DWLBC REPORT

Baseline survey of refugia pools in the north-eastern Willochra Creek and western Lake Frome Catchments

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

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FOREWORD

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

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

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

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

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SUMMARY

This report focusses on permanent refugia pools of semi-arid watercourses located in the eastern Willochra Creek and western Lake Frome catchments of South Australia. The study area is contained within the Northern and Yorke (NY) Natural Resources Management (NRM) region, and this work was funded by the local NRM Board. This work completes the baseline mapping of permanent aquatic refugia habitat within the Willochra Creek Catchment and extends this work into the Lake Frome Basin, as far east as the South Australian Arid Lands region.

Nineteen permanent pools were identified through consultation, then mapped and surveyed during autumn 2006. Surveys collected data on environmental and biological variables enabling the broad ecological character of pools to be described.

Survey data collected were augmented by data from Kanyaka Creek—a monitoring site in the west of the study area. Data included flow, macroinvertebrate and water quality parameters for the period 1995–2005, allowing variation over time to be determined. A conceptual landscape model predicting the bio-physical character and ecological significance of pools is discussed.

Refugia pools within a landscape context

Permanent refugia pools are firstly recognised as being groundwater dependent ecosystems, although surface flows also perform critical ecological roles. Within this context, sites can be classified subject to landscape position, predicting both their broad physical and chemical properties as well as their ecological values.

The location of study sites across the landscape gradient from hillside springs to valley floor water table pools is representative of the hydrological and hydrogeological setting as well as the ecological function of refugia. From an ecological perspective the most important pools are those found in the valley floor settings which form core refuge areas. These pools were found to have higher diversity and abundance of benthic macroinvertebrates than the more isolated and smaller springs of higher elevations. Hillside pools still represent significant biodiversity assets as they provide a broader range of environmental conditions and reduce dispersal distances between refugia. The separate functional roles of these refugia types suggests that the loss of any permanent pool represents a risk to biodiversity at landscape scale, with the impacts dependent upon their relative location.

Spatial and temporal patterns

Water quality was highly variable between sites and through time, but was generally of moderate to high salinity. Mean electrical conductivity (EC) observed at the autumn 2006 survey sites was 8812 EC, comparing with mean values from Kanyaka Creek of around 13 000 EC for autumn samples. Acidity of pools ranged from neutral to moderately alkaline, a mean value of 7.5 observed for survey sites compared to 7.8 at Kanyaka Creek over all seasons.

Broad community composition was similar in both macroinvertebrate datasets. Only six of 79 species collected for this study were not represented in the 130 species from the Kanyaka Creek autumn edge samples. Midges (family: Chironomidae) were the dominant taxonomic grouping, comprising 40 and 50% of total abundance in survey and Kanyaka samples respectively. Other common taxa included amphipods, mayfly nymphs and mosquitoes.

Lake Eyre hardyhead was the only species of fish that was recorded from two sites on Boolcunda Creek. Although not widely dispersed, this population represents a significant biodiversity asset.

Species richness and between-site diversity was high with, on average, only 17% of animals shared between survey sites. The main factors influencing pool-scale biodiversity measures of macroinvertebrate communities were the physical dimensions of the pool and its landscape position. Variability between temporal samples was also high, although less than spatial diversity, and on average 36% of the species collected in a given year were again present in the sample from the following year.

Flow data for the period 1978–2005 revealed a highly predictable seasonal baseflow, commencing every year between April and June and continuing for several months. July and August are the most reliable baseflow months, with discharge volumes being 20 times less variable than streamflow from direct runoff. This flow pattern is not a direct result of rainfall, to which monthly baseflow was only weakly correlated, and is an important ecological factor in determining biodiversity.

Management considerations

Two main issues need consideration by resource managers: protection of environmental water requirements, and encouraging best practice management of permanent pools.

Environmental water requirements are not considered to be at threat of broad-scale development, but are most likely to be compromised by excessive farm dam development on watercourses, direct pumping from permanent pools, or locating wells within the zone of influence of the pools. Appropriate water allocation policies must consider the need to regulate direct use of pools to protect refugia water quantity and quality. Policy should also recognise that, if accompanied by stock removal, sustainable levels of pumping from pools to troughs and fencing pools rather than allowing direct access to waterholes may lead to environmental gains.

Landholder management of springs and waterholes generally focusses on maintaining stock waters. Assuming this practice will continue, best practice approaches could still potentially lead to improved ecological function. Such practises could be developed through implementing targeted trials, provided these are effectively monitored, the results analysed and the findings communicated.

1. INTRODUCTION

1.1 MOTIVATION OF THE WORK

Water resource management in Australia has undergone considerable reform over the last two decades. Along with our increasing awareness of the need to actively manage our fragile resource base has grown an appreciation of the environment as a legitimate user of water. Management frameworks now seek to ensure that adequate water will be available to provide for the requirements of water dependent ecosystems (WDEs) before any consumptive pool is evaluated. This is necessary to ensure these ecosystems can continue to provide the ecosystem services that human users rely upon, as well as providing intact natural aquatic ecosystems for purposes of biodiversity conservation. Recognition of environmental needs for water has led to a large body of work, aimed at quantifying what is now referred to as the EWR—environmental water requirements—of such WDEs.Scientific studies to determine EWR in Australia initially concentrated on areas where large-scale water resource development had already occurred, typically within major river systems of the east coast and Murray-Darling Basin (MDB). More recently, areas in arid central Australia where significant WDE are located (but as yet relatively little development has occurred) have come under scrutiny. There is an awareness that these resources are as yet not over-developed and the aquatic ecosystems these resources support are, by comparison with developed areas, unimpacted. There is growing recognition in these areas of the need for careful management based on scientific understanding if we are to prevent a repeat of the degradation now so apparent in over-developed areas such as the MDB. Examples of this focus on arid zone water resources include both the Lake Eyre Basin—a major dryland river drainage system featuring extensive permanent and ephemeral wetlands of critical importance to water birds, native fish and other aquatic organisms—and the Great Artesian Basin (GAB)—surface discharges from which support the unique, and nationally protected Mound Springs communities.

Despite the attention now being paid to the EWR of WDE in Australia, the focus on large scale surface water resources has led to considerable gaps in existing policy and scientific understanding. An example is the small permanent springs and waterholes generally associated with ephemeral streams or localintermediate groundwater flow systems found all over arid and semi-arid Australia. The lack of direction of work to such areas in the past is understandable, given resource limitations, but nonetheless these still represent water dependent ecosystems, and are at times subject to extractive pressures. Natural resource managers and authorities at all levels have a legal obligation and responsibility to ensure human uses of the resource do not impact on the environmental needs of these systems for water. To date the approach to these systems has been either to presume they are self-managing—an approach assuming the resource will not be subject to development pressures owing to poor yields or water quality—or to apply principles of management developed for use on systems in higher rainfall areas.

Management principles for small aquatic ecosystems in semi-arid areas cannot rely on work from higher rainfall environments. The structure and function of semi-arid systems bear little in common with their wetter cousins. As with all riverine ecosystems, flow maintains a critical structuring role (Poff et al 1997, Richter et al 1996, Walker et al 1995), but flow events in these environments are highly unpredictable. The ecology of large arid zone streams and rivers are considered to have a 'boom–bust' ecology (e.g. Bunn et al 2006). Large flood flows provide boom times, delivering sediment, nutrients and reproductive propagules to downstream catchment areas and providing periods of extended connectivity in three dimensions. This increases the range and area of habitat enormously, allowing organisms to complete their life cycles or to disperse, temporarily extending their range. Between these extreme episodic flow events aquatic flora and fauna are restricted to small permanent aquatic habitats referred to as refugia pools. This name provides an indication of their importance to stream ecosystems, as these allow for the persistence of aquatic organisms within the setting of a generally hostile terrestrial environment. Smaller streams in arid zones also exhibit analogous 'boom–bust' ecologies, but on much smaller scales.

The limited work undertaken on stream ecosystems in semi-arid northerly areas of the NY NRM region in South Australia suggests that permanent pool refugia are dependent upon groundwater to persist (Deane et al 2005, Boulton and Williams 1996). Where present, these groundwater-fed permanent pools and springs are an important component of semi-arid and arid systems. These pools provide habitat, refugia, and resources for a wide variety of animal taxa including amphibians, fish, insects, invertebrates, mammals, marsupials, and reptiles, as well as submerged and emergent vascular plants and algae. Permanent surface aquatic habitat has also been found to feature a greater abundance and diversity of organisms when compared to temporary habitat (e.g. Brock et al 2003). Within the setting of ephemeral and intermittent streams, aquatic organisms without a dessication resistant life-history phase are able to persist within the system by retreating to these permanent refugia pools as flow ceases (Ward et al 1998). This value has been demonstrated by a number of researchers, where refugia pools immediately following the cessation of flow have been found to have the highest biodiversity of all habitat types (Boulton and Lake 1992, Acuna et al 2005). This is attributed to a behavioural response where organisms retreat to the remaining wetted habitat as flow volumes decrease. When suitable flow conditions present, these organisms are then able to re-colonise the entire catchment ensuring a higher overall level of biodiversity is maintained at the landscape scale.

As the only reliable source of water available, groundwater is also critical to support human activities, and for the area of interest in this study, grazing is by far the most common land use. Although volumes used by individual graziers are low compared to activities such as irrigated horticulture, the fragility of semi-arid water resources is such that even small extracted volumes may result in loss of aquatic habitat. The likely extent and duration of any impacts increases with the level of extraction imposed. The development of arid zone water resources for high volume uses such as feedlotting, irrigated agriculture and mining, has significant potential to affect the capacity of WDEs to function. There is currently no meaningful water management framework available to protect both human and environmental needs for water. Consequently, the EWR of surface and groundwater dependent ecosystems in semi-arid regions are becoming an important focus for natural resource management authorities.

In South Australia our understanding of the composition and ecological value of small refugia pools is relatively poor, as is our knowledge of appropriate management strategies to maximise environmental outcomes. Such strategies would seek not only to ensure the sustainability of the pools, but also to optimise their biodiversity values. The first step in improving our ability to manage such systems is to increase our understanding of ecosystem structure and function. To achieve this, it is firstly necessary to increase our knowledge of the spatial distribution of permanent water and gain an appreciation of the basic biological components found within them. This study aims to commence the process of improving understanding of the ecology of groundwater fed permanent pools and springs by providing information about:

- the location of permanent pools and springs
- the baseline ecological character and the biodiversity values they represent
- their apparent condition and any threatening processes which are evident.

1.2 DESCRIPTION OF THE STUDY AREA

The Willochra Creek Catchment (Fig. 1) is situated in the upper reaches of the Northern Agricultural District of South Australia, with the Southern Flinders Ranges forming the western catchment boundary. Although isolated high-elevation locations near Mount Remarkable may receive 600 mm of rainfall annually, conditions rapidly become drier with movement to the north and east, and semi-arid to arid climatic conditions predominate in the catchment. As a result, although the total catchment area of the Creek is significant, exceeding 6400 km^2, mean annual discharge is low and catchment-wide flows are extremely rare.

Willochra Creek itself flows in a northerly direction to terminate in Lake Torrens, but major tributaries drain both the eastern and western catchment. Owing to the orographic affects of the Southern Flinders Ranges, the relatively high and reliable rainfall areas in the south-west of the catchment contribute the majority of streamflow to the system. The sub-catchments of streams draining the eastern portion of the catchment, such as Boolcunda and Wirreanda Creeks, have average rainfalls of less than 400 mm/y. Streams in this region have episodic and ephemeral or intermittent flow regimes. Despite the lack of permanent or even seasonal streamflow, permanent waterholes can still be found among the eastern tributaries. As is the case with many semi-arid streams in South Australia and elsewhere, these are to a large extent dependent upon groundwater discharge to persist through the long periods between flow events.

An episodic flow regime is also characteristic of streams in the Lake Frome Basin (Fig. 1), which adjoins the Willochra Catchment to the east. Although comprising a very large total area, the Basin is best thought of as comprising numerous small, unconnected streams radiating out from Lake Frome rather than a single common drainage line. The increasingly arid conditions with distance to the east result in flow regimes of watercourses in the Lake Frome Basin that are also increasingly episodic. As is the case with streams found in the eastern Willochra Creek Catchment, permanent water holes in the Lake Frome Basin are dependent upon groundwater to persist.

Permanent surface pools supported by groundwater represent refugia sites for aquatic organisms during the periods between flow events, which although rare, still support important ecological processes within the river systems such as providing for connection between refugia allowing for dispersal. As such they remain ecologically highly significant at the landscape scale in terms of maintaining biodiversity.

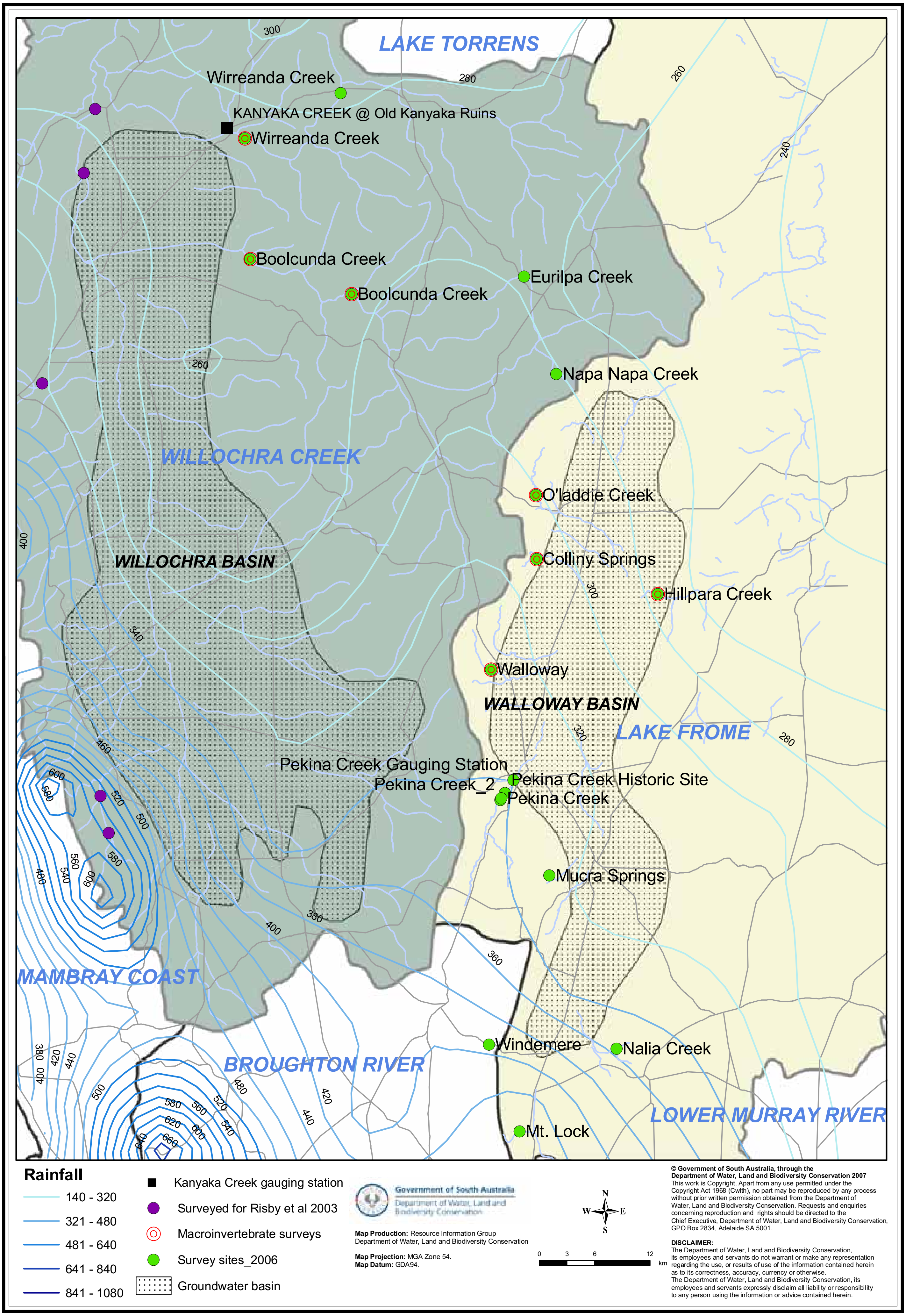

Figure 1. Map of the study region showing the location of ecological surveys

The climate is dominated by extreme events, in particular drought, but is periodically subject to heavy rainfall and flooding. Such climatic hardships have resulted in a significant turnover of landholders since European settlement. Owing to the infrequent and irregular rainfall and therefore streamflow, cropping and grazing virtually throughout the region has, and continues to be, dependent upon groundwater resources. The quality and quantity of groundwater however, varies considerably throughout the region (Risby et al 2003, Martin et al 1998) dictating the possible uses to which it can be put. Owing to the generally low yields and high salinities, stock and domestic use to support grazing activies is predominant.

Large areas of land have been cleared of native vegetation as a result of farming practices, burning, and the introduction of exotic species (Goyder Soil Conservation Board 1997). This has resulted in the irreversible loss of native vegetation throughout much of this region (Goyder Soil Conservation Board 1997).

Survey work undertaken in 2002 (Risby et al 2003) mapped and described small pool ecosystems associated with the main stem of the Willochra Creek and major tributaries entering the Creek from the Southern Flinders Ranges. This study focuses on previously unsurveyed areas of the NY NRM region encompassing tributaries of the eastern Willochra Creek Catchment and the western portion of the Lake Frome Basin.

As a result, this work completes the baseline mapping of permanent aquatic refugia habitat within the Willochra Creek Catchment and extends this work into the Lake Frome Basin as far east as the boundary of the South Australian Arid Lands region.

2. AIM AND OBJECTIVES

The Department of Water, Land and Biodiversity Conservation (DWLBC) undertook this study on behalf of the Northern and Yorke Natural Resource Management Board (NY NRMB).

The central aim of this project was to complete the mapping of the location of permanent pool habitats within the north-eastern Willochra Creek (filling data gaps from Risby et al 2003) and western Lake Frome catchments and describe their basic ecological character and condition.

Secondary aims wereas follows.

- Identify potential threats to the sustainability of refugia.
- Appreciate the values landholders ascribe to permanent waters, record any concerns they have regarding their condition or management.
- Make recommendations on the future management of similar ecological assets in semi-arid parts of the region.

3. METHODOLOGY

3.1 APPROACH

This study consisted of three stages:

1. Surveying relevant agency staff and local landholders to identify the location of permanent waters and also local opinions and concerns regarding a variety of issues relating to permanent waterholes.
2. Conducting snapshot environmental assessments of permanent pools and springs within the study area.
3. Review and collation of available hydrological and ecological data, statistical analyses and reporting.

3.1.1 LANDHOLDER SURVEYS

A community consultation survey was developed to better understand the social values of permanent pools and springs in the study area. Specifically, this survey aimed to investigate the value of permanent water and its usage, as well as to increase knowledge of any changes or perceived modifications in the Catchment over the past ten to fifty years. Survey questions primarily centred around the value and usage of permanent pools, features of the local streamflow regime, and general observations of any changes to the water resource over time.

Landholders were invited to participate in the study after initial phone conversations to determine whether they had permanent water on their property. A total of 21 surveys were sent to local landholders. Of these, 11 were returned and responses were assessed to better understand the views, perceptions and opinions of local communities.

3.1.2 ENVIRONMENTAL ASSESSMENTS

Site selection

Following landholder surveys, sites for environmental assessment were selected based on:

- The presence of permanent water.
- The location of the pool within the Catchment (where possible, spatially diverse sites were preferred in order to represent a significant area of the Catchment).
- The capacity to gain access to private lands.

