed that locals had put the trout into dams and permanent pools.

Ken Walter (Hundred of Gregory, near Bruce)

- High intensity rainfall of approx 4-5 inches is required to generate stream flow. A large loss of water occurs, presumably through the gravel beds of streams. Ken said that you could have significant flows of water upstream of the gravel beds and as soon as the water hits the gravel bed it disappears underground and downstream would be absolutely dry.

Reg Noll (hundred of Willochra, near Wilmington)

- Reg recalls significant vegetation change around the 1950’s, the area was used for grazing and only saltbush existed. Nida bushes, lignum bushes and boxthorns soon encroached upon the areas south of Bruce (previously they existed north of Bruce). Reg noticed that the water levels fell when these bushes became established and suggested that they contributed to the falling watertable in the area.
- Reg is of the belief that the shallow saline groundwater feeds the Willochra Creek, he use to go swimming in the saline waters of the Willochra Creek and there existed small fishes approximately 2 inches long which looked similar to sardines (*Note: possibly Lake Eyre Hardy head has similar growth characteristics and can tolerate salinity*). Reg has not seen these fishes since the watertable fell and the saline groundwater no longer feeds the Willochra Creek (1950 – 1960). He also recalled small beetles that lived in the mud which he hasn’t seen either.
- The River red gums along the main channel of the Willochra have been dead the entire time Reg has lived in the area and were dead when his father first moved to the area, and were dead before white settlement in the area. Reg suggested the saline groundwater, which flowed to the Willochra caused the Eucalypts to die. The trees ran from the hundred of Gregory to Partacoona in the main channel, a number of which have died. Other tributaries to the Willochra have healthy trees.

Margaret Deer (Partacoona / Quorn)

- Glen and Margaret recall permanent water located near the shearing shed, at Duck Pond, near where Stevens Creek enters the Willochra and Boundary White Cliffs in the Willochra (Eastern side of the Creek).
- Glen recalls that there was permanent water in the main stem of the Willochra down through Partacoona Station all the time. Margaret confirmed this and told of 3 main pools that were very deep. Glen recalls the pools almost drying up in extreme dry years, and specifically 1984 when they were “just little puddles”. It is not currently know if they are still there as they left Partacoona Station in 1989.

- The water in the permanent pools was saline, and the sheep would only drink from selected pools. The permanent pools had water in them all year round
- Margaret noted that the pool(s) supported small minnow shaped fish (possibly Lake Eyre Hardy Heads).
- Margaret's son (from Wallerberdina Stn.) recorded Lake Eyre Hardyhead and the following waterbird species on Lake Torrens:
  - Pelican
  - Black Swan
  - Magpie Geese
  - Black Duck
  - Wood Duck
  - Grey Teal
  - Musk Duck
  - Blue Billed Duck
  - White Eyed Duck (or Hardhead)
  - Yellow-billed Spoonbill
  - Royal Spoonbill
  - Great cormorant
  - Pied cormorant (Pied / Little Pied?)
  - Little Black cormorant
  - Oyster catcher (Pied / Sooty?)
  - Red necked Avocets
  - Dotterels
  - Plovers (three types)
  - Snipe (Painted / Lathams?)