Government of South Australia
South Australian Arid Lands Natural Resources Management Board

June 2009

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Identification of permanent refuge waterbodies in the Cooper Creek and Georgina-Diamantina river catchments for Queensland and South Australia

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Identification of Permanent Refuge Waterbodies in the Cooper Creek & Georgina-Diamantina River Catchments for Queensland and South Australia

Final Report to South Australian Arid Lands Natural Resource Management Board

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June 2009



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Executive Summary

This project investigated the permanence of waterbodies across the Cooper Creek, Diamantina and Georgina River catchments of Queensland and South Australia. Together, these systems contribute the bulk of flow to Lake Eyre. Their catchments lie almost wholly within that portion of Australia classified as semi-arid (<500mm average annual rainfall) and arid (<250mm). However, the area is dotted with sources of permanent and semi-permanent water, providing reliable moisture and stability in a system overwhelmingly characterised by aridity and variability. Their tiny surface area relative to the immensity of the surrounding landscape belies their immense ecological, cultural, economic and social significance. Reliable sources of water provide vital drought refugia for a variety of biota, and have been the focus of human endeavour in the region for millennia.

This project aimed to identify permanent refuge waterbodies in the three catchments, and compile an inventory of all semi-permanent and permanent waterbodies within this area. Ultimately, this provides an understanding of the distribution and permanence of water across a vast area. For this project, semi-permanent waterbodies were defined as those that contained water for more than 70% of the time on average. There are four types of semi-permanent waterbodies in the study area: waterholes, lakes, rockholes and springs. Waterbody permanence was assessed through interviews with more than 170 long-term land managers and researchers across the LEB. The ecological, social and cultural significance of each waterbody type was also explored through interviews, consultation of primary and secondary written sources, and field work.

The primary finding was the paucity of truly permanent water, given the size of the study area. 1367 permanent and semi-permanent waterbodies were mapped across the study area, including 532 that were considered permanent. For each mapped waterbody, the spatial database contains information on name, location, naturalness, permanence (including water-holding capacity, frequency of drying and timeframe of observations) and other information relating to the hydrology, ecology or cultural significance of that particular waterbody. Permanence is split into five categories for waterholes and lakes, ranging from permanent (has not gone dry since European settlement as far as could be ascertained) to annually dry. Great Artesian Basin (GAB) springs are classified as either active or inactive, while non-GAB springs and rockholes are ranked as permanent, almost-permanent or semi-permanent.

The Cooper catchment has by far the highest number and density of both permanent and semi-permanent waterbodies, particularly south of Jundah where permanent waterholes become a feature of the system. In contrast, the Diamantina and Georgina catchment are characterised by a small number of widely-spaced permanent waterholes, interspersed with clusters of semi-permanent ones and long reaches with very little reliable water. Rockholes, springs emanating from local

aquifers and Great Artesian Basin springs are clustered in discrete areas, with the latter two features most prevalent in ranges near the watersheds of catchments. Away from spring/rockhole clusters and major drainage lines, there is very little lasting water. Interestingly, without the influence of groundwater in some form, there would only be four truly permanent waterbodies across the entire Georgina catchment.

Waterholes, simply defined as enlarged segments of the channel which hold water after flow has ceased, are the most numerous and conspicuous source of permanent and semi