Table 1. Field survey sites and numbers

Site number	Stream or spring name
1	Mt Lock
2	Windemere
3	Nalia Creek
4	Mucra Springs
5	Pekina Creek (site 1)
6	Pekina Creek (Winflete)
7	Pekina Creek Gauging Station
8	Pekina Creek Historical Site
9	Pekina Creek
10	Walloway
11	Colliny Springs
12	O'laddie Creek
13	Napa Napa Creek
14	Hillpara Creek
15	Eurilpa Creek
16	Boolcunda Creek (upstream)
17	Boolcunda Creek (downstream)
18	Wirreanda Creek (downstream)
19	Wirreanda Creek (upstream)

Data collection

A total of 19 sites were visited between March and April 2006 (Table 1, Fig. 1). At each site, surveys of varying detail were conducted to quantify important components within the ecosystem. Basic descriptive data were collected at all sites including: chemical and physical properties of the pool environments, riparian and aquatic vegetation, and surrounding land use. In addition, biological sampling for fish and macroinvertebrates was conducted at seven sites as follows:

Macroinvertebrate sampling: Macroinvertebrates were collected in accordance with national AusRivAS protocol, which involves sweeping a D-framed pond net through the water over a ten metre area—areas were selected to represent as much habitat diversity as possible. Specimens were preserved in ethanol until they were returned to the laboratory, where sub-samples were obtained and sorted (a minimum of ten percent of the sample). Sub-samples that contained fewer than 200 individuals were sorted further until a minimum 200 individuals had been sorted for identification. The Australian Water Quality Centre (AWQC) identified specimens to species or morphospecies level (species that look indistinguishable).

Fish sampling: Fish survey work was undertaken by a contractor from Native Fish Australia (South Australian Branch). Sampling was undertaken via seine netting and/or dipnetting, depending on the extent of the aquatic habitat and suitability for each method. Where found, a sample of any species collected was preserved in 90% ethanol solution and lodged with the South Australian Museum.

The data collected as a result of the survey phase of this work is presented within the field survey summaries found in Appendix D.

3.1.3 STATISTICAL ANALYSIS

In addition to the data collected in this study, historical data from the South Australian Environment Protection Authority (EPA) was obtained for a site within the focus area and analysed. The data collected includes water quality and macroinvertebrate data for a permanent waterhole located at Kanyaka Creek in the northern Willochra Creek Catchment, within the study region (Fig. 1). These data represent samples taken twice yearly over the period 1994–2005. Comparisons are made with the EPA dataset throughout this report, as this provides an indication of the variation over time within the Catchment, whereas sites in this study provide an example of the spatial variations in habitat.

Macroinvertebrate and environmental datasets were subjected to analysis using bivariate and multivariate statistical techniques in order to search for patterns that would assist in describing the factors influencing community composition. This analysis has been submitted for publication in a peer reviewed scientific journal (Deane et al, in preparation). Separate analyses undertaken for the purpose of this report were limited to summary statistics, but the findings of the reviewed article are referenced throughout.

Spatial data regarding the location of permanent pools and springs were incorporated into a Geographic Information Systems (GIS) database for analysis and for reference in future work.

4. RESULTS

4.1 LANDHOLDER SURVEY RESPONSES

As might be expected, landholders consider permanent water on their properties to be a valuable asset, and this value is linked primarily to its use for stock watering. All eleven survey respondees stipulated that their pools were primarily used to water domestic animals. In contrast, only two landholders had pools they considered to be recreational assets, with swimming and general aesthetics uses listed by only one respondent. This is in contrast with surveys of pastoralists in the far north of South Australia, who valued Great Artesian Basin boredrain wetlands very highly for aesthetics and recreation in a similar survey undertaken recently in that region (Phipps 2005). This difference in attitudes reflects the limited depth and extent of the pools in the current survey, many of which were small, shallow and of limited spatial extent.

Landholders reported that some springs in the region feature episodic flow, but the majority indicated that flow was either permanent or seasonal during the higher rainfall months. Three springs flowed only during certain times of the year. Eight of the eleven respondents indicated that they have observed changes to their pools and springs as a result of the current drought, indicating that the frequency and magnitude of flow events has decreased.

Around half of the survey responses indicated that landholders have detected changes to the quality and quantity of ambient groundwater during their time in the region. Despite this decline, only 30% of responses suggested any concurrent decrease in the abundance or diversity of organisms observed utilising permanent waters. The importance of pools for both terrestrial and aquatic biota was reflected in one survey question and the faunal groups most commonly observed around pools were frogs, birds and kangaroos.

4.2 FINDINGS OF FIELD SURVEYS AND HISTORICAL DATA

4.2.1 GENERAL SITE CHARACTER

The character of sites was typical of what would be expected for pools and springs located in a semi-arid climate during autumn, and within the context of a grazing land use. Sites of permanent water were located at all elevations. Sites at higher elevations were generally of small dimensions, particularly in terms of depth, and had little to no flow observed. In contrast, some of the valley floor pools were located on higher order watercourses and could be quite extensive in surface area and depth. Whereas pools at higher elevations were often isolated single pools, valley floor sites often had more than one pool present, although limited flow between pools was observed.

Very limited vegetation of any kind was observed surrounding pools, with few exceptions. Riparian vegetation was often either not comprised of aquatic species or consisted only of small stands of emergent species, such as sedges. There were also very few submerged vascular plants observed, and charophytes or filamentous green algae were the predominant true aquatic species (see Section 4.2.3). Some of the sites, especially those found at higher elevations had River Red Gums present, which provide shading of pools. However, generally even where red gums were present, it was only individuals or small numbers of trees, and shading was not complete. The majority of pools and springs were exposed to direct sunlight over much, if not all, of their surface area.

4.2.2 WATER QUALITY

Spatial variation – field survey findings

Table 2 summarises the range of water quality variations observed across the survey sites. The parameters presented all exert an influence on the range and physiological processes of biota present in the pool. Parameters presented are: pH which is a measure of the acidity of the water, temperature, dissolved oxygen (DO) concentration in the water column, and two measures of salinity—electrical conductivity (EC) is measured directly and total dissolved solids (TDS) are derived from this value. Statistics presented in the table are the mean (average), median, maximum, minimum and inter-quartile range (IQR). Interquartile range is a measure of the variability in a data set, representing the difference between the first and third quartiles. This is often used where data do not follow a normal distribution, and measures of spread in the data such as the standard deviation are misleading.

Although conditions are generally fairly typical of a semi-arid region, the data indicate a wide range of conditions was represented across all of the pools surveyed. Electrical conductivity, a direct measure of salinity, is generally high, with a mean value of around 8000 EC (~5700 mg/L). The minimum and maximum values are outliers as shown by comparison of the mean and IQR. The minimum of 1069 EC was recorded from a pool created by direct runoff following a recent storm. The maximum salinity of 27 190 EC was recorded from Hillpara Creek, which is a likely discharge point from the Walloway groundwater basin. Typical salinities were closer to the mean value of 8434 EC.

Table 2. Observed range in water quality parameters

Statistical measure	**pH**	**Water temperature** (ºC)	**Dissolved oxygen** (mg/L)	**Electrical conductivity** (μs/cm)	**Total dissolved solids** (mg/L)
Mean	7.49	20.70	6.80	8434	5734
Max.	8.77	29.79	13.86	27 191	17 670
Min.	6.82	13.48	0.65	1069	695
Median	7.60	20.40	7.1	6603	4689
IQR*	0.60	5.60	4.0	6230	3955

* Interquartile range – the difference between the values of the 25th and 75th percentiles

The values for temperature and DO typically change significantly over a daily period, so the main factor of interest in both of these parameters is whether or not they become biologically limiting over the course of daily and longer cycles. Continuous logging required to determine this was beyond the scope of these snapshot surveys, and being spot measures, the temperature and DO readings provide limited information. DO concentrations below 5.0 mg/L are generally considered to be stressful to aquatic respiratory processes, while levels that drop below 1–2 mg/L will have significant effects on aquatic biota, particularly fish. DO concentrations recorded during this study varied considerably across the region, ranging from 0.85–13.86 mg/L (mean concentration of 6.8 mg/L). Hence the majority of readings indicated well oxygenated conditions and relatively mild temperatures that would be unlikely to present any physiological stress to the resident biota. The minimum value of 0.65 mg/L would be considered to be highly restrictive, but as this was recorded from a small, stagnant pool isolated from the main water body, it reflects anoxic conditions typical of such an aquatic environment.

At some sites, adjacent pools displayed large differences in DO concentrations. This is an indication that pools within close proximity can experience very distinct conditions. This results from the influence of factors such as flow, degree of shading, evaporation rates, organic load, and biological activity. Most influential in still water pools is the balance between photosynthesis and respiration processes. While the majority of pools registered DO concentrations well above 5.0 mg/L, this does not necessarily mean that DO never becomes limiting. Large fluctuations in DO can occur within a short time frame, which would lead to greater stress on aquatic life than gradual changes.

Although pH values also change over the course of a day, these are less likely to be as pronounced as the changes in temperature and dissolved oxygen. The acidity of the natural waters ranged from slightly acidic (6.82) to strongly basic (8.77). The majority of values were however close to the mean value of around 7.5. This range of values would not be considered limiting, and are as would be expected from natural waters in the region (Risby et al 2003).

Temporal variations

Water quality data for the EPA monitoring site at Kanyaka Creek provide a comparison with the survey data and an indication of seasonal variations. Table 3 shows summary statistics for water quality parameters from the Kanyaka Creek site for the period 1972–2005 divided into autumn and spring.

When considering the spatial and temporal variations represented by the common values in Tables 2 and 3, comparisons should be based on autumn values, reflecting the time of year surveys were undertaken. Salinities were closer to the range observed in the spring samples from Kanyaka, suggesting that conditions at survey sites represented a range of conditions that are of a higher ambient water quality than Kanyaka Creek. The variability in all parameters was higher based only on autumn samples, indicating that a more diverse range of water quality conditions are presented at landscape scale through the presence of a number of different sites, when compared to those evident in seasonal variations at a single site.

Very little variation in acidity, water temperature, or phosphorus concentrations is evident between seasons based on these data. In contrast, EC and total nitrogen concentrations are generally considerably higher during autumn, whereas turbidity (NTU) is much lower. Autumn is at the end of the annual seasonal drought, and as discussed in the following section, these patterns reflect the influence of streamflow which dilutes pool waters, decreasing the concentrations of dissolved substances.

Table 3. Seasonal variations in water quality – Kanyaka Creek

Spring	pH	Water temperature (ºC)	Dissolved oxygen (mg/L)	Electrical conductivity (µs/cm)	Turbidity (NTU)	Total nitrogen (mg/L)	Total phosphorus (mg/L)
Mean:	7.9	20	10.8	8312	58	1.2	0.10
Median	8.0	19	10.0	7391	5	0.9	0.04
Max.	8.6	31	16.1	26 600	999	3.4	0.99
Min.	7.0	6	7.6	215	1	0.4	0.01
IQR	0.3	6	3.0	3678	6	0.7	0.04
Autumn	**pH**	**Water temperature** (ºC)	**Dissolved oxygen** (mg/L)	**Electrical conductivity** (µs/cm)	**Turbidity** (NTU)	**Total nitrogen** (mg/L)	**Total phosphorus** (mg/L)
Mean:	7.8	18	13.1	12 996	6	2.5	0.10
Median	7.9	18	13.7	13 050	4	1.8	0.06
Max.	8.7	24	15.9	29 166	17	13.2	0.33
Min.	7.4	13	9.0	1790	1	1.1	0.02
IQR	0.4	4	3.1	5503	5	1.0	0.04

Interquartile range – the difference between the values of the 25th and 75th percentiles

Influence of flow on water quality

Flow data from Kanyaka Creek gauging station (App. E) was used to assess the influence of direct runoff and baseflow on water quality parameters. Streamflow is comprised of sub-surface and direct runoff components as well as groundwater discharges (baseflow) which occur every year creating a reliable flow signal. Although relatively small in volume compared with direct runoff, these still have a considerable influence on water quality in refugia.

The mean monthly baseflow for May and June explained around one quarter of the variation in the concentration of salinity (measured as EC), and over half the variation in nitrogen, phosphorus and organic carbon. Direct runoff is less predictable, but has more influence on water quality owing to the greater volumes. June streamflow explained 50% of the variation in salinity of autumn water quality. Surface runoff also introduces suspended solids, and higher runoff volumes increase turbidity during spring.

4.2.3 EMERGENT AND SUBMERGED VEGETATION

Emergent and submerged vegetation plays an integral role in the functioning of freshwater ecosystems. For instance, aquatic vegetation supplies habitat for macroinvertebrates, birds and fish, shelters organisms against predators, acts as a nursery for juvenile fish, and is an important component of nutrient addition and nutrient recycling (Romo et al 1996). Thus, any loss of aquatic vegetation is likely to have significant effects on the ability of the system to cycle nutrients and will result in declines in the abundance and diversity of taxa that inhabit these ecosystems.

There was a low diversity of emergent and submerged vegetation at all of the sites that were surveyed, which is a fairly typical feature of the region more generally. *Cyperus gymnocaulous* and *Typha* were the most widely distributed emergent species, although the level of cover observed varied considerably across sites. Similarly, the cover and distribution of other plant genera also varied greatly (Table 4). For instance, species of *Cotula*, *Potamogeton* and *Bolboschoenus* were only observed at one site, while *Ruppia* and *Triglochin* were rare.

Charophytes (stoneworts) were the most widespread submerged aquatic plant, being observed at eight sites, but their densities varied greatly. In many permanent pool habitats in the region where submerged vascular plants are often rare, they have been found to be the dominant submerged aquatic plant. Charophytes are also especially well suited to ephemeral systems, being able to resist dessication and disperse rapidly during flow events (Deane et al 2005; Figuerola and Green 2002). Given their wide distribution in pools throughout many of the smaller pools in the mid-north region, they can be expected to be ecologically important, although currently, our understanding of their characteristics, role and function remains largely unknown (Casanova 2005).

Table 4. Species of aquatic vascular plants observed

Functional Grouping	Genus	Species
Emergent	*Cyperus*	*gymnocaulous*
	Typha	*domingensis*
	Juncus	*kraussii*
	Schoenoplectus	*littoralis (adult)*
	Triglochin	*striatum*
	Sarcocornia	*quinqueflora*
	Samolus	*repens*
	Carex	*[unknown]*
	Bolboschoenus	*caldwellii*
Submerged	*Ruppia*	*maritima*
	Schoenoplectus	*littoralis* (juvenile, submerged form)
	Cotula	*coronopifolia*

4.2.4 FISH

Fish surveys were conducted at seven of the nineteen sites, at Nalia Creek, Mucra Springs, Eurilpa Creek, Boolcunda Creek (upstream and downstream), and Wirreanda Creek (two pools at the upstream site). Lake Eyre hardyhead was the only species of fish that was collected. Whilst it was only sampled at one site—Boolcunda Creek (upstream)—there is a high probability it was present at the downstream Boolcunda Creek site, where a fish was observed in the mid-water column that appeared to be similar. This species was clearly not the other fish known to be present in the Willochra Creek Catchment, which is the plague minnow *Gambusia*. Plague minnow was not observed at any site in this study, despite being found along with the Lake Eyre hardyhead at a number of sites previously surveyed in the central and western Willochra Creek (see Risby et al 2003).

4.2.5 MACROINVERTEBRATES

Spatial patterns – survey results

A total of 2647 invertebrates representing 79 morphospecies from 31 different families were collected at the seven survey sites (Fig. 2), with the complete data set presented as Appendix A. The Chironomidae (midge) family was represented at all of the sites, and comprised the bulk of the fauna at five of the seven sites—O'laddie Creek, Boolcunda Creek (upstream), Boolcunda Creek (downstream), Wirreanda Creek and Hillpara Creek. Other fauna that were captured in large numbers include amphipods, mosquitoes, mayfly nymphs, damselflies, and hemiptera. Family level descriptions are at a coarse taxonomic scale however and do not provide an indication of the true diversity represented, and almost 95% of the total abundance comprised animals from only 13 families (Fig. 2). The two major characteristics of the dataset is the species turnover between sites (known as beta diversity) and the number of different animals that occur in only very low numbers. More than one third of the different taxa collected were found at only one site. Only 17 out of 79 different types of animals collected were found at more than two sites, and only one animal was found at all seven sites.

Summary data on macroinvertebrate communities are shown in Table 5. Shown are the number of different types of animals (known as morphospecies), the total number of all animals, the SIGNAL grade score, and the effective number of species calculated from the Gini-Simpson Index of Diversity (see Jost 2006). The latter two values are indices describing different characteristics of the observed community. The SIGNAL (Stream Invertebrate Grade Number Average Level, Chessman 2003) score indicates the average sensitivity of the invertebrate community to environmental conditions and the effective species illustrates how evenly the biodiversity is distributed between the different species—in other words, how many species would be expected if the abundance were evenly distributed between species.

The number of families and morphospecies in each sample varied greatly across sites, but would generally be considered to be fairly diverse. The mean number of 21 morphospecies was present across all sites. Boolcunda Creek (upstream) had the highest diversity (26 different animals), and O'laddie Creek the lowest (16).

The total number of animals collected varied greatly across the sites, with the mean abundance being 378 animals. The highest abundance was found at Wirreanda Creek and, as was the case with the diversity of species, the lowest abundance observed was from O'laddie Creek with 260 animals.

The SIGNAL grade score provides an indication of the sensitivity of the community. The score is the arithmetic mean of scores allocated to each family, which reflects their sensitivity to pollution, with higher numbers indicating increased sensitivity. The scores for the study sites range from 2.8–3.7 of a possible 10, suggesting a tolerant and robust macroinvertebrate community. The most sensitive macroinvertebrate sample was that collected from the community at Boolcunda Creek (downstream), and the least sensitive community was sampled from O'laddie Creek.

Table 5. Macroinvertebrate community descriptors (adapted from Deane et al in prep)

Site name	Number of Species	Total animals collected*	SIGNAL grade score	Effective number of species
Boolcunda (d/s)	23	399	3.74	7
Boolcunda (u/s)	26	280	2.81	14
Wirreanda	21	539	3.24	4
Colliny	18	492	2.89	2
O'laddie	16	260	2.75	9
Hillpara	19	414	3.11	3
Walloway	22	265	3.05	7
Mean values	21	378	3.08	6.5

Abundance adjusted to provide representative comparison - see Deane et al in prep

The effective number of species provides an indication of the evenness with which community diversity is distributed, and is complementary to the species richness (simply the number of species). Generally, a community with an even distribution of abundance is considered more diverse than a community where most of the abundance comes from only a few species. The effective species can be thought of as the number of species that would be present if each had equal abundance. Where the species richness and effective number of species differ greatly, a few individuals dominate the sample. The Boolcunda Creek (upstream) site is the most diverse by both effective species and species richness. In contrast, within the Colliny Springs sample, four of the observed 18 species constituted over 92% of the abundance. Colliny Springs has a higher species richness than O'laddie Creek, but in fact was much less diverse owing to the numerical dominance of only a small number of species.

Temporal variations – Kanyaka Creek historical data

As was the case with the water quality data, macroinvertebrate data were available from the EPA sampling program from the Kanyaka Creek site. These data were collected twice yearly over the period 1994–2005 and were compared with the data collected for this study to provide an indication of seasonal variability.

The total diversity for all samples collected at Kanyaka Creek was 181 morphospecies from a total of 65 families. The eleven autumn edge samples, which would be expected to most resemble the samples for this survey (see previous section), had a total of 130 morphospecies from 54 different families, compared to the 79 morphospecies from 31 families in samples collected for this study. The pooled relative abundances at family level for both datasets are shown in Figure 2. A notable feature is the agreement between the two datasets on the two most abundant sub-families, which comprised a similar proportion of the total abundances.

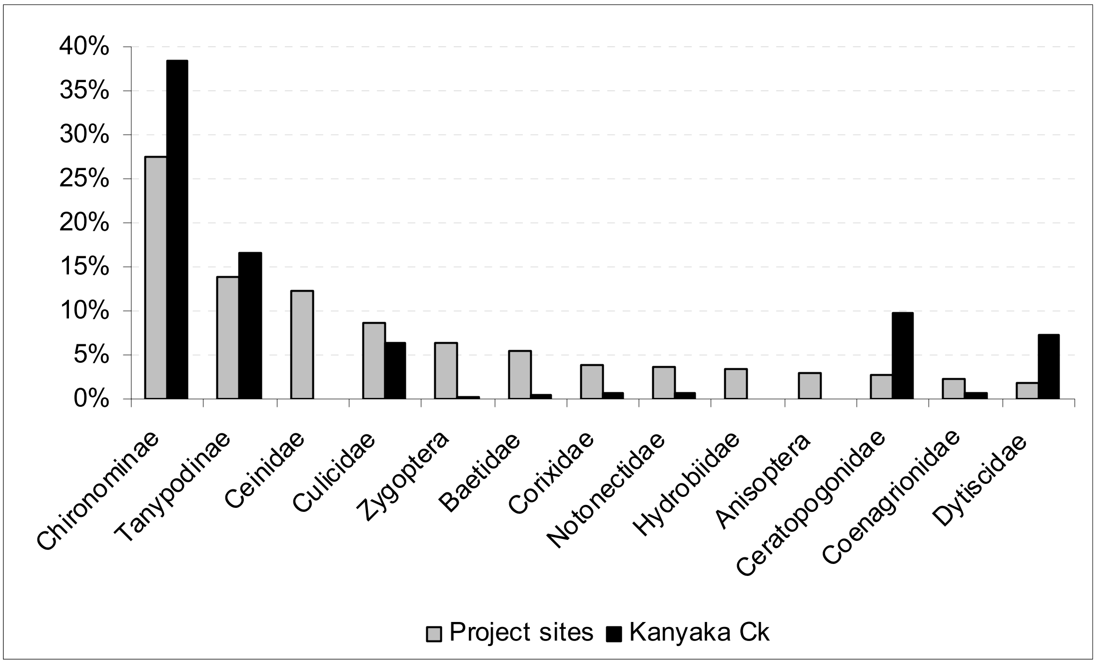

Figure 2. Comparison of autumn macroinvertebrate community composition at family level: Kanyaka Creek (1994–2005) and project sites (March 2006)

The most common groups were both sub-families of the Chironimidae (midge family). Most abundant was the Chironominae in both datasets, comprising 27% of the total abundance of macroinvertebrates collected for this study and 39% of all autumn edge samples from Kanyaka Creek over the period 1994–2005. The second most numerous group was the Tanypodinae, comprising 14% and 17% of samples from the present study and the Kanyaka Creek data respectively. The majority of the morphospecies collected during this project have been recorded at the Kanyaka Creek site with only six morphospecies (8% of total diversity) not common to both datasets.

As was the case for data collected for this study, many animals were only sampled on one or a few occasions. Of the 130 different animals recorded from the 11 autumn edge samples, 65 animals were recorded only once. Only 40 morphospecies—less than a third of total recorded diversity—have been collected more than twice. The data do suggest that variability in macroinvertebrate communities is higher between different sites than for consecutive year samples from the same site; the mean number of species found in consecutive year samples was almost 40% of the mean species richness, whereas the mean number of shared species between survey sites was only 17% of the mean species richness (Deane et al in prep). Overall, both datasets were dominated by rare species and comparison of individual samples across space or time yielded few common species.

A comparison of the diversity indices presented in Table 5 for the sites from this project and Kanyaka Creek autumn edge samples is shown in Table 6. The diversity of samples collected from Kanyaka Creek is on average around 30% higher than the samples assessed in this study, and the mean richness is higher than the maximum diversity observed in this study. The average number of animals collected in each sample is also much greater. The minimum number of different species observed in a given sample is similar, but the maximum diversity of species collected among the Kanyaka Creek samples is much higher.

Table 6. Comparison of macroinvertebrate sample characteristics: survey sites and Kanyaka Creek

Statistic*	Kanyaka Creek autumn edge	Survey sites
Mean species richness	28	21
Maximum species richness	44	26
Minimum species richness	18	16
Mean abundance	516	378

Species richness is the number of different morphospecies collected. Abundance represents the relative total number of all animals collected

Influence of flow on biodiversity

Flow data from Kanyaka Creek gauging station (see App. E) was compared with biodiversity indices to determine the influence of flow on pool communities. Rainfall, baseflow, and salinity were all correlated with increased species richness, with baseflow the major contribution. This may in part explain the higher richness and abundance from the Kanyaka Creek samples as these were generally collected during June, after baseflow has commenced.

In terms of the number of shared species at Kanyaka Creek across consecutive years, larger streamflow events appear to lead to increased biodiversity in downstream sites, and would increase both the species richness of samples later the same season as well as the number of species persisting at the same site the following year.

5. DISCUSSION

5.1 POOL-SCALE PATTERNS

The main spatial factors influencing pool-scale biodiversity measures of macroinvertebrate communities were the physical dimensions of the pool and its landscape position which was recorded as elevation (Deane et al in prep). Both pool depth and width were positively correlated with species richness, abundance and sensitivity to pollution (SIGNAL score) of the samples. Landscape position had a negative correlation with the diversity indices—that is, diversity was higher at sites of lower elevation.

Rather than being purely size or elevation related effects, these correlations were interpreted by the authors as indicative of the association between biodiversity and the increased habitat extent and complexity found in pool systems located on higher order streams. Even in semi-arid zones, high-order streams can be expected to receive more frequent flow inputs of higher volume and duration, as storm events anywhere in the catchment upstream of their position have the potential to produce flow events that will reach the pool. An analogous concentration of water towards high-order streams in valley floors will also exist for groundwater flow systems, and in this respect larger pool dimensions are simply an indication of this greater availability of water. A further result of this is that these sites are typically associated with multiple pools, further increasing the extent and potential variety of local habitat.

A further finding was that although variations in water quality between pools helped explain the spatial distribution of organisms at different sites, water quality parameters were not highly correlated with pool-scale measures of biodiversity. In other words, different water chemistries supported different suites of species, but overall biodiversity was little influenced by this. Salinity has been shown to be correlated with species richness of macroinvertebrates, and 6000 EC has been suggested as a threshold above which richness declines (McEvoy and Goonan 2003). Species richness assessed in this study were in broad agreement with data presented in that study.

5.2 PUTTING FINDINGS INTO A LANDSCAPE CONTEXT

Despite the general similarities observed in the regional climatic setting and prevailing land use of catchments surrounding survey sites, there were considerable differences in the observed environmental conditions and biological communities. Variations can to some extent be explained by the landscape position of the permanent pools. Relative landscape location is a surrogate measure of the underlying hydrological (flow regime) and hydrogeological (flow system) factors shaping the environmental conditions at the site (Deane et al in prep).

At the simplest level, sites can be divided into springs and soaks, generally located on hillsides, and still water pools that are surface expressions of groundwater tables associated with local topographic depressions. This distinction should be recognised as a generalisation reflecting the end points of a continuum of both groundwater and surface water flow systems. With progress along the stream network, pools can be expected to gain a degree of complexity resulting from the accumulated effects of sediment and organic matter transported through the system, as well as generally increasing in size and permanence. This framework helps to place sites within the context of the functional ecological role they perform within their respective catchment and landscape settings.

Spring systems are generally of higher elevations, occuring on lower order streams, and tend therefore to be isolated pools of relatively modest dimensions, perhaps presenting surface areas of only a few metres square. Surface flows in these locations will have only a limited influence on the ecology, as direct runoff is likely to very much follow rainfall patterns. As a result, flows tend to be of short duration and low volume, compared to sites lower in the catchment. As a result of their smaller size, these sites are often more likely to be shaded, where even a single tree can provide significant shading to the pool surface area.

In contrast with this, high order streams found in valley floor locations are subject to more lengthy and frequent periods of flow, as they drain much larger catchment areas. They are also likely to receive significant groundwater discharges (or baseflow), further increasing the magnitude, duration, and frequency of flow events. Appendix C shows the mean monthly flow at Kanyaka Creek gauging station, where a reliable flow is experienced every year, commencing between April and June and often persisting until September. This flow is groundwater discharge, which is likely to be greatly reduced in sites higher in the catchment. The concentration of surface and groundwater flow systems in lower catchments results in a much higher probability of finding a number of pools in close proximity in valley floor settings. These pools are also typically present in a more complex geomorphic setting, resulting from the movement of sediment and organic matter through the stream network.

The above classification also in part helps to explain variations in the chemical composition of water between sites. Hillside springs represent local discharge points for fractured rock aquifers, where the orientation, spacing, and flow patterns through the fractures coincidentally result in a proportion of the groundwater flow system discharging to the surface. The residence times for spring water is likely to be much lower than that of regional groundwater tables, which may have travelled long distances to reach the topographic lows where they discharge to the surface. As a result of this longer residence time, water quality would be expected to be generally lower in these systems from evapo-concentration and dissolution of ions, than in small springs close to the catchment divide. The influence of regional groundwater flow systems is also apparent in the findings, further supporting this landscape model. Pools nearer to the discharge point for the Willochra (northern extent of the basin) and Walloway (north-eastern extent) sedimentary groundwater basins (Fig. 1) were observed to have high salinities in this and prior studies. The extreme case of the Hillpara Creek site is a good example, where salinities recorded at this site of around 18 000 EC are comparable to those reported in Risby et al (2003) for hyper saline pools located in the discharge zone of the Willochra sedimentary basin. The analogous saline Willochra Creek sites had an electrical conductivity which varied between 17 000–31 000 EC. These pools are reliant upon different groundwater systems, but it is clear that processes at catchment scale produce environmental conditions which are comparable. In contrast, sites further up the flow path of the groundwater systems, such as Boolcunda and Wirreanda Creeks are of a progressively lower salinity.

The above descriptions inform consideration of the ecological importance of both hillside springs and valley floor pool sites. Owing to their larger dimensions, the presence of multiple interconnected pools and relatively high structural complexity, it is clear that valley floor pools represent a core refuge area for the river system as a whole. From the catchment perspective, smaller, more isolated pools such as springs and soaks, perform at least two vital functions: they represent a broader range of water quality conditions, and reduce the distance between core refuge areas, allowing dispersal between river systems of more mobile taxa.

While individually not as critical to regional biodiversity maintenance, owing to the diverse range of conditions they represent, at catchment scale these sites are critically important. The very low number of shared species between sites suggests that a higher number of refugia will aid in maintaining biodiversity through both provision of a broader range of environmental conditions and the increased probability that dispersal processes will be successful.

A final point to acknowledge in this discussion is the importance of recognising these pools as groundwater dependent ecosystems and making any ecological interpretation within this context. The condition of the pools, in particular the core refuge areas, is therfore very closely linked to the sustainable management of groundwater resources.

5.3 REGIONAL BIODIVERSITY CONSIDERATIONS

The majority of species collected in this study were present in the samples collected from Kanyaka Creek over an 11–year period, however six species (including an introduced limpet, *Potamopyrgus antipodarum*) were not. Outside the two dominant sub-families however, there were very large differences in community composition across both spatial and temporal samples. The region appears to be diverse in terms of the number of species despite ambient salinities that might be considered limiting. Based on the evidence presented, there appears to be a large potential suite of species, and while local conditions such as water chemistry or shading may exert some influence it would appear that there is a significant random element that dictates whether a species will appear at a given site at a given time. Under such conditions it is likely that the more permanent (and temporary) aquatic habitats are available with a diversity of environmental conditions, the higher the probability that a given species will be present somewhere in the landscape. The loss of permanent pools at any point in the catchment is likely to have an influence on the ecology, with the impact depending on the uniqueness of conditions at the site which is lost and the spatial distribution of the remaining sites.

Based on the findings of this report it is reasonable to expect a benthic macroinvertebrate community sampled using the AusRivAS protocols from a core refuge pool during autumn to exhibit a species richness of the order of 20–30 different animals, especially following the onset of seasonal baseflow. Furthermore, it is likely that such a sample will contain a high proportion of chironomid midge larvae, and the most abundant sub-families are likely to be Chironominae and Tanypodinae. It is difficult to make such generalisations as to the likely levels of diversity from smaller, isolated pools, other than to say it will likely be less than predicted above.

Although only one native species of fish has been recorded from the Willochra Creek Catchment, this study has provided important information regarding the distribution of the Lake Eyre hardyhead, complementing information presented in Risby et al (2003). Notable in its absence from the two Boolcunda Creek sites where the species was observed in this study was the plague minnow, Gambusia. Risby et al (2003) found the two species individually and co-occuring in sites in the lower Willochra Creek. This raises the potential for inter-species competition, and locating a tributary to the river system where Gambusia has not yet invaded is an important finding. The two Boolcunda Creek sites present additional opportunities to investigate whether biological ‘top-down’ control structures macroinvertebrate communities. This could be compared to sites lower in the Willochra where Gambusia is known to be found, as well as sites such as Wirreanda Creek where no fish species were present.

Protection of the valley floor core refuge areas is critical for the maintenance of biodiversity. The more even distribution of biomass suggests a more diverse, resilient ecosystem than can be expected to be found in isolated pools. These sites are also the most likely place where fish species can persist, in particular during extended drought periods.

Spring-fed pools also provide important biodiversity services and it is evident that these refugia support a greater range of water quality variations and reduce the necessary dispersal distances between refugia. The latter point is important as it is apparent that there is a significant random element dictating which exact species will be present in a given pool from one year to the next. It follows therefore, that the larger the number of available pools, the more likely it will be that landscape scale diversity is maintained.

5.4 MANAGEMENT CONSIDERATIONS

Previous work that was conducted in this catchment indicated that lowered flow rates and volumes have affected the lateral and longitudinal connectivity of pools in the western area of the catchment (Risby et al 2003). That study indicated that water extraction practices have led to reduced duration of streamflow as well as variability in flood events, which was thought to have led to reduced dispersal opportunities and the isolation of taxa, including populations of Lake Eyre hardyhead.

The much lower availability and poorer quality of water resources in the eastern Willochra and Lake Frome Catchments, means that large-scale resource development is not currently a high risk. The risk of local or direct over-pumping of refugia pools is however, a very real risk, and is an activity that may warrant policy development.

Management strategies in the southern and western regions of the Willochra Creek Catchment will require particular emphasis on water allocation, delineation of the ‘high value’ areas for protection (relating to biodiversity, degradation and disturbance regimes), and methods to improve connectivity between groundwater-fed pools. Alternatively, management of the eastern section of the catchment should focus on developing management strategies to protect the water supplies supporting refugia pools and ensuring minimal ecological damage during excavation of pools.

5.4.1 THREATENING PROCESSES

In general, management strategies need to be based around either controlling threats to ecosystem integrity, or alternatively focus on opportunities to improve ecosystem condition. Catchment threats in the study area warranting management consideration are discussed below.

5.4.1.1 Declines in water quality

A decline in water quality is a commonly encountered problem in freshwater systems worldwide. In recent times, human influence on these environments has resulted in changes to the natural salinity, nutrient content, level of pollutants, pH, dissolved oxygen conditions, and turbidity of the water. Changes to these conditions may potentially affect community structure with implications for ecological integrity and resilience. For instance, Sommer and Horwitz (2001) observed that the acidification of a lake in Western Australia resulted in changes to the composition of the macroinvertebrate community, including the complete loss of amphipods, mayflies and gastropods.

Since water quality is of fundamental importance to the survival of many species, it is essential that this is maintained wherever possible. Possible methods of optimising water quality include:

- Sensitive use of agricultural chemicals, avoiding contamination of pools through overspray or runoff. Persistent chemicals may accumulate over time in valley floor settings as these represent terminal water bodies in all but high flow events.
- Preventing stock from approaching pools and streams. Stock can contribute to bank erosion and thus increase turbidity and sedimentation. Grazing or trampling of seedlings and vegetation affects species composition, and stock wastes increase nutrient concentrations in the water.
- Ensuring the siting and storage capacity of dams does not reduce the frequency, duration, or magnitude of freshening flows.
- Ensuring groundwater extraction does not impact on the quality of water in refugia pools.

5.4.1.2 Reduced availability of water

Groundwater extraction, or the removal of water from underground aquifers, is a major threat to ecosystems in many regions. In the Willochra Basin, Magarey and Deane (2005) found levels in many water table aquifers had shown continued decline since 1993. This was thought to represent a combination of the impacts from human extraction and climatic cycles (see also Risby et al 2003). Although the levels of extraction seen in the southern Willochra, especially from the sedimentary basin, are much greater than the study area for this report, the small pool dimensions make them susceptible to degradation as a result of water loss.

In order to maintain pools in their current state, it is suggested that the drilling of any wells in areas near to refugia pools should allow an adequate buffer distance to ensure no impact will result. These distances could be based on rules developed for the Clare Valley (NYRMB 2006), with allowance made for the relative differences in annual rainfall. In addition, direct pumping of pools should be subject to a compliance system involving monitoring that will protect pool water levels and quality and preclude further pumping if either are impacted.

During this study, a number of landholders commented on the fact that they are currently experiencing a decline in water levels or the complete loss of water from their permanent pools. While this issue is widespread throughout the catchment, it does not affect all properties. The difference in water availability across regions should be considered when devising management plans or prioritising sites for protection. Anecdotal evidence and monitoring data suggest that formerly permanent pools and springs are drying for the first time in recorded history. Climatic uncertainties present arguably the greatest indirect risk to aquatic ecosystems in the region.

5.4.1.3 Stock access

As previously mentioned, direct stock access to watercourses can have major impacts on aquatic ecosystems. Preventing stock from accessing pools and streambeds by fencing the riparian zone will significantly reduce degradation of these habitats, decrease physical and chemical disturbance, and promote the regeneration of aquatic and emergent vegetation. Pool water can still be utilised by establishing troughs outside of fences and pumping to these, subject to the protection of pool water quality and level (see above).

5.4.1.4 Sedimentation

Sedimentation is the process by which sedimentary materials and organic detritus gradually accumulate within pools and streams. This may impede upwelling of groundwater, deposit fine layers of sediment smothering pool surfaces including plants, increase the turbidity of the water, and decrease pool depth (Downes et al 2006). These impacts can interrupt ecological processes and decrease habitat complexity.

This is a common problem for pools in arid zones, where flushing flows are rare, and it creates problems for landholders where pools are also stock water points. A lack of flooding through recent times has resulted in the accumulation of sediment and organic matter in pools and streambeds throughout the study area. In cases where pools become completely filled with sediment, these require excavation to restore surface water habitat. This may potentially have ecological benefits, but ideally this activity would be under some type of policy control, or at least some best practice guidelines.

Sedimentation also decreases the depth of the pools, enabling Typha reeds to grow throughout the middle of the pools rather than limiting them to the edges. Reed growth of this nature subsequently increases sedimentation further because reed beds reduce flow velocity, thus increasing sediment deposition around stems and roots.

It may not be possible to increase the removal of sediments, since freshwater flow is required to flush these pools, however, negative effects may be limited by activities such as:

- Preventing stock access to pools.
- Managing reed beds such as Typha. Management plans for controlling Typha should be based on Native Vegetation Clearance Guidelines and ecologically sensitive approaches—for example, ensuring that Typha is not cleared completely or during the nesting season.
- Sensitive design of culverts, crossings and other infrastructure within streams in order to maintain natural hydrology.
- Re-establishment of native vegetation—plants, groundcover, perennial grasses—to reduce the impact of rainfall on the soil, slowing the flow of runoff, and binding the soil.
- Avoiding overgrazing and over-use of agricultural lands.
- Re-establishing riparian vegetation along the banks of streams to reduce erosion during flooding.
- Promoting low/no-tillage agriculture.
- Growing forage crops in rotation or as a permanent cover.

- Contour ploughing and windbreaks.
- Educating local communities about the negative effects of soil erosion on agriculture and the natural environment.

5.4.1.5 Invasion of exotic species

Invasive species pose a significant threat to many ecosystems because they have been associated with:

- Losses of native species (Priddel, Carlile and Wheeler 2000).
- Reductions in agricultural productivity (Cohn and Bradstock 2000).
- Interruption of ecosystem processes (Jackson et al 2002, Woodward and Hildrew 2001).
- Alteration of the natural environment (Spencer, McClelland and Stanford 1991, Talley, Crooks and Levine 2001).

A number of exotic weeds are prevalent in the Willochra Creek Catchment. In particular, boxthorn and artichoke threaten to displace native plants, resulting in the creation of a homogeneous habitat. It is important that these weeds are controlled where possible, as this will reduce their spread into adjacent areas. Moreover, exotic species often spread via freshwater flows, so control of riparian weeds is essential to prevent spread downstream during flow events.

Similarly, anthropogenic disturbance is often associated with the invasion of exotic species (Hobbs and Huenneke 1992, Thompson et al 2001). Thus, by reducing the extent of disturbance in areas around pools and streams, it may be possible to limit the invasion success of exotic species. Such disturbances include trampling by domestic animals, use of excavation equipment, nutrient enrichment of the water and surrounding areas, disposal of rubbish, chemicals and other materials into pools, and the implementation of dams and drains.

A previous study within this catchment found populations of Lake Eyre hardyhead and Gambusia (Risby et al. 2003). While fish surveys that were conducted during this study failed to capture Gambusia at any of the sites, it is likely that this area is under threat from the invasion of this highly noxious pest species since the Boolcunda Creek has its confluence near to some permanent waters on the main stem of the Willochra Creek. The introduction of Gambusia to this site would potentially have negative effects on the Lake Eyre hardyhead population through competition for resources and predation of eggs. Future work should focus on methods to completely eradicate (although this is unlikely) or prevent the further spread of this species.

5.4.1.6 Climate change

Climate change is a global issue that threatens to irreversibly alter the state of the natural environment. Predicted changes to Australian climatic patterns vary depending on the location of the site in question. With the current state of knowledge, predicting the potential influence of changed climate is beyond the scope of this report.

Speaking generally, the most apparent risk to the aquatic biodiversity of the region would be the loss of permanent pools, or transition of their status from permanent to temporary. This applies in particular to the core refuge areas, which represent a more substantial biodiversity asset. However, even loss of small isolated refugia will potentially have some influence, depending on where these are located and the relative uniqueness of the conditions at the sites.

It is important that the predicted effects on climate in all regions are assessed within the local context. Predictions that are currently made at continental or sub-continental scales need to be evaluated at regional levels to examine likely impacts. This process will better inform planning of ameliorative actions and appropriate management options.

6. CONCLUSIONS AND RECOMMENDATIONS

This project has mapped the location of permanent refugia pools in the eastern Willochra Creek and western Lake Frome Catchments, and described their basic ecological character.

Permanent refugia pools are firstly recognised as being groundwater dependent ecosystems, although surface flows also perform critical ecological roles. Within this context, sites have been classified subject to landscape position, predicting both their broad physical and chemical properties as well as their ecological values.

Pools of this nature are well known ecological assets supporting landscape-scale biodiversity, and their continued persistence is critical as a result. They are also however, valuable commercial assets for landholders, providing watering points for stock, and most are inevitably used for this purpose. These two values, while not totally compatible, can still be reconciled to some extent and considerable improvement in the condition of many existing refugia would appear to be possible.

At the scale of individual pools, the extraction of even modest volumes has the potential to create considerable impacts. Clearly the use of water resources supporting refugia pools needs to be subject to adequate care, to ensure that activities are not impacting on water quantity or quality. This is however, only one aspect of managing human impact on these ecosystems. Rather than simply protecting refugia pools from impacts, changes to grazing practices that may produce a net improvement in the condition of refugia could also be encouraged.

In terms of restoring or improving habitat, general principles of watercourse management can initially be applied, but it is important that continued improvement in actions and outcomes occurs. Many watercourse management principles are based on research of systems found only in higher rainfall areas, and local trials through on-ground works programs should be targeted for monitoring[1] and evaluation to identify the most effective strategies in this climatic and landuse setting. This requires that the success of on-ground actions are properly monitored, including pre-implementation conditions, allowing increased certainty in locally appropriate methods to be developed. Policy development and education—through for example, best practice guidelines—could then follow. Topics that could be addressed include:

- Further work and education on the ecological values of permanent pool refugia.
- Developing and trialling ecologically sensitive excavation techniques for permanent pools to combat infilling.
- Developing and trialling ecologically sensitive management techniques for reed beds in pools.
- Comparative studies to determine differences in ecological condition resulting from managing stock access to watercourses and waterholes.
- Identifying optimal water resource management to avoid impacts on permanent pool hydrology or water quality—e.g. siting of farm dams and wells.
- Developing local re-vegetation guidelines for arid zone waterholes and riparian areas.

[1] recognising the potential for monitoring activity itself to be damaging in arid environments.

APPENDICES

A. MACROINVERTEBRATE ABUNDANCES

Common name	Phylum	Class	Order	Family	Genus/species	Total abundance across all sites
Roundworm	Nematoda	–	–	–	–	5
Flatworm	Platyhelminthes	Turbellaria	–	–	–	3
Mite	Arthropoda	Arachnida	Acari	Acarina	*Acarina* sp.	1
				Oribatida	*Oribatida* sp. A	3
				Unionicolidae	*Neumania* sp.	2
				Hygrobatidae	*Aspidiobates geometricus*	1
Seed shrimp	Arthropoda	Crustacea	Ostracoda	–	Ostracoda sp.	1
Amphipod	Arthropoda	Malacostraca	Amphipoda	Ceinidae	*Austrochiltonia australis*	325
Freshwater limpet	Mollusca	Gastropoda	Prosobranchia	Hydrobiidae	*Potamopyrgus antipodarum*	93
Springtail	Arthropoda	Insecta	Collembola	Sminthuridae	Sminthuridae sp.	1
				Entomobryidae	Entomobryidae sp.	1
				Hypogastruridae	Hypogastruridae sp.	4
Non-biting midge	Arthropoda	Insecta	Diptera	Chironomidae (Chironominae)	*Kiefferulus* sp.	54
					Polypedilum sp.	2
					Chironomus sp.	83
					Riethia sp.	2
					Paracladopelma sp.	2
					Tanytarsus sp.	248

Common name	Phylum	Class	Order	Family	Genus/species	Total abundance across all sites
					Paratanytarsus sp.	4
					Cladotanytarsus sp.	78
					Dictrotendipes sp.	17
					Chironomini sp.	6
					Tanytarsini sp.	129
					Chironominae sp.	103
				Chironomidae (Tanypodinae)	*Larsia* sp.	67
					Procladius sp.	298
					Tanypodinae sp.	2
				Chironomidae (Orthocladinae)	*Paralimnophyes* sp.	3
					Cricotopus sp.	1
Biting midge	Arthropoda	Insecta	Diptera	Ceratopogonidae	*Culicoides* sp.	53
					Forcipomyia sp.	2
					Nilobezzia sp.	3
					Sphaeromiini sp.	5
					Ceratopogonidae sp.	8
Mosquito	Arthropoda	Insecta	Diptera	Culicidae	*Anopheles* sp.	34
					Culex sp.	32
					Aedes sp.	160
House fly	Arthropoda	Insecta	Diptera	Muscidae	Muscidae sp.	1
Soldier fly				Stratiomyidae	Stratiomyidae sp. 1	6
					Stratiomyidae sp.	12
Moth fly				Psychodidae	Psychodidae sp.	1

Common name	Phylum	Class	Order	Family	Genus/species	Total abundance across all sites
Water Boatmen	Arthropoda	Hexapoda	Hemiptera	Corixidae	*Sigara* sp.	19
					Micronecta gracilis	3
					Micronecta sp.	20
					Agraptocorixa parvipunctata	4
					Agraptocorixa sp.	43
					Corixidae sp.	12
Backswimmer	Arthropoda	Hexapoda	Hemiptera	Notonectidae	*Anisops thienemanni*	4
					Anisops sp.	95
Water strider	Arthropoda	Insecta	Hemiptera	Veliidae	*Mesovelis* sp.	2
					Microvelia peramoena	1
Caddisfly	Arthropoda	Insecta	Trichoptera	Leptoceridae	*Oecetis* sp.	14
					Triplectides australis	1
					Leptoceridae sp.	1
Mayfly	Arthropoda	Insecta	Ephemoptera	Baetidae	*Cloeon* sp.	139
					Baetidae sp.	5
Dragonfly	Arthropoda	Insecta	Odonata	Aeshnidae	Aeshnidae sp.	26
				Anisoptera	Anisoptera sp.	81
				Libellulidae	Libellulidae sp.	4
Damselfly	Arthropoda	Insecta	Zygoptera	Coenagrionidae	*Ischnura heterosticta*	1
					Ischnura sp.	5
					Xanthagrion erythroneurum	1
					Coenagrionidae sp.	54
				Lestidae	*Austrolestes annulosus*	9
					Austrolestes psyche	3
					Austrolestes sp.	8

Common name	Phylum	Class	Order	Family	Genus/species	Total abundance across all sites
				Zygoptera	Zygoptera sp.	166
Diving beetle	Arthropoda	Insecta	Coleoptera	Dytiscidae	*Sternopriscus* sp.	1
					Necterosoma sp.	19
					Necterosoma pencillatus	3
					Necterosoma dispar	3
					Arrenurus sp.	9
					Allodessus sp.	1
					Dytiscidae sp.	23
Water scavenger beetle	Arthropoda	Insecta	Coleoptera	Hydrophilidae	*Berosus* sp.	1
					Hydrophilidae sp.	5
Marsh beetle	Arthropoda	Insecta	Coleoptera	Scirtidae	Scirtidae sp. 1	4
Tree frog	Chordata	Amphibia	Anura	Hylidae	*Litoria ewingi*	1
					TOTAL	2647

B. NOTES ON MACROINVERTEBRATE COMMUNITIES

(Compiled by Anne Walters)

There was considerable variation in the water quality, habitat diversity and ecological community composition across sites in this study. Specifically, the macroinvertebrate community assemblages showed great diversity across sites, making it difficult to make accurate conclusions about ecosystem functions and the quality of habitat at each site. Non-biting midges (Chironomidae) made up the bulk of the fauna at all but two of the sites. This family was responsible for the similarities in the composition observed at several sites. Moreover, when midges were removed from the analysis, the composition of macroinvertebrates was significantly different at all but two of the sites.

Chironomids are widely distributed and are often the most abundant group of invertebrates in freshwater ecosystems (Sharley, Pettigrove and Parsons 2004). They play an important role in food webs in these systems, linking primary and secondary producers and terrestrial and aquatic communities (Henriques-Oliveira, Nessimian and Dorvillé 2003). They constitute a large component of the biomass of these systems, and are often a primary resource for fish and other invertebrate fauna (Sharley, Pettigrove and Parsons 2004). Moreover, chironomids have been used as biological indicators of ecosystem health because they are widespread, diverse, abundant, and respond readily to changes in environmental conditions. For instance, a study conducted in North America found that midges are particularly affected by variations in the volume of water because of the subsequent changes that occur to the quality of the water (Lobinske, Ali and Stout 1996). Moreover, since many of the species are sediment-dwelling fauna, they may be used to infer information about the quality of the sediment at some sites (Sharley, Pettigrove and Parsons 2004).

Sensitive taxa (primarily dragonflies and damselflies) were collected at all sites with the exception of O'laddie Creek. The presence of these taxa indicates that all of the sites that were surveyed are unpolluted, and therefore of value to a broad range of flora and fauna. Moreover, these pools exhibited relatively pristine water quality, high abundances and diversity of taxa, relatively low numbers of exotic species, and extensive habitat structure, suggesting that many of these pools are in an appropriate state to justify protection for the future. Since current research recommends the conservation and preservation of ecological assets prior to their degradation, it is recommended that steps be implemented to protect these permanent pools while they remain in this condition.

Following are notes relating to the macroinvertebrate communities, highlighting interesting features of the animals found at each survey site.

Colliny Springs

Colliny Springs supports a diverse and abundant assemblage of macroinvertebrates. When compared with the other sites that were surveyed, this site contained the second greatest abundance of individuals and the second highest number of families. The diversity of morphospecies was slightly lower than that of some of the other sites, indicating that while this site can support a high diversity of families, the number of species within these families is slightly lower. The macroinvertebrate community composition at this site differed significantly from all other sites, primarily because this site supported considerably fewer midges (Chironomidae).

The samples were primarily composed of the amphipod *Austrochiltonia australis*, the freshwater limpet *Potamopyrgus antipodarum*, and two genera of Culicid mosquitos, *Culex* and *Aedes*.

Austrochiltonia australis was observed at five of the seven surveyed sites, however it was observed in considerably higher numbers at Colliny Springs relative to any of the other sites. Interestingly, this amphipod is generally associated with low salinities (Timms 1974), but was nevertheless observed at the most saline sites in this study, suggesting that salinity is not a factor limiting the distribution of this species in the study area. A previous macroinvertebrate survey in the Flinders Ranges concluded that this species was relatively depauperate in this region because it does not survive desiccation and is a poor coloniser of waterbodies (Goonan and Schulze 2001).

The freshwater limpet *Potamopyrgus antipodarum* is native to New Zealand but has successfully invaded freshwater and estuarine locations in Australia, North America and Europe (Schreiber et al 1998). Its success has been largely attributed to its capacity to reproduce parthenogenetically (without the requirement for fertilisation), as well as its wide tolerance of differing temperatures, habitat, and food regimes (Schreiber et al 1998). Moreover, the invasion success of this species has been correlated with anthropogenic disturbance such as grazing, forestry, towns and dams (Schreiber et al 2003). For this reason, it's persistence at Colliny Springs is somewhat surprising, since this site displayed a relatively intact riparian zone, high-quality water parameters, a range of habitats, and low disturbance levels relative to many of the other sites (normal water odours, no surface oils and minor sedimentation). Nevertheless, *Potamopyrgus antipodarum* is often highly abundant in agricultural systems (Davies et al 2002), which may explain its presence at this site.

Both *Austrochiltonia australis* and *Potamopyrgus antipodarum* are rapid colonisers of habitat following disturbance (Quinn, Lake and Schrieber 1998). This site displayed evidence of recent flooding and the abundance of these taxa may be a reflection of this flood.

A large number of mosquito larvae were collected at Colliny Springs. Mosquitos prefer to lay their eggs in water that is high in organic matter, since this enhances the growth of larvae (Victor and Reuben 2000). Colliny Springs is high in both organic matter and leaf litter, which provides suitable environmental conditions for large numbers of mosquitoes from a diversity of genera (e.g. *Anopheles*, *Culex*, and *Aedes* species). These conditions also explain the presence of several families of fly larvae (Muscidae and Stratiomyidae), which feed on decaying plant material and organic matter.

Other significant but less abundant taxa recorded from Colliny Springs include the following.

- *Microvelia peramoena* (Hemiptera: Veliidae), which prefers areas with extensive stands of reeds, such as this pool.
- The two dragonfly species, *Aeschna brevistyla* and *Diplacodes haematodes*. Both of these species are predatory, although *Aeschna* is generally only found in and around permanent waters, while *Diplacodes* may be collected at both temporary and permanent waters. *Aeschna* is an ambush predator that requires silt, rocks or plants to conceal it from prey species.
- Two species of Coenagrionid damselflies, *Ischnura* and *Austroagrion watsoni*. Like dragonflies, damselflies are highly intolerant of pollutants.
- Scirtid beetles (Coleoptera: Scirtidae) are filter-feeding detritivores that live among aquatic plants or within organic matter. They are usually associated with freshwater.

The abundance and diversity of fauna observed at this site may be attributed to a number of factors, including habitat structure, water quality, substrate diversity, or disturbance regimes. For instance, the water quality at this site fell within normal parameters; the site displayed a highly diverse habitat structure including woody debris, leaf litter, reeds, aquatic vegetation, and algae. Despite this relatively high abundance and diversity, the macroinvertebrate fauna was largely comprised of insensitive and tolerant species. This was surprising since the site was only affected by minor levels of disturbance (e.g. stock trampling) compared with other sites, and was therefore expected to display higher diversity and abundances of sensitive taxa.

Wirreanda Creek

This site supported the highest abundances of macroinvertebrates, with an intermediate number of families and a large number of morphospecies. There were large numbers of chironomid, dragonfly and damselfly larvae collected at this site, however many of these individuals were too small to identify accurately. Of those that were large enough to identify, two midges, *Tanytarsus* and *Procladius*, and damselflies (Coenagrionidae) dominated the fauna.

Tanytarsus was recorded in large numbers at this site as well as at nearby sites along Boolcunda Creek (upstream and downstream). These sites share several characteristics that may explain the large numbers of *Tanytarsus*. For instance, all three sites displayed slight water turbidities, indicating suspended sediment and organic matter in the water column. *Tanytarsus* are obligate filter feeders (Robson, Chester and Davis 1999), and therefore require high levels of suspended algae, organic matter, detritus, inorganic particles and diatoms in the water column (Ingvason, Olafsson and Gardarsson 2002, Henriques-Oliveira, Nessimian and Dorvillé 2003). Moreover, all three sites support communities of aquatic vegetation and algae, which will further contribute to the availability of organic matter. Nevertheless, this is not likely to be the only factor affecting the abundances and distribution of *Tanytarsus* since other abiotic conditions (water quality, habitat diversity) and biotic factors (number and abundance of predatory species, competition) will also affect their abundance and distribution.

In other studies, species of *Procladius* have been described as ubiquitous (Timms 1974), abundant during the summer (Maher and Carpenter 1984), and primarily located in permanent water bodies (Nielsen, Hillman and Smith 1999). Thus, its presence at this site is not surprising.

The predatory nature of *Procladius* means that it relies on other species as a food source. Moreover, it has been suggested that *Procladius* may benefit from sediment disturbances during flooding because other fauna may be forced out of the sediment (Brodersen and Lindegaard 1999). Species of *Procladius* are often one of the primary predators of *Tanytarsus* (Einarsson et al 2002). The abundance of *Tanytarsus* will therefore subsequently affect the population sizes of *Procladius*—for instance, should the population size of *Tanytarsus* decline, it would be expected that *Procladius* will also display similar reductions in their population sizes due to reduced abundances of prey. Alternatively, increased numbers of *Tanytarsus* will support larger populations of *Procladius*. It is therefore not surprising that these two species displayed high numbers in the presence of one another. Nevertheless, this will also depend on other factors, including:

- The abundances of other prey species, as this will provide alternative food sources for *Procladius*.

- The habitat structure of the pool or spring, as this will provide shelter and protection for prey species.
- The specific tolerances of the species of *Procladius* and *Tanytarsus*.

Coenagrionid damselflies are active predators, feeding on a wide variety of taxa and organisms (Koperski 1997). Moreover, they are capable of shifting their diet in response to changes in the availability of prey or in response to increased predatory risk (Koperski 1997). Thus, the composition of the macroinvertebrate community is unlikely to explain the abundances of Coenagrionid larvae at this site. In North America, coenagrionid damselflies have been associated with particular species of aquatic vegetation including Juncus and Nephar (Gibbons et al 2002). While these relationships appear to be highly species-specific and are therefore difficult to relate to Australian taxa, Goonan and Schulze (2001) suggested that both dragonflies and damselflies tended to be correlated with high abundances of macrophytes, thus supporting this hypothesis. Another study suggests that space may be an important limitation for coenagrionid damselflies since smaller areas are likely to increase the number of aggressive interactions between individuals (Baker 1981). The pool on Wirreanda Creek was considerably smaller than four of the other sites that were surveyed, but may have been of sufficient size to reduce interactions between coenagrionid damselfly larvae.

Other important taxa that were recorded from Wirreanda Creek include:

- *Dicrotendipes* (Diptera: Chironomidae). In one study, *Dicrotendipes* was correlated with lakes recording high phosphorus levels (Brodersen, Dall and Lindegaard 1998) suggesting that it may be found in locations with high nutrient loads.
- *Larsia* species (Diptera: Chironomidae).
- Dragonflies (Libellulidae and Aeschnidae) and damselflies (Lestidae). Generally, dragonflies and damselflies avoid polluted waters. This suggests that the pool on Wirreanda Creek is relatively pristine.

The macroinvertebrate fauna collected at this site was both diverse and abundant. While large numbers of *Tanytarsus* were present, suggesting high organic loads, there were also large numbers of dragonflies and damselflies, suggesting that pollutants do not adversely affect this water. The permanent water that was surveyed at this site displayed reasonably high salinities and total dissolved solids. Moreover, while there was also relatively diverse habitat, the site lacked reeds along the banks of the pool and was exposed to high levels of light due to a lack of riparian vegetation. There was minor trampling by stock around the banks, which is likely to have negative effects on biodiversity. However, the high salinity of the water may reduce use by stock, thus limiting the extent of disturbance.

Hillpara Creek

Hillpara Creek contained the third highest number of individuals, the largest number of families and the third highest number of morphospecies across all sites. The amphipod *Austrochiltonia australis*, the non-biting midge *Procladius* sp, and the biting midge *Culicoides*, dominated the macroinvertebrate fauna at Hillpara Creek.

The community composition of this site is primarily of generalist, and highly tolerant species. For instance, previous research has characterised members of the ceratopogonid family (biting midges) as well as the amphipod *Austrochiltonia australis* as 'opportunistic' because they are relatively insensitive to changes in environmental conditions (Marchant, Mitchell and Norris 1984). Moreover, this site comprised species of *Anisops* and dysticid beetles, which are generally associated with temporary pools because of their broad tolerances and ability to rapidly recolonise water bodies (Jeffries 2003). This suggests that while this site is comprised of large numbers of species from a diversity of genera, the species that are present are relatively common and insensitive.

A previous study concluded that species of non-baetid Ephemoptera, Plecoptera and Trichoptera had at least some tolerance of high salinities, while species of Corixidae, non-corixid Hemiptera, Coleoptera, Hydracarina, Odonata, Decapoda, Isopoda and Amphipoda demonstrated higher tolerance levels (Kefford, Papas and Nugegoda 2003). The results obtained in this study concur with those results, since only representatives from the latter taxa were observed at this site. For instance, while most corixids tend to be intolerant of high salinity conditions, species of *Agraptocorixa* and *Sigara* are better able to persist at higher salinities (Knowles and Williams 1973), thus explaining the presence of *Sigara* species at Hillpara Creek. Similarly, *Culicoides* species requires estuarine conditions to breed (Edwards 1989, Cribb et al 2003, Goonan and Schulze 2001), which may explain why it was only collected at the two most saline sites in this study in Wirreanda Creek and Hillpara Creek.

Other significant taxa recorded from Hillpara Creek include:

- Dragonflies (Anisoptera: Aeschnidae) and damselflies (Zygoptera: Lestidae)—these taxaare sensitive to pollution.
- Corixid and Notonectid bugs—these taxa are common throughout South Australia because of their capacity to rapidly colonise waterbodies. Corixids will only be located in areas with aquatic plants or on a firm substrate since they require these conditions to lay their eggs. While corixids may be located in both flowing and standing waters, notonectids prefer standing waters. Both groups will tolerate fresh and saline waters, however, only some species are tolerant of pollution, suggesting that they will generally inhabit relatively unpolluted sites.
- Pyralid moths—members of this family are known pests of fruit, grains, nuts, flour and plants both in Australia and overseas.

The apparent abundances and diversities observed at this site were surprising since this was the most saline of all the sites that were surveyed, and was therefore expected to be relatively depauperate. Moreover, this site was shallow and heavily silted, experienced no shade due to an absence of riparian vegetation, and displayed lower habitat diversity than many of the other sites. These conditions may explain the presence of large numbers of generalist species.

Boolcunda Creek (downstream)

This sample comprised a relatively large number of macroinvertebrate specimens with relatively low family diversity, but high morphospecies diversity when compared with other sites. This result suggests that the conditions are not suitable for large numbers of families, but those that are able to tolerate or persist under these conditions may form diverse communities. This site was completely dominated by chironomid midges, including species of *Tanytarsus*, *Cladotanytarsus* and *Larsia*. Many chironomids were too small to identify and were subsequently grouped into the Tanytarsini tribe.

Tanytarsus and *Cladotanytarsus* larvae are commonly collected in macroinvertebrate surveys throughout Australia. They have broad environmental tolerances, rapid reproduction rates, omnivorous diet, and an adult form capable of dispersal, making them successful in both temporary and permanent habitats. While *Cladotanytarsus* prefers sites with a low abundance of macrophytes and nutrients (Goonan et al 1992, Silver Botts 1997, van den

Berg et al 1997), it is capable of surviving in large numbers at sites that are high in macrophytes and organic matter.

Other significant but less abundant taxa recorded from Boolcunda Creek (downstream) include:

- Two caddisfly species, *Oecetis* and *Triplectides australis*. Trichopteran lavae are considered to be particularly sensitive taxa, although they show widespread distributions under a variety of flow conditions, salinities and water permanencies. *Triplectides* has been labelled as having 'intermediate sensitivity' as it has shown high sensitivity to pollutants in some areas and low sensitivity in others.
- Libellid, coenagrionid and lestid dragonflies since they are not found in polluted waters.

The salinity and total dissolved solids recorded at this site were relatively high. There is a high diversity of habitat at this site, including small quantities of reeds, dead trees, aquatic vegetation, and large rocks and boulders. The pool itself is quite deep, which may promote higher species diversity through increased availability of habitat and reduced water quality fluctuations. Sedimentation at this site is minor, consisting of a fine layer of sediment on the bottom of the pool. There is evidence of excessive stock trampling on the banks, however the extent of trampling varies throughout the pool, as some areas are inexcessible to stock and display greater abundances of reeds and sedges.

Boolcunda Creek (upstream)

As a result of the low numbers of macroinvertebrates that were obtained in the initial ten percent of the sample, it was necessary to sort 22% of this sample in accordance with the AusRivAS methodology. The numbers that would be collected in ten percent of the sample were subsequently calculated to enable comparisons to be made with data from other sites. This site displayed relatively low abundances and diversity of macroinvertebrates compared with other sites. The site was dominated by two chironomid midge species, *Kiefferulus* and *Tanytarsus*, and the Hemipteran, *Anisops* (Notonectidae).

Species of *Tanytarsus* have been used as environmental indicators because the species may be found in a variety of locations, representing a diversity of habitats and conditions (Cranston 2000). For instance, Cranston et al (1997) found that one species of *Tanytarsus* in their study was closely correlated with polluted waters, while another study found that *Tanytarsus* were more prevalent at undisturbed sites (Walsh et al 2001). Yet another study found that the environmental tolerances of *Tanytarsus* were highly species-specific (Cranston 2000). Thus, it is difficult to make conclusions regarding the presence of *Tanytarsus* at this site.

Large numbers of the non-biting midge fly *Kiefferulus* were collected at this site. The reasons for the differences are largely unknown, since there is currently very little information available regarding the biology and ecology of this genus. However, Walsh et al (2001) observed that *Kiefferulus* was present in fewer numbers at the metropolitan sites in their study (Victoria, Australia), suggesting that it is relatively intolerant of disturbance.

Other significant but less abundant taxa recorded from Boolcunda Creek (downstream) include:

- Species of *Riethia* and *Dictotendipes* (Diptera: Chironomidae). The non-biting midge, *Riethia* species was collected exclusively at Boolcunda Creek (upstream). This species was collected in very low numbers, which may be expected since it is a rare and sensitive genus (Marchant, Mitchell and Norris 1984). In previous studies, this genus has been used as an indicator of ecosystem health because it is sensitive to changes in water quality (Marchant, Mitchell and Norris 1984). The presence of *Riethia* therefore suggests that the water quality at this site is relatively stable, despite displaying high salinities.

- Stratiomyid flies (Diptera: Stratiomyidae). Many species of dipteran fly are considered to be sensitive to pollution.
- The baetid mayfly nymph, *Cloeon.*
- *Mesovelia* species (Hemiptera: Veliidae). This family of hemiptera tend to be associated with still or stagnant water bodies with vegetation (which adults lay their eggs on and cling to).
- Aeschnid and coenagrionid dragonflies.

This site was highly saline with high readings of total dissolved solids. There were also high temperatures, low levels of shading, high habitat diversity, minor sedimentation and extensive stock trampling. It is possible that either the presence of Lake Eyre hardyhead in large numbers and/or the high levels of stock trampling may have resulted in the low diversity and abundances of macroinvertebrates at this site. Nevertheless, the presence of several rare and sensitive taxa suggests that the water quality at this site is relatively pristine and stable.

Walloway

Due to the lower numbers of macroinvertebrates it was necessary to sort 25% of this sample to obtain the required 200 individuals in accordance with AusRivAS methodology. The abundance and diversity of macroinvertebrates collected at this site was low, particularly when the percentage of the sample that was sorted was considered relative to other sites. Very few individuals of any of the taxa were collected in large numbers with exception of the mayfly, *Cloeon* species (Ephemoptera: Baetidae) and the two hemipteran genera, *Agraptocorixa* species (Hemiptera: Corixidae), and *Anisops* species (Hemiptera: Notonectidae). The latter taxa are often associated with temporary waters because they are rapid recolonisers following rainfall or refilling of pools (Boulton and Lake 1988).

Unlike the other sites, this site supported very few chironomids and large numbers of the mayfly *Cloeon*. While mayflies (Ephemoptera) generally prefer cool, unpolluted waters, *Cloeon* favours warm, still waters, and they are tolerant of poor water qualities (Goonan and Schulze 2001). Conversely, Marchant, Mitchell and Norris (1984) suggested that high abundances of *Cloeon* reflect high water quality. These differing results suggest that different species of *Cloeon* may vary in their environmental requirements.

Species of *Anisops* prey heavily on other invertebrates, including meiofauna and aquatic insects (Sarnelle et al 1998, Nielsen, Hillman and Smith 1999). For this reason, it has been suggested that midges and other dipteran species will preferentially select sites that display low abundances of *Anisops* (Eitam, Blaustein and Mangel 2002). This hypothesis is supported by the results obtained at this site, where midges were relatively scarce. However, large numbers of *Anisops* were also collected at Boolcunda Creek (upstream) where considerable numbers of non-biting midges were collected, suggesting that there are other factors affecting the distribution of non-biting midges in the Willochra Creek Catchment.

Some of the other taxa found that are worth noting include:

- Dragonflies (Anisoptera: Aeschnidae) and damselflies.

- *Paratanytarsus* (Diptera: Chironomidae), which is described as having 'intermediate sensitivity' because it has shown different responses to pollutants and environmental conditions across locations.
- Leptocerid caddisfly nymphs (Trichoptera: Leptoceridae) because they are highly sensitive to pollution.

The composition of macroinvertebrates at this site differed significantly from that of other sites, particularly in relation to the abundances of chironomids that were collected. Samples collected from this site and from Colliny Springs displayed considerably fewer chironomids than any of the other sites. The water quality at this site was relatively saline, however the salinity falls within the acceptable limits for healthy growth of domestic animals. The site did contain a high diversity of habitats including reeds, aquatic vegetation, large rocks and boulders, woody debris and leaf litter, although these were present in low abundances. The pool was heavily sedimented and excessively trampled by domestic animals.

O'laddie Creek

In accordance with AusRivAS protocols the entire sample from this site (100%) was sorted. This sample contained very low abundances and diversities of families and morphospecies, especially when data were calculated to allow comparisons to be made with other sites. The depauperate faunal composition that was observed at this site may be due to the fact that this pool has experienced extensive drying in recent times. This site also encounters high watering pressure by stock, which may affect the abundance and diversity of macroinvertebrate fauna.

The macroinvertebrate fauna collected at this site was almost completely dominated by the non-biting midge *Chironomus* species (Chironomidae) and the mosquito larvae, *Aedes* species (Culicidae).

The genus of *Chironomus* is generally recognised as an indicator of organic enrichment, environmental stress or toxicity (Sharley, Pettigrove and Parsons 2004). For this reason, *Chironomus* has been described as 'opportunistic' (Marchant, Mitchell and Norris 1984), and is therefore able to occupy niches that have been vacated by more sensitive taxa (Sheldon and Walker 1998). Its capacity to be used as a biological indicator has meant that this genus has been used widely for ecotoxicological studies in many locations (Sharley, Pettigrove and Parsons 2004). For instance, a study conducted on the La Trobe River of Victoria concluded that *Chironomus* (taxa group 5) could be used as an indicator of organically polluted water (Marchant, Mitchell and Norris 1984). Despite this however, many Australian species of *Chironomus* display similar morphologies, making them difficult to separate in the laboratory (Sharley, Pettigrove and Parsons 2004). In addition, there are a number of rare and cryptic species of Australian *Chironomus* that have not yet been identified and described (Sharley, Pettigrove and Parsons 2004). These constraints have resulted in *Chironomus* displaying limited use as a biological indicator within Australia (Sharley, Pettigrove and Parsons 2004).

The presence of large numbers of *Chironomus* and *Aedes* at the O'laddie Creek site may therefore indicate either: polluted waters, temporary waters, or some other factor that has yet to be identified.

Chironomus was also collected at Colliny Springs, Hillpara Creek and Boolcunda Creek (downstream), however because they displayed low abundances, these findings are not conclusive. Further study is required to better understand the potential uses of *Chironomus* as a biological indicator, the species-specific requirements of those species that are located in the Willochra Catchment, and the environmental conditions that each species is able to tolerate.

Some other significant fauna that were observed at this site (albeit in smaller numbers) include:

- A moth fly (Diptera: Psychodidae) and several soldier flies (Diptera: Stratiomyidae).
- Springtails (Collembola), which were not observed at any of the other sites. While springtails are relatively common and tolerant of pollutants, they feed on the microorganisms associated with decaying plant material, and their presence in these samples provides important information about the ecology and functioning of this site.

While the diversity of habitats was high, they were generally present in small quantities and no reeds were present, which would limit the diversity and abundances of many fauna. Moreover, this site was relatively depauperate in abundance and diversities of aquatic vegetation, which may be a result of the extensive stock trampling, high light levels, and/or gravel and rocky substrate.

C. RAINFALL AND STREAMFLOW SUMMARY - KANYAKA CREEK

Rainfall records were obtained from the Bureau of Meteorology (BoM) for the nearest streamflow gauging station to the study area, being 'Kanyaka Creek at Old Kanyaka Ruins' (A5090503). These data correspond to the period 1884–2004. Annual and monthly rainfall statistics were calculated for this period to provide an indication of the seasonal and interannual variations in rainfall patterns. Table C1 summarises the highlights of the annual record, and Figure C1 shows the monthly rainfall patterns.

Table C1. Seleced annual rainfall statistics – Kanyaka Creek

Statistic	**Rainfall** (mm)	**Period or year**
Mean annual rainfall	300	1884–2004
Median annual rainfall	282	1884–2004
Maximum	626	1974
Minimum	85	1982
Coefficient of variation	0.34	1884–2004
S80 index	0.50	1884–2004

The coefficient of variation (CV)—the standard deviation divided by the mean—and the S80 index—the difference between the 20th and 80th frequency percentiles divided by the median—provide an indication of the variability in the record. The rainfall CV of 0.34 and S80 of 0.50 compares to the respective values for the upper Torrens River of 0.22, and 0.35 indicating annual rainfall that is still variable within more southerly catchments, but considerably more uniform than Kanyaka Creek.

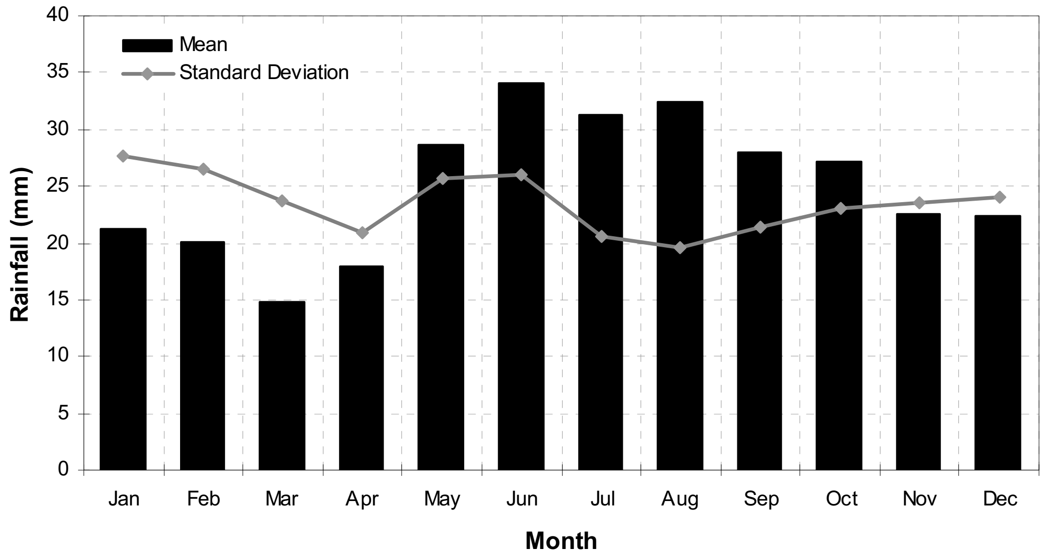

Figure C1. Monthly rainfall and standard deviation 1884–2004: Kanyaka Creek

The Government of South Australia, through the Department of Water, Land and Biodiversity Conservation, have maintained a surface water flow gauging site at Kanyaka Creek, near the Old Kanyaka homestead ruins, since 1973. The most reliable period of record is from 1978–2004, which is effectively continuous, with the exception of a six–month period during 1996, where flood waters destroyed the station.

The daily flow records, with the 1996 records removed, were analysed for this report, as follows:

- A baseflow separation was undertaken using the Lynne–Hollick method.
- Annual and monthly baseflow and streamflow statistics were calculated.

The annual streamflow in megalitres for the period 1978–2004 (less 1996) is shown in Figure C2, along with the mean for the period of 499 ML/y (corresponding to 3 mm depth of runoff). The median annual flow for the same period is 112 ML (around 0.5 mm depth of runoff).

The most apparent feature in the record is the episodic nature of the catchment, and extreme events dominate more typical runoff patterns. The coefficient of variation for the flow data between 1978–2004 was 1.9, comparing with 1.1 for the River Torrens at Mt Pleasant. The streamflow S80 index is 5.3, indicating the extreme variation in annual discharge, which is an order of magnitude more variable than the rainfall. This is evident in the extreme annual values, and the highest annual streamflow volume for the period of record was 4454 ML in 1978, compared to just 29 ML, the lowest total observed, in 1999.

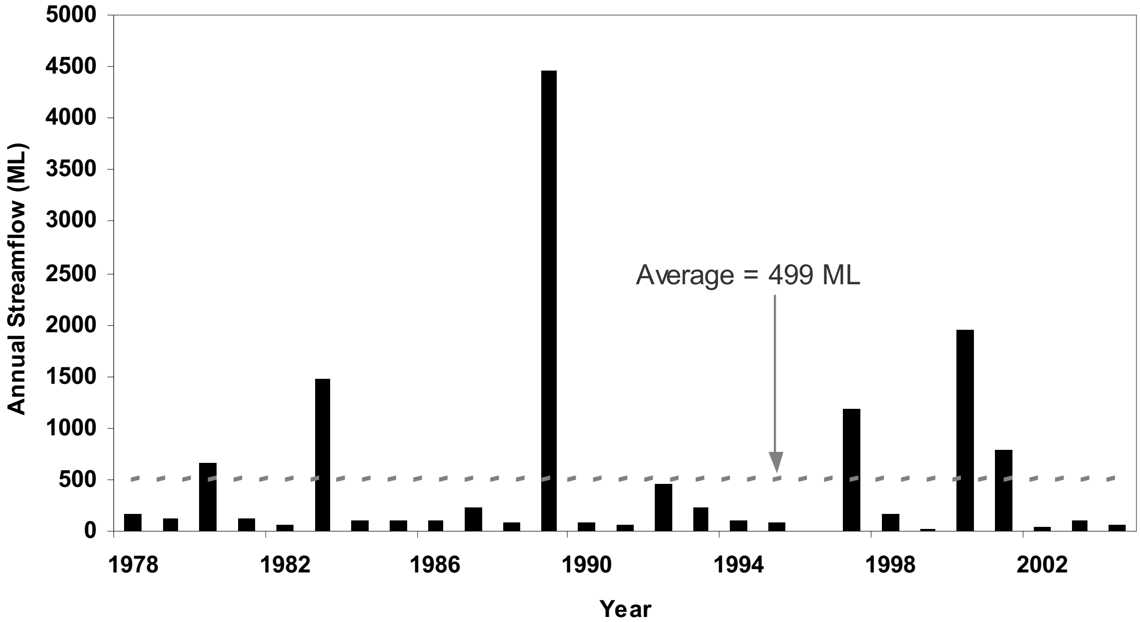

Figure C2. Total annual streamflow for 1978–2004 (not including 1996): Kanyaka Creek gauging station A5090503

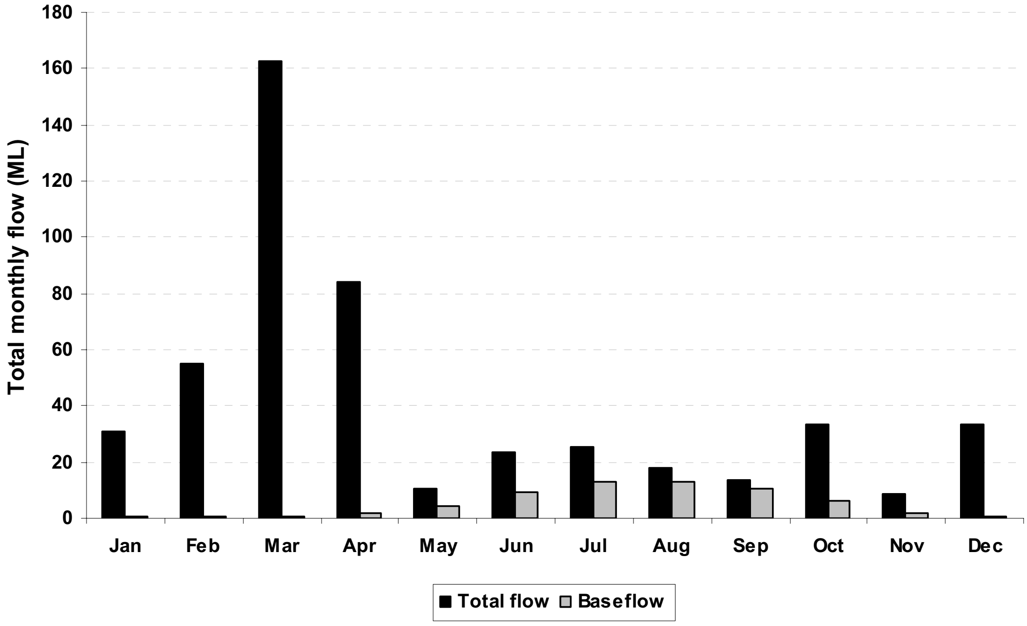

Figure C3. Monthly streamflow and baseflow volumes for the period 1978–2004 (not including 1996): Kanyaka Creek gauging station A5090503

Shown above in Figure C3 are the mean monthly volumes for the period 1978–2004 (not including 1996) for total streamflow and derived baseflow (groundwater discharging to the surface as streamflow). A seasonal pattern in the baseflow can be seen, where relatively reliable discharges occur in the months of May–October, being especially predictable in July–August, where the S80 values are 0.26 and 0.18 respectively, (around 20–30 times more predictable than the annual streamflow by this measure). Reliable seasonal baseflow is a pattern commonly observed in South Australian streams of more temperate zones, and is not directly dependent upon rainfall for it to occur.

This reliable baseflow is superimposed on the highly episodic flow regime evident in the direct runoff record. In addition to the value for the S80 index, the episodic nature of rainfall in the region is also evident in Figure C3, with the highest flow month being March, the driest month in terms of rainfall. This is the result of a single month's flow in 1989, where over 4400 ML was recorded at the site. This volume is almost ten times the mean annual total for the period concerned, leading to its numerical dominance in the monthly total.

D. FIELD SURVEY SUMMARIES

Site Number: 1 **Site Name**: Mt. Lock

Date of Assessment: 22 March 2006

Time of Assessment: 15.00–15.45

Site Photo: David Deane, Neil Collier

Landholder comments:

- Water has decreased in depth over the past five years.
- Will see increases in depth following several heavy rains – not immediately.
- Once this water was drinkable, but that is no longer the case.
- Contour banks have been present since the 1960s.
- There were once permanent pools along an adjacent creek – dried in recent times.
- Creeks will only flow following heavy rains.

Water quality parameter	Bottom	
pH	7.09	–
Water Temperature	16.45	ºC
Dissolved Oxygen	0.95	mg/L
	10.4	%
EC	4980	µS cm^{-1}
TDS	3238	ppm = mg/L
Redox potential	-11.8	–

Site Number: 2 **Site Name**: Windemere

Date of Assessment: 20March 2006
Time of Assessment: 14.30–15.45
Site Photos: David Deane, Neil Collier

Landholder comments:

- Landholder has been on this property for the past 25 years. His family has always owned this property
- Only permanent spring on the property;all other water is pumped from underground
- Flows out of the ground and downhill – doesn't form a pool
- Flow has dropped significantly over the past 15 years. The area has been particularly dry over the past few years.

Water quality parameter	Surface	
pH	7.27	–
Water Temperature	17.67	ºC
EC	3507	µS cm^{-1}
TDS	2280	mg/L

Spring too shallow to obtain dissolved oxygen or redox measurements.

In-stream habitat type	% habitat
Riffle	Very limited
Pool	100
Reeds	>60
Aquatic vegetation	<30
Sediment/banks	>60
Aquatic vegetation	% cover
Typha	>60
Juncus	<30
Triglochin striatum	<10

Geomorphology	Left bank	Right bank
Steepness	<45 º	<45 º
Undercut	None	None
Exposed tree roots	None	None
Slumping/sloughing	None	None
Stock trampling	Extensive	Extensive
Bank scouring	None	None
Maximum bank sediment size	Gravel	Gravel
Dominant bank sediment size	Silt/clay	Silt/clay
Vegetation between bank top and toe	<10%	<10%

Site Number: 3 **Site Name**: Nalia Creek

Site Location: Zone 54H, 0286462, 6346364

Date of Assessment: 23 March 2006

Time of Assessment: 11.15–12.00

Site Photos: David Deane, Neil Collier

Samples collected: Macroinvertebrates and fish, but because of thick anoxic sludge throughout the entire pool, it was not possible to sort the macroinvertebrate sample.

Fish collection methods: Dipnet

Fish collected: None

Water quality parameter	**Surface**		**Bottom**	
pH	7.53	–	7.55	–
Water Temperature	18.47	ºC	18.70	ºC
Dissolved Oxygen	8.42	mg/L	6.90	mg/L
	95.3	%	79.0	%
EC	14495	µS cm^{-1}	15411	µS cm^{-1}
TDS	9437	mg/L	1005	mg/L
Redox potential	-53.7	mV	-64.7	mV

General comments:

- In streambed, but pools are isolated due to sedimentation.
- Two pools connected.
- Overgrown with *Juncus kraussii.*
- Highly silted, thick, black, anoxic sediment throughout pool (approximately 50 cm deep on the bottom of the pool).
- Entire creek bed covered with reeds/sedges.
- Small stand of *Typha.*
- A few weeds spotted throughout streambed.
- Filamentous algae.
- Too turbid for water plants.
- Bank on right hand side relatively bare, few sparse grasses.

In-stream habitat type	% habitat
Pool	100
Reeds	>60
Aquatic vegetation	0–10
Algae	0–10
Aquatic vegetation	% cover
Typha	30–60
Juncus	>60
Triglochin striatum	<30
Pool dimensions	(m)
Length	13.5
Width	8
Depth	1 (sediment >50 cm deep)

Geomorphology	Left bank	Right bank
Steepness	<45º	45–70º
Undercut	None	None
Exposed tree roots	None	None
Slumping/sloughing	None	None
Stock trampling	None	None
Bank scouring	None	None
Maximum bank sediment size	Silt/clay	Silt/clay
Dominant bank sediment size	Silt/clay	Silt/clay
Vegetation between bank top and toe	>50%	10–50%

Site Number: 4 **Site Name**: Mucra Springs

Site Location: Zone 54H, 0279195, 6365055

Date of Assessment: 23 March 2006

Time of Assessment: 08.30–09.25

Site Photos: David Deane, Neil Collier

Samples collected: Fish

Fish collection methods: Dipnet

Fish collected: None. Unidentified tadpoles present

Water quality parameter	Surface		Bottom	
pH	7.50	–	7.47	–
Water Temperature	17.2	ºC	17.02	ºC
Dissolved Oxygen	4.82	mg/L	4.39	mg/L
	50.3	%	45.9	%
EC	3439	µS cm^{-1}	3435	µS cm^{-1}
TDS	2236	mg/L	2232	mg/L
Redox potential	126.3	mV	132.4	mV

Landholder comments:

- Landholder has had to dig out pools in recent times.
- Have had lots of problems with sedimentation particularly due to *Typha* reeds.
- Have noticed a decrease in water depth over the past 15 years.
- Have lost many springs in the area – thought due to sedimentation.
- Flood in March. Washed mud and gravel into the spring.
- The area with the spring was once a water reserve – supply for farmers.

- In recent times, the 40 foot deep well has dried.
- Formerly a number of pools further upstream, now filled with mud and silt.
- Property advertised in 1880s as having running water. No longer present.
- Formerly another permanent pool (1930s), now only fills with surface runoff.
- The salinity of the well water is gradually increasing.
- Area was formerly infested with artichokes. Landholder has since controlled these.

General comments:

- Several very small pools within streambed.
- Evidence of sheep trampling.
- Oil present on the water surface.

In-stream habitat type	% cover
Reeds	10–30
Large Rocks/Boulders	>60
Aquatic vegetation	10–30
Leaf litter	0–10
Algae	0–10
Sediment/banks	10–30
Aquatic vegetation	% cover
Cyperus	<30
Typha	30–60
Chara	<30
Watercress	<30
Pool dimensions:	(m)
Length	8
Width	5
Depth	1

Geomorphology	Left bank	Right bank
Steepness	45–70º	<45º
Undercut	None	None
Exposed tree roots	None	None
Slumping/sloughing	None	None
Stock trampling	Extensive	Extensive
Bank scouring	None	None
Maximum bank sediment size	Bedrock	Bedrock
Dominant bank sediment size	Bedrock	Bedrock
Vegetation between bank top and toe	0–10%	0–10%

Site Number: 5 **Site Name**: Pekina Creek (Site 1)

Site Location: Zone 54H, 0273935, 6373223

Date of Assessment: 3 Feb 2006

Time of Assessment: 08.30–09.40

Site Photos: David Deane

General comments:

- Extremely heavily trampled by cattle and sheep on both sides of the bank.
- Oily residue on the surface.
- Lots of reed die-back resulting in a high organic load in the pool.
- Both ends of the pool are shaded but the middle of the pool is open.
- Thick mats of algae and aquatic vegetation in shallow water.
- Lots of leaf litter and plant debris.
- Woody debris – logs on edge of the pool.
- Area around banks is free of any vegetation – dry and bare.
- Water is black, quite turbid, almost milky in appearance.
- Anoxic odour to the water.
- According to Mark (volunteer), about ten years ago there was a series of small pools along the reach. These pools are no longer present.

In-stream habitat type	% cover
Pool	100
Reeds/sedges	0–10
Aquatic vegetation	30–60
Leaf litter	10–30
Woody debris	0–10
Dead trees	0–10
Algae	10–30
Sediment/banks	>60
Aquatic vegetation	% cover
Cyperus	<30
Chara	30–60
Pool parameters:	(m)
Length	60
Width	8
Depth	1

Canopy cover	Left bank	Right bank
Above stream	>60%	31–60%
5 m downstream	31–60%	31–60%
10 m downstream	1–10%	1–10%
15 m downstream	0%	0%
20 m downstream	0%	0%
Geomorphology	Left bank	Right bank
Steepness	<45 º	<45 º
Undercut	None	Minor
Exposed tree roots	Minor	Minor
Slumping/sloughing	None	None
Stock trampling	Extensive	Extensive
Bank scouring	None	None
Maximum bank sediment size	Silt/clay	Silt/clay
Dominant bank sediment size	Silt/clay	Silt/clay
Vegetation between bank top and toe	0–10%	0–10%

Site Number: 6 **Site Name**: Pekina Creek – Winfleet

Site Location: Zone 54H, 6367757, 0274172
Date of Assessment: 24 March 2006
Time of Assessment: 10.00–10.30
Site Photos: David Deane, Neil Collier, Anne Walters

Water quality parameter	Bottom	
pH	8.02	–
Water Temperature	13.48	ºC
Dissolved Oxygen	8.35	mg/L
	88.9	%
EC	6603	µS cm^{-1}
TDS	4292	mg/L
Redox potential	34.3	mV

Landholder comments:

- Permanent spring near to Brian McNamara's property.
- The local council has been removing water from this spring for road works.

General comments:

- Evidence of stock trampling and truck activity on banks.
- Lots of leaf litter and debris on the bottom of the pool.

- Bordered by a number of River Red Gums, which create significant shade.
- Sediment mound adjacent to pool – road works?
- Sparse *Typha* on edges of the pool.
- Some *Cyperus* plants surrounding edges in patches.

In-stream habitat type	% habitat
Pool	100
Reeds	10–30
Overhanging Vegetation	0–10
Leaf litter	>60
Sediment/banks	>60
Aquatic vegetation	% cover
Cyperus	<30
Typha	<30
POOL DIMENSIONS	(m)
Length	10
Width	15
Depth	>2

Canopy cover	Left bank	Right bank
Above stream	31–60%	31–60%
5–20 m downstream	0%	0%
Geomorphology	Left bank	Right bank
Steepness	<45 º	>70 º
Undercut	Minor	None
Exposed tree roots	None	None
Slumping/sloughing	None	None
Stock trampling	Extensive	Extensive
Bank scouring	None	None
Maximum bank sediment size	Gravel	Gravel
Dominant bank sediment size	Silt/clay	Silt/clay
Vegetation between bank top and toe	0–10%	>50%

Site Number: 7 **Site Name**: Pekina Creek Gauging Station

Site Location: Zone 54H, 0275347, 6375369

Date of Assessment: 3 Feb 2006

Time of Assessment: 10.00–11.00

Site Photos: David Deane

Water quality parameter	Surface	Bottom	
pH	7.73	NR	–
Water Temperature	23.98	23.96	ºC
Dissolved Oxygen	7.21	6.7	mg/L
	87.0	82.29	%
EC	4642	4602	µS cm^{-1}
TDS (ppm = ppt x1000)	3016	2990	ppm = mg/L
Redox potential	105.4	NR	mV

In-stream habitat type	% habitat
Pool	100
Reeds	>60
Overhanging Vegetation	0–10
Large Rocks/Boulders	30–60
Aquatic vegetation	10–30
Leaf litter	0–10
Aquatic vegetation	**% cover**
Typha	30–60
Juncus	<30
Cyperus	<30
Pool dimensions:	**(m)**
Length	70
Width	10
Depth	>1.5

Redgum canopy cover	**Left bank**	**Right bank**
Above stream	0%	0%
5 m downstream	1–10%	1–10%
10 m downstream	11–30%	11–30%
15 m downstream	1–10%	1–10%
20 m downstream	1–10%	0%
Geomorphology	**Left bank**	**Right bank**
Steepness	<45 º	45–70 º
Undercut	None	None
Exposed tree roots	None	None
Slumping/sloughing	None	None
Stock trampling	None	None
Bank scouring	None	None
Maximum bank sediment size	Bedrock	Bedrock
Dominant bank sediment size	Bedrock	Bedrock
Vegetation between bank top and toe	>50%	10–50%

Site Number: 8 **Site Name**: Pekina Creek – Historical Ruin

Site Location: Zone 54H, 0274405, 6373982
Date of Assessment: 24 March 2006
Time of Assessment: 07.40–08.05
Site Photos: David Deane, Neil Collier

General observations:

- Isolated, turbid pool within Pekina Creek streambed.
- Several large Eucalypts on right bank create shade for pool.
- Right bank very steep with exposed sediment banks. Some bedrock apparent low on the right bank.
- Left bank and streambed covered with low lying shrubs and regenerating Eucalypts. Left bank has exposed bedrock.
- Lots of stock trampling at downstream end of the pool.

In-stream habitat type	% habitat
Pool	100
Large Rocks/Boulders	30–60
Aquatic vegetation	10–30
Leaf litter	0–10
Woody debris	0–10
Sediment/banks	>60
Aquatic vegetation	**% cover**
Cyperus	30–60
Pool dimensions	(m)
Length	100
Width	10
Depth	~1.5

Redgum canopy cover	Left bank	Right bank
Above stream	1–10%	11–30%
5 m downstream	11–30%	11–30%
10 m downstream	11–30%	1–10%
15 m downstream	11–30%	1–10%
20 m downstream	11–30%	11–30%
Geomorphology	**Left bank**	**Right bank**
Steepness	45–70º	>70º
Undercut	None	Minor
Exposed tree roots	None	Minor
Slumping/sloughing	None	Minor
Stock trampling	Extensive	Extensive
Bank scouring	Minor	Minor
Maximum bank sediment size	Silt/clay	Bedrock
Dominant bank sediment size	Silt/clay	Bedrock
Vegetation between bank top and toe	>50%	10–50%

Site Number: 9 **Site Name**: Pekina Creek

Site Location: Downstream Pekina Creek Reservoir
Date of Assessment: 24 Feb 0226
Time of Assessment: 08.20–09.20
Site Photos: David Deane, Neil Collier

Water quality parameter	**Pool 1**	**Pool 2**	**Units**
pH	6.99	7.49	–
Water Temperature	17.21	18.37	º C
Dissolved Oxygen	0.65	0.85	mg/L
	7.0	9.86	%
EC	1069	4594	µS cm^{-1}
TDS	695	2983	mg/L
Redox potential	-137.0	-82.0	mV

Landholder comments:
- In 1941 there was a pool on their property, but this is no longer present.
- Prior to 1997, the creek used to flood every year.
- During the 1970s and 1980s, the creeks would trickle during the winter.
- During 1997 they received 4 inches of rain in 40 minutes.
- 1997/1998: cleaned out pool to keep it filled with water.
- Water level has been down over the past 3–4 years.

General comments:

- Banks are very bare and exposed.
- Lots of boxthorns throughout the streambed.
- *Typha* reeds at one edge of the pool – they are dead and dying.
- Thick scum on the surface of the water.
- Approximately 100 m along the streambed there is another pool which is much larger (50 m x 5 m). This pool has extensive stands of *Typha.*
- Evidence of stock trampling. *Cyperus* chewed off.

In-stream habitat type	**% habitat**
Pool	100
Reeds	30–60
Leaf litter	10–30
Sediment/banks	>60
Aquatic vegetation	**% cover**
Cyperus	30–60
Typha	30–60
Pool 1 dimensions	**(m)**
Length	15
Width	15
Depth	>2
Pool 2 dimensions	**(m)**
Length	50
Width	5
Depth	>2

Redgum canopy cover	**Left bank**	**Right bank**
Above stream	11–30	31–60
5 m downstream	1–10	31–60
10 m downstream	0	11–30
15 m downstream	0	11–30
20 m downstream	0	0
Geomorphology	**Left bank**	**Right bank**
Steepness	>70 º	0–10%
Stock trampling	Extensive	Extensive
Maximum bank sediment size	Silt/clay	Silt/clay
Dominant bank sediment size	Silt/clay	Silt/clay
Vegetation between bank top and toe	0–10%	0–10%

Site Number: 10 **Site Name**: Walloway

Site Location: Zone 54H, 0272885, 6387311

Date of Assessment: 20 March 2006

Time of Assessment: 16.30–17.45

Site Photos: David Deane, Neil Collier

Samples collected: Macroinvertebrates

Water quality parameter	**Surface**	**Bottom**	
pH	7.79	7.60	–
Temperature	23.16	19.82	ºC
Dissolved Oxygen	6.79	5.53	mg/L
	80.2	62.0	%
EC	5425	5485	$\mu S\ cm^{-1}$
TDS	3526	3567	mg/L
ORP	1.65	150.6	mV

General comments:

- Pool isolated within a wide stream channel (approximately 10 m on either side). Several smaller pools also evident within the channel.
- Large numbers of artichoke throughout the streambed. Many overgrown weeds further downstream of the pool. Caterpillar weed, boxthorn and wild tobacco also present.

- Some evidence of recent flooding. Debris present approximately 2 m up the rock face of the bank.
- *Typha* reeds on both sides of the water – but probably too deep for growth in the middle of the pool.
- Muddy, exposed areas of the pool without weed growth.
- Blue Gums upstream. Some smaller trees in the area – evidence of regeneration.
- Large stands of *Typha* downstream.
- Rocky.
- Evidence of erosion on top of the bank as well as in the streambed.
- Trampling by cattle apparent on both ends of the pool.

In-stream habitat type	% habitat
Reeds	30–60
Large Rocks/Boulders	0–10
Aquatic vegetation	0–10
Leaf litter	0–10
Woody debris	0–10
Sediment/banks	30–60
Aquatic vegetation	% cover
Typha	30–60
Cyperus gymnocaulous	<30
Pool dimensions	(m)
Length	38
Width	12
Depth	1.5

Geomorphology	Left bank	Right bank
Steepness	>70 º	>70 º
Undercut	Extensive	Minor
Exposed tree roots	None	None
Slumping/sloughing	Minor	Minor
Stock trampling	Extensive	Extensive
Bank scouring	None	None
Maximum bank sediment size	Gravel	Gravel
Dominant bank sediment size	Clay/silt	Clay/silt
Vegetation between bank top and toe	0–10%	0–10%

Macroinvertebrate survey results:

Common name	Family	Species/Genera	Abundance
Roundworm	Nematoda	–	4
Amphipod	Ceinidae	*Austrochiltonia australis*	1
Yabby	Parastacidae	*Cherax destructor*	Residue*
Midge	Chironominae	*Kiefferulus* sp.	4
		Polypedilum sp.	1
		Tanytarsini sp.	1
		Tanytarsus sp.	9
		Paratanytarsus sp.	4
		Dictrotendipes sp.	2
		Larsia sp.	1
		Procladius sp.	2
Water boatmen	Corixidae	*Micronecta* sp.	7
		Micronecta gracilis	3
		Agraptocorixa sp.	42
		Agraptocorix parvipunctata	4
Backswimmer	Notonectidae	*Anisops* sp.	21
		Anisops deanei	Residue*
Caddisfly	Leptoceridae	Leptoceridae sp.	1
Mayfly	Baetidae	*Cloeon* sp.	138
		Baetidae sp.	5
Dragonfly	Aeschnidae	Aeschnidae sp.	11
		Aeschna brevistyla	Residue*
Damselfly	-	Zygoptera sp.	1
Diving beetle	Dytiscidae	*Necterosoma dispar*	2
		Necterosoma pencillatus	1
Tadpole		*Limnodynastes* sp.	Residue*
		TOTAL	265

* According to the AusRivAS methodology, it is necessary to sort and identify a minimum of ten percent of the sample. In this case, 25% of the sample was sorted to obtain 200 individuals in accordance with AusRivAS requirements). However, this method of sub-sampling means that it is possible to miss species and therefore incorrectly assess diversity. To account for this, the remainder of the sample is also sorted and any species that were not in the original sub-sample are included in the analyses (although their abundances are not known).

Site Number: 11 **Site Name**: Colliny Springs

Site Location: Zone 54H, 0277831, 6399254
Date of Assessment: 24 March 2006
Time of Assessment: 11.30–12.15
Site Photos: Neil Collier, David Deane
Samples collected: Macroinvertebrates

Water quality parameter	Main pool	Overflow	Units
pH	7.54	7.43	–
Water Temperature	18.30	18.55	ºC
Dissolved Oxygen	0.93	8.05	mg/L
	10.5	89.2	%
EC	4767	10713	µS cm^{-1}
TDS	3099	6962	mg/L
Redox potential	-126.0	-7.3	mV

Landholder comments:

- Purchased property in 1976. Over the past five years have observed a decline in the depth of the water on their property.

General comments:

Main pool and smaller pool:
- Completely filled with *Typha.*
- Well shaded by overhanging Eucalypts along the riparian corridor.
- Banks with limited bare ground.
- Abundant leaf litter within the pool.
- Understorey is relatively invaded by exotic species (particularly boxthorns).
- Sediment anoxic.

Overflow pool:
- Relatively deep (40–60 cm).
- Very little surrounding vegetation.
- Overhanging *Cyperus gymnocaulous* into the water.

Habitat type	**% of habitat**
Pool	100
Reeds	>60
Overhanging Vegetation	10–30
Large Rocks/Boulders	0–10
Aquatic vegetation	0–10
Leaf litter	>60
Woody debris	10–30
Algae	0–10
Sediment/banks	10–30
Aquatic vegetation	% cover
Cyperus gymnocaulous	30–60
Typha	>60
Watercress	<30
Chara	<30
Pool 1 dimensions	(m)
Length	0.5
Width	0.3
Depth	0.1
Pool 2 dimensions	(m)
Length	15
Width	6
Depth	0.2

Canopy cover	Left bank	Right bank
Above stream	80%	80%
5 m downstream	80%	80%
10 m downstream	–	1–10%
15 m downstream	–	1–10%
20 m downstream	–	1–10%
Geomorphology	Left bank	Right bank
Steepness	45–70 º	<45 º
Undercut	Minor	None
Exposed tree roots	Minor	Minor
Slumping/sloughing	Minor	None
Stock trampling	Minor	Minor
Bank scouring	Minor	Minor
Maximum bank sediment size	Boulders	Boulders
Dominant bank sediment size	Silt/clay/cobble	Silt/clay
Vegetation between bank top and toe	10–50%	>50%

Macroinvertebrate survey results:

Common name	Family	Species/Genera	Abundance
Flatworm	Turbellaria	–	3
Mite	Oribatida	*Oribatida* sp. A	3
Amphipod	Ceinidae	*Austrochiltonia australis*	277
Freshwater limpet	Hydrobiidae	*Potamopyrgus antipodarum*	93
Midge	Chironominae	*Chironomus* sp.	3
		Tanytarsus sp.	1
		Chironominae sp.	1
		Paralimnophyes sp.	1
Mosquito	Culicidae	*Anopheles* sp.	7
		Culex sp.	32
		Aedes sp.	53
House fly	Muscidae	Muscidae sp.	1
Soldier fly	Stratiomyidae	Stratiomyidae sp. 1	6
Water strider	Veliidae	*Microvelia peramoena*	1
Dragonfly	Aeschnidae	*Aeschna brevistyla*	Residue*
	Libellulidae	*Diplacodes haematodes*	Residue*
Damselfly	Coenagrionidae	*Ischnura* sp.	4
		Austroagrion watsoni	Residue*
Diving beetle	Dytiscidae	*Necterosoma dispar*	1
Marsh beetle	Scirtidae	Scirtidae sp. 1	4
Tree Frog	Hylidae	*Litoria ewingi*	1
		TOTAL	492

* According to the AusRivAS methodology, it is necessary to sort and identify a minimum of ten percent of the sample. However, this method of sub-sampling means that it is possible to miss species and therefore incorrectly assess diversity. To account for this, the remainder of the sample is also sorted and any species that were not in the original sub-sample are included in the analyses (although their abundances are not known).

Site Number: 12 **Site Name**: O'laddie Springs

Site Location: Zone 54H, N – 0277746, E – 6406170
Date of Assessment: 24 March 2006
Time of Assessment: 13.00–13.40
Site Photos: Neil Collier, David Deane
Samples collected: Macroinvertebrates

Water quality parameter	**Bottom**	
pH	6.82	–
Water Temperature	21.92	ºC
Dissolved Oxygen	7.35	mg/L
	86.7	%
EC	8860	µS cm^{-1}
TDS	5810	mg/L
Redox potential	35.3	mV

Landholder comments:

- Over the past three years, the springs have started drying up.
- Previous owner used to rely on this spring for permanent water.
- The pool dried up completely until two recent floods regenerated the area.
- Pool is used extensively for sheep grazing, not reliant on spring for stock water.
- Formerly large stands of reeds. Cattle seemed to get rid of them.

General comments:

- Large areas of bedrock – significant riffle when flooded.
- Sheen/flecks of oil on the water surface.
- Some algae on the bottom of the pool.
- Stands of River Red Gums provide lots of shade, but very little understory.
- Evidence of stock access.

In-stream habitat type	**% habitat**
Riffle	<10
Pool	100
Overhanging Vegetation	30–60
Large Rocks/Boulders	30–60
Aquatic vegetation	0–10
Leaf litter	0–10
Woody debris	0–10
Dead trees	0–10
Algae	10–30
Sediment/banks	>60
Aquatic vegetation	% cover
Cyperus	<30
Pool parameters:	(m)
Length	100
Width	1
Depth	0.5

Canopy cover	Left bank	Right bank
Above stream	0%	>6 0%
5 m downstream	0%	0%
10 m downstream	0%	0%
15 m downstream	0%	11–30%
20 m downstream	0%	11–30%
Geomorphology	Left bank	Right bank
Steepness	45–70 º	<45 º
Undercut	Minor	None

Exposed tree roots	Minor	Minor
Slumping/sloughing	Minor	None
Stock trampling	Extensive	Extensive
Bank scouring	Minor	Minor
Maximum bank sediment size	Bedrock	Bedrock
Dominant bank sediment size	Silt/Clay	Silt/Clay
Vegetation between bank top and toe	0–10%	0–10%

Macroinvertebrate results:

Common name	Family	Species/Genera	Abundance
Sea Shrimp	Ostracoda	Ostracoda sp.	1
Amphipod	Ceinidae	*Austrochiltonia australis*	9
Springtail/Collembola	Sminthuridae	Sminthuridae sp.	1
	Entomobryidae	Entomobryidae sp.	1
	Hypogastruridae	Hypogastruridae sp.	4
Midge	Chironominae	*Chironomus* sp.	76
		Tanytarsus sp.	2
		Chironominae sp.	26
Mosquito	Culicidae	*Anopheles* sp.	19
		Aedes sp.	105
Soldier fly	Stratiomyidae	Stratiomyidae sp.	8
Moth fly	Psychodidae	Psychodidae sp.	1
Water boatmen	Corixidae	*Micronecta* sp.	1
		Agraptocorixa sp.	1
Diving beetles	Dytiscidae	*Allodessus* sp.	1
		Dytiscidae sp.	4
		TOTAL	260

*According to the AusRivAS methodology, it is necessary to sort and identify a minimum of ten percent of the sample.In this case, 100% of the sample was sorted to obtain 200 individuals in accordance with the AusRivAS requirements.

Site Number: 13 **Site Name**: Napa Napa Springs

Site Location: Zone 54H, 0279968, 6419261
Date of Assessment: 21 March 2006
Time of Assessment: 14.30–15.05
Site Photos: David Deane, Neil Collier
Sampling undertaken: Fish
Fish collection methods: Dipnet
Fish collected: None

Water quality parameter	Pool 1		Pool 2	
pH	7.17	–	7.95	–
Water Temperature	21.61	° C	28.87	° C
Dissolved Oxygen	14.46	mg/L	13.86	mg/L
	172.5	%	185.4	%
EC	7613	µS cm^{-1}	9463	µS cm^{-1}
TDS	4917	mg/L	6159	mg/L
Redox potential	82.4	mV	85.7	mV

General comments:

- Some small surface water pools nearby because of recent rains.
- Rocky area.
- Very little vegetation to provide shade.
- Some larger trees, a few shrubs.
- No reeds.
- Small plant of *Cyperus.*
- Boxthorn present.
- Heavily silted with gravel in sections between pools.

In-stream habitat type	**% habitat**
Pool	100
Overhanging Vegetation	10–30
Large Rocks/Boulders	30–60
Leaf litter	0–10
Sediment/banks	>60
Pool dimensions	**(m)**
Length	20
Width	5
Depth	0.2

Canopy cover	**Left bank**	**Right bank**
Above stream	0%	1–10%
5 m downstream	0%	1–10%
10 m downstream	0%	11–30%
15 m downstream	0%	11–30%
20 m downstream	0%	0%

Site Number: 14 **Site Name**: Hillpara Creek

Site Location: Zone 54H, 0290923, 6395484
Date of Assessment: 22 March 2006
Time of Assessment: 09.30–10.00
Site Photos: David Deane, Neil Collier, Anne Walters
Samples collected: Macroinvertebrates

Water quality parameter	**Surface**		**Bottom**	
pH	8.77	–	8.53	–
Water Temperature	14.45	ºC	15.4	ºC
Dissolved Oxygen	6.69	mg/L	7.54	mg/L
	74.7	%	84.3	%
EC	31458	µS cm^{-1}	27191	µS cm^{-1}
TDS	2044	mg/L	1767	mg/L
Redox potential	119.5	mV	60.3	mV

Landholder comments:

- There was once a freshwater soak into the channel from the hills.
- Need a flood to clear out the thick sediment on the bottom of the pools.
- In the past there were no reeds in the pools, but it is now thick with them.

- At one time, there were pools located in other areas, but they are no longer present. The pools that are currently present were not there in the past.

General comments:

- Many pools connected for approximately 1–1.5 km.
- Thick sediment on the bottom of the pools.
- Lots of smaller pools positioned together (continuous).
- Some evidence of trampling by sheep.

In-stream habitat type	**% habitat**
Pool	100
Reeds	10–30
Aquatic vegetation	30–60
Algae	10–30
Sediment/banks	>60
Aquatic vegetation	% cover
Typha	<30
Triglochin striatum	30–60
Ruppia meritima	<30
Pool dimensions	(m)
Length	84
Width	10
Depth	>0.7

Canopy cover	**Left bank**	**Right bank**
Above stream	0%	0%
5–20 m downstream	0%	0%
Geomorphology	Left bank	Right bank
Steepness	>70 º	<45 º
Undercut	Minor	None
Exposed tree roots	None	None
Slumping/sloughing	None	None
Stock trampling	Minor	Minor
Bank scouring	None	None
Maximum bank sediment size	Bedrock	Silt/clay
Dominant bank sediment size	Silt/clay	Silt/clay
Vegetation between bank top and toe	0–10%	0–10%

Macroinvertebrate survey results

Common name	Family	Species/Genera	Abundance
Roundworm	Nematoda	-	1
Mite	Acarina	*Acarina* sp.	1
	Hygrobatidae	*Aspidiobates geometricus*	1
Amphipod	Ceinidae	*Austrochiltonia australis*	32
Midge	Chironominae	*Chironomus* sp.	3
		Tanytarsus sp.	19
		Procladius sp.	234
Biting midge	Ceratopogonidae	*Culicoides* sp.	51
		Ceratopogonidae sp.	2
Water boatmen	Corixidae	*Sigara* sp.	9
		Agraptocorixa eurynome	Residue*
Backswimmer	Notonectidae	*Anisops thienemanni*	1
		Anisops sp.	18
Dragonfly	Aeshnidae	Aeshnidae sp.	1
	–	Anisoptera sp.	1
Damselfly	Lestidae	*Austrolestes annulosus*	9
	Zygoptera	Zygoptera sp.	10
Diving beetle	Dytiscidae	*Necterosoma* sp.	15
Scavenger beetle	Hydrophilidae	*Berosus* sp.	1
		Hydrophilidae sp	5
Pyralid moth	Pyralidae	Pyralidae sp.	Residue*
		TOTAL	414

* According to the AusRivAS methodology, it is necessary to sort and identify a minimum of ten percent of the sample. However, this method of sub-sampling means that it is possible to miss species and therefore incorrectly assess diversity. To account for this, the remainder of the sample is also sorted and any species that were not in the original sub-sample are included in the analyses (although their abundances are not known).

Site Number: 15 **Site Name**: Eurilpa Creek

Site Location: Zone 54H, 0276470, 6429776
Date of Assessment: 21 March 2006
Time of Assessment: 12.00–13.00
Site Photos: David Deane, Neil Collier
Samples collected: Macroinvertebrates and fish
Fish collection methods: Dipnet
Fish collected: Yabbies (2)

Water quality parameter	Pool 1	Pool 2	Pool 3	Unit
pH	8.18	8.16	7.58	–
Water Temperature	24.15	20.55	19.69	ºC
Dissolved Oxygen	11.9	9.72	8.32	mg/L
	146.2	110.5	94.0	%
EC	7214	7288	7352	µS cm^{-1}
TDS	4689	4738	4782	mg/L
Redox potential	4.0	NR	51.5	mV

Landholder comments:
- Heavily silted with gravel since last rains. Usually bulldoze out the silt so that the water seeps into these areas again.

General comments:

- Four small, connected pools.
- Small area of reeds on one side of the pool.
- Virtually no vegetation on the banks, all open and exposed.

In-stream habitat type	**% habitat**
Pool	100
Reeds	0–10
Overhanging Vegetation	0–10
Large Rocks/Boulders	0–10
Aquatic vegetation	0–10
Leaf litter	0–10
Algae	0–10
Sediment/banks	30–60
Aquatic vegetation	% cover
Charophytes	0–10
Pool 1 dimensions	(m)
Length	45
Width	3-5
Depth	0.2
Pool 2 dimensions	(m)
Length	24.3
Width	3–5
Depth	0.2
Pool 3 dimensions	(m)
Length	10.2
Width	3–5
Depth	0.7

Canopy cover	**Left bank**	**Right bank**
Above stream	0%	0%
5–20 m downstream	0%	0%
Geomorphology	Left bank	Right bank
Steepness	<45 º	<45 º
Undercut	None	None
Exposed tree roots	None	None
Slumping/sloughing	None	None
Stock trampling	None	Minor
Bank scouring	Minor	Minor
Maximum bank sediment size	Boulders	Boulders
Dominant bank sediment size	Silt/clay	Silt/clay
Vegetation between bank top and toe	0–10%	0–10%

Site Number: 16 **Site Name**: Boolcunda Creek (upstream)

Site Location: Zone 54H, 0257822, 6427902
Date of Assessment: 23 March 2006
Time of Assessment: 15.00–16.45
Site Photos: David Deane, Neil Collier
Samples collected: Macroinvertebrates and fish
Fish collection methods: Seine netting, dipnet
Fish collected: Lake Eyre hardyhead, yabbies, tadpoles (species unknown).

Water quality parameter	Bottom	
pH	7.85	–
Water Temperature	23.65	ºC
Dissolved Oxygen	6.43	mg/L
	78.8	%
EC	10982	µS cm^{-1}
TDS	7141	mg/L
Redox potential	73.5	mV

General comments:

- Pools isolated within the streambed.
- Many pools located within close proximity.

- Extensive system of pools within the channel, mostly to the right side of the channel (looking downstream).
- *Typha* reedbeds through middle and left hand side of the pool, fewer reeds on the right side (which has a large rock face approximately 30 m upwards).
- Left bank displays a more gradual rise in the sides of the channel.
- Extensive sheep access.
- Vast stands of *Juncus* throughout much of the downstream channel.
- Thick clumps of algae in pool. Thick algal mats on the bottom of the pool.

In-stream habitat type	**% habitat**
Pool	100
Reeds	30–60
Large Rocks/Boulders	10–30
Aquatic vegetation	0–10
Leaf litter	30–60
Woody debris	30–60
Algae	10–30
Sediment/banks	10–30
Aquatic vegetation	% cover
Cyperus	<30
Typha	>60
Juncus	>60
Cotula	<30
Charophytes	<30
Pool dimensions	(m)
Length	80–100
Width	30
Depth	>2

Canopy cover	**Left bank**	**Right bank**
Above stream	1–10%	0%
5–20 m downstream	1–10%	1–10%
Geomorphology	Left bank	Right bank
Steepness	45–70 º	>70 º
Undercut	Extensive	None
Exposed tree roots	None	None
Slumping/sloughing	None	None
Stock trampling	Extensive	Extensive
Bank scouring	Minor	Minor
Maximum bank sediment size	Gravel	Bedrock
Dominant bank sediment size	Silt/clay	Silt/clay
Vegetation between bank top and toe	>50%	10–50%

Macroinvertebrate survey results

Common name	Family	Species/Genera	Abundance
Amphipod	Ceinidae	*Austrochiltonia australis*	6
Midge	Chironominae	*Kiefferulus* sp.	44
		Riethia sp.	2
		Tanytarsus sp.	77
		Dicrotendipes sp.	7
		Chironominae sp.	7
		Chironomidae sp.	1
		Procladius sp.	5
		Paralimnophyes sp.	2
		Cricotopus sp.	1
Biting midge	Ceratopogonidae	*Forcipomyia* sp.	2
Mosquito	Culicidae	*Anopheles* sp.	8
		Aedes sp.	2
Soldier fly	Stratiomyidae	Stratiomyidae sp.	4
Water boatmen	Corixidae	*Micronecta* sp.	12
Backswimmer	Notonectidae	*Anisops* sp.	53
		Anisops thienemanni	3
Water strider	Veliidae	*Mesovelia* sp.	2
Mayfly	Baetidae	*Cloeon* sp.	1
Dragonfly	Aeschnidae	Aeschnidae sp.	13
		Hemianax pepuensis	Residue*
	-	Anisoptera sp.	14
Damselfly	Coenagrionidae	*Ischnura heterosticta*	1
		Ischnura aurora	Residue*
		Ischnura sp.	1
		Xanthagrion erythroneurum	Residue*
	-	Zygoptera sp.	5
Diving beetle	Dytiscidae	*Necterosoma pencillatus*	1
		Necterosoma sp.	4
		Hyphydrus sp.	Residue*
Fish larvae	-	–	2
		TOTAL	280

* According to the AusRivAS methodology, it is necessary to sort and identify a minimum of ten percent of the sample. In this case, 22% of the sample was sorted to obtain 200 individuals in accordance with AusRivAS requirements. This method of sub-sampling means that it is possible to miss species and therefore incorrectly assess diversity. To account for this, the remainder of the sample is also sorted and any species that were not in the original sub-sample are included in the analyses (although their abundances are not known).

Site Number: 17 **Site Name**: Boolcunda Creek (downstream)

Site Location: Zone 54H, 0246862, 6431680
Date of Assessment: 2 Feb 2006
Time of Assessment: 16.00–18.30
Site Photos: David Deane
Samples collected: Macroinvertebrates.

Water quality parameter	Surface	Bottom	Units
pH	8.16	8.13	–
Water Temperature	29.26	29.79	ºC
Dissolved Oxygen	11.09	10.83	mg/L
	155.3	149.4	%
EC	5386	5409	$\mu S\ cm^{-1}$
TDS	3499	3514	mg/L

General comments:

- Isolated pool within the banks of a dry streambed.
- Two pools near to one another.
- Water seeps from rock wall on one side of the pool.
- Abundant groundcover on edges, very few trees (only 1 Eucalypt).
- Streambed made up of cobble and gravel.
- Very little vegetation within the pool – some growing on the ledge to one side.
- One side of the pool – a little growth of sedges, flowering.

- Point bar: lots of sediment collected around it, very little vegetation.
- Duck and cormorant observed in reeds on right side of pool (looking downstream).
- Fish observed in mid water column – appeared to be Lake Eyre hardyhead.

In-stream habitat type	**% habitat**
Reeds	0–10
Large Rocks/Boulders	0–10
Aquatic vegetation	0–10
Dead trees	0–10
Algae	0–10
Sediment/banks	0–10
Aquatic vegetation	% cover
Ruppia	<10
Juncus gymnospora	<10
Triglochin	<10
Potogomedon trimenculatus	<10
Potogomedon pectinatus	<10
Bulboschinous	<10
Nigella (charophyte)	<10
Chara (Charophyte)	<10
Pool dimensions	(m)
Length	75–100
Width	15
Depth	>3

Canopy cover	**Left bank**	**Right bank**
Above stream	0%	0%
5 m downstream	1–10%	1–10%
10 m downstream	11–30%	11–30%
15 m downstream	11–30%	11–30%
20 m downstream	0%	0%
Geomorphology	Left bank	Right bank
Steepness	<45 º	>70 º
Undercut	None	Minor
Exposed tree roots	None	None
Slumping/sloughing	None	None
Stock trampling	Minor	None
Bank scouring	None	None
Maximum bank sediment size	Bedrock	Bedrock
Dominant bank sediment size	Silt/clay	Silt/clay
Vegetation between bank top and toe	10–50%	10–50%

Macroinvertebrate survey results:

Common name	Family	Species/Genera	Abundance
Mite	Unionicolidae	*Neumania* sp.	2
	Hydracarina	*Arrenurus* sp.	4
Midge	Chironominae	*Kiefferulus* sp.	6
		Polypedilum sp.	1
		Chironomus sp.	1
		Paracladopelma sp.	2
		Chironomini sp.	6
		Tanytarsini sp.	74
		Tanytarsus sp.	74
		Cladotanytarsus sp.	78
		Larsia sp.	65
		Procladius sp.	19
Biting midge	Ceratopogonidae	Sphaeromiini sp.	5
		Ceratopogonidae sp.	6
Water boatmen	Corixidae	*Sigara* sp.	10
		Corixidae sp.	12
Caddisfly	Leptoceridae	*Oecetis* sp.	14
		Triplectides australis	1
Dragonfly	Hemicordulidae	*Hemicordulia tau*	Residue*
	Libellulidae	*Orthetrum caledonicum*	Residue*
	–	Anisoptera sp.	3
Damselfly	Coenagrionidae	Coenagrionidae sp.	4
		Austroagrion watsoni	Residue*
	Lestidae	*Austrolestes annulosus*	Residue*
	–	Zygoptera sp.	10
Diving beetle	Dytiscidae	*Sternoprisius* sp.	1
		Necterosoma pencillatus	1
		TOTAL	399

* According to the AusRivAS methodology, it is necessary to sort and identify a minimum of ten percent of the sample. However, this method of sub-sampling means that it is possible to miss species and therefore incorrectly assess diversity. To account for this, the remainder of the sample is also sorted and any species that were not in the original sub-sample are included in the analyses (although their abundances are not known).

Site Number: 18 **Site Name**: Wirreanda Creek (downstream)

Site Location: Zone 54H, 0246290, 6444724
Date of Assessment: 23 March 2006
Time of Assessment: 09.30–10.34
Site Photos: David Deane, Neil Collier
Samples collected: Fish and macroinvertebrates
Fish collection methods: Seine netting and dipnet
Fish collected: No fish. Some tadpoles captured

Water quality parameter	Surface	Bottom	Units
pH	7.71	7.86	–
Water Temperature	21.76	21.90	ºC
Dissolved Oxygen	6.06	6.70	mg/L
	72.7	81.3	%
EC	14278	14382	µS cm^{-1}
TDS	9287	9349	mg/L
Redox potential	182.5	147.1	mV

Landholder comments:

- Site 2: 4.5 m x 1 m. Not always permanent. Turbid. Usually larger, but flood in November caused gravel to collect in the creek bed, reducing the water level.

General comments:

- Site 1: Some aquatic vegetation on left hand bank (facing downstream), sand and gravel bottom, little sediment on bottom of pool, lots of gravel within the streambed (deposited by flood), large rocks and boulders on right bank, muddy banks surrounding pool (evidence of stock trampling), large mat of charophytes within pool, very little aquatic vegetation in water.
- Pools isolated within creek bed.

In-stream habitat type	**% habitat**
Large Rocks/Boulders	10–30
Aquatic vegetation	10–30
Leaf litter	0–10
Woody debris	0–10
Algae	30–60
Sediment/banks	>60
Aquatic vegetation	% cover
Cyperus	<30
Schoenoplectus	30–60
Charophytes	30–60
Pool dimensions	(m)
Length	34.2
Width	10
Depth	0.9

Canopy cover	**Left bank**	**Right bank**
Above stream	0%	0%
5–15 m downstream	0%	0%
20 m downstream	1–10%	1–10%
Geomorphology	Left bank	Right bank
Steepness	45–70º	45–70º
Undercut	None	None
Exposed tree roots	None	Minor
Slumping/sloughing	Minor	Minor
Stock trampling	Extensive	Extensive
Bank scouring	Minor	Minor
Maximum bank sediment size	Bedrock	Bedrock
Dominant bank sediment size	Bedrock	Silt/clay
Vegetation between bank top and toe	>50%	>50%

Macroinvertebrate survey results

Common name	Family	Species/Genera	Abundance
Mite	Hydracarina	*Arrenurus* sp.	5
Midge	Chironominae	Tanytarsini sp.	54
		Tanytarsus sp.	66
		Dicrotendipes sp.	8
		Chironominae sp.	68
		Larsia sp.	1
		Procladius sp.	38
		Tanypodinae sp.	2
Biting midge	Ceratopogonidae	*Culicoides* sp.	2
		Nilobezzia sp.	3
Backswimmer	Notonectidae	*Anisops* sp.	3
Dragonfly	Aeschnidae	Aeschnidae sp.	1
		Hemianax papuensis	Residue*
	Hemicorduliidae	*Hemicordulia tau*	Residue*
	Libellulidae	Libellulidae sp.	4
	–	Anisoptera sp.	63
Damselfly	Coenagrionidae	*Xanthagrion erythroneurum*	1
		Coenagrionidae sp.	50
		Ischnura heterosticta	Residue*
		Ischnura sp.	Residue*
	Lestidae	*Austrolestes psyche*	3
		Austrolestes sp.	8
		Austrolestes annulosus	Residue*
	–	Zygoptera sp.	140
Diving beetle	Dytiscidae	Dytiscidae sp.	19
		Eretes australis	Residue*
		Antiporus gilberti	Residue*
		Necterosoma pencillatus	Residue*
		Necterosoma sp.	Residue*
		TOTAL	539

* According to the AusRivAS methodology, it is necessary to sort and identify a minimum of ten percent of the sample. However, this method of sub-sampling means that it is possible to miss species and therefore incorrectly assess diversity. To account for this, the remainder of the sample is also sorted and any species that were not in the original sub-sample are included in the analyses (although their abundances are not known).

Site Number: 19 **Site Name**: Wirreanda Creek (upstream)

Site Location: Zone 54H, 0256654, 6449623
Date of Assessment: 23 March 2006
Time of Assessment: 13.05–14.20
Site Photos: David Deane, Neil Collier
Fish collection methods: Seine netting
Fish collected: None

Water quality parameter	**Pool 1**	**Pool 2**	**Pool 3**	**Units**
pH	8.77	8.06	8.30	–
Water Temperature	23.20	23.9	23.7	ºC
Dissolved Oxygen	7.71	10.07	10.97	mg/L
	91.6	126.2	132.7	%
EC	4899	15474	6963	µS cm^{-1}
TDS	3184	10060	4520	mg/L
ORP	114.5	81.5	52.5	mV

Note: pools number sequentially from the house in a downstream direction

General comments:

- Several pools connected and several isolated pools within deep valley. Rocky outcrops on one side and mud/sediment hill face on right side of banks (looking downstream).
- Fine layer of silt covering rocks on bottom of the pool.
- Large sections of bedrock and boulders throughout the channel.
- Extensive stands of *Typha* and lots of sedges in areas between the pools.
- Deep layer of anoxic sediment on bottom of the pools.
- Pools downstream: relatively deep (>3 m) with clear water, patches of algae on the bottom of the pond, rocky habitat, sediment layer on the bottom of the pool, gravel siltation between pools, *Cyperus gymnocaulous*, *Juncus*, sparse Red Gum, no reeds along banks due to grazing/trampling by cattle.

In-stream habitat type	**% habitat**
Overhanging Vegetation	0–10
Large Rocks/Boulders	30–60
Leaf litter	0–10
Algae	30–60
Sediment/banks	>60
Aquatic vegetation	% cover
Cyperus	<30
Typha	<30
Juncus	<30
Charophytes	<30
Pool 1 dimensions	
Length	>100
Width	10–20
Depth	>3

Canopy cover	**Left bank**	**Right bank**
Above stream	1–10%	1–10%
5–20 m downstream	0%	0%
Geomorphology	Left bank	Right bank
Steepness	>70º	45–70º
Undercut	None	None
Exposed tree roots	None	None
Slumping/sloughing	None	Minor
Stock trampling	Extensive	Extensive
Bank scouring	None	None
Maximum bank sediment size	Bedrock	Boulders
Dominant bank sediment size	Silt/clay	Silt/Clay
Vegetation between bank top and toe	10–50%	0–10%

UNITS OF MEASUREMENT

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

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

Shortened forms

EC	electrical conductivity (µS/cm)
pH	acidity
ppm	parts per million
TDS	total dissolved solids (mg/L)
ORP	oxidation-reduction potential (mV)

GLOSSARY

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

Ambient water monitoring — All forms of monitoring conducted beyond the immediate influence of a discharge pipe or injection well, and may include sampling of sediments and living resources

Ambient water quality — The overall quality of water when all the effects that may impact upon the water quality are taken into consideration

Aquatic community — An association of interacting populations of aquatic organisms in a given water body or habitat

Aquatic ecosystem — The stream channel, lake or estuary bed, water, and/or biotic communities, and the habitat features that occur therein

Aquatic habitat — Environments characterised by the presence of standing or flowing water

Aquatic macrophytes — Any non-microscopic plant that requires the presence of water to grow and reproduce

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

AusRivAS — Australian River Assessment System; a national river and stream health assessment program run by the Australian Government

AWQC — Australian Water Quality Centre

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

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

Biodiversity — (1) The number and variety of organisms found within a specified geographic region. (2) The variability among living organisms on the earth, including the variability within and between species and within and between ecosystems

Biota — All of the organisms at a particular locality

BoM — Bureau of Meteorology, Australia

Bore — See 'well'

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

CV — Coefficient of Variation

Diversity — The distribution and abundance of different kinds of plant and animal species and communities in a specified area

DO — Dissolved Oxygen

d/s — Downstream

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

EC — Electrical conductivity; 1 EC unit = 1 micro-Siemen per centimetre (µS/cm) measured at 25°C; commonly used as a measure of water salinity as it is quicker and easier than measurement by TDS

Ecological indicators — Plant or animal species, communities, or special habitats with a narrow range of ecological tolerance; for example, in forest areas, such indicators may be selected for emphasis and monitored during forest plan implementation because their presence and abundance serve as a barometer of ecological conditions within a management unit

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

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

Ecology — The study of the relationships between living organisms and their environment**Ecosystem** — Any system in which there is an interdependence upon, and interaction between, living organisms and their immediate physical, chemical and biological environment

Environmental water provisions — That part of environmental water requirements that can be met; what can be provided at a particular time after consideration of existing users' rights, and social and economic impacts

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

EPA — Environment Protection Authority (Government of South Australia)

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

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

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

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

EWR — Environmental Water Requirements

Flow bands — Flows of different frequency, volume and duration

Flow regime — The character of the timing and amount of flow in a stream

GAB — Great Artesian Basin

Geomorphic — Related to the physical properties of the rock, soil and water in and around a stream

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

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

Groundwater — Water occurring naturally below ground level or water pumped, diverted and released into a well for storage underground; see also 'underground water'

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

Hydrogeology — The study of groundwater, which includes its occurrence, recharge and discharge processes, and the properties of aquifers; see also 'hydrology'

Hydrology — The study of the characteristics, occurrence, movement and utilisation of water on and below the Earth's surface and within its atmosphere; see also 'hydrogeology'

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

IQR — Interquartile Range. A measure of the variability in a data set, representing the difference between the first and third quartiles. This is often used where data do not follow a normal distribution, and measures of spread in the data such as the standard deviation are misleading

Macro-invertebrates — Aquatic invertebrates visible to the naked eye including insects, crustaceans, mollusks and worms that inhabit a river channel, pond, lake, wetland or ocean

MDB — Murray-Darling Basin

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

NTU — Nephelometric Turbidity Unit

NY — Northern and Yorke

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

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

Quickflow — Also known as direct run-off or event flow, refers to that portion of streamflow generated during a storm event that enters the watercourse via direct run-off. It is defined as that volume of total observed streamflow for a given day that remains following subtraction of the volume identified as baseflow by the digital baseflow filter.

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

Riffles — Shallow stream section with fast and turbulent flow

Riparian — Of, pertaining to, or situated or dwelling on the bank of a river or other water body

Riparian areas — Geographically delineable areas with distinctive resource values and characteristics that comprise the aquatic and riparian ecosystems

Riparian habitat — The transition zone between aquatic and upland habitat. These habitats are related to and influenced by surface or subsurface waters, especially the margins of streams, lakes, ponds, wetlands, seeps, and ditches

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

Riverine habitat — All wetlands and deep-water habitats within a channel, with two exceptions — wetlands dominated by trees, shrubs, persistent emergent mosses or lichens, and habitats with water that contains ocean-derived salt in excess of 0.5 parts per thousand

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

Sensitive species — Those plant and animal species for which population viability is a concern

SIGNAL — Stream Invertebrate Grade Number Average Level, developed by Chessman (2003); indicates the average sensitivity of the invertebrate community to environmental conditions

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

Sub-catchment — The area of land determined by topographical features within which rainfall will contribute to run-off at a particular point

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

Sustainability — The ability of an ecosystem to maintain ecological processes and functions, biological diversity, and productivity over time

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

TDS — Total dissolved solids, measured in milligrams per litre (mg/L); a measure of water salinity

TKN — Total Kjeldahl Nitrogen; the sum of aqueous ammonia and organic nitrogen; used as a measure of probable sewage pollution

Tributary — A river or creek that flows into a larger river

Turbidity — The cloudiness or haziness of water (or other fluid) caused by individual particles that are too small to be seen without magnification, thus being much like smoke in air; measured in Nephelometric Turbidity Units (NTU)

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

u/s — Upstream

Viable population — A population that has the estimated numbers and distribution of reproductive individuals to ensure the continued existence of the species throughout its existing range in the planning area

Water body — Includes watercourses, riparian zones, floodplains, wetlands, estuaries, lakes and groundwater aquifers

Water column — a section of water extending from the surface of a body of water to its bottom. In the sea or ocean, it is referred to as 'pelagic zone'

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

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

Water quality data — Chemical, biological, and physical measurements or observations of the characteristics of surface and groundwaters, atmospheric deposition, potable water, treated effluents, and wastewater, and of the immediate environment in which the water exists

Water quality monitoring — An integrated activity for evaluating the physical, chemical, and biological character of water in relation to human health, ecological conditions, and designated water uses

WDE — Water dependent ecosystem

Well — (1) An opening in the ground excavated for the purpose of obtaining access to underground water. (2) An opening in the ground excavated for some other purpose but that gives access to underground water. (3) A natural opening in the ground that gives access to underground water

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

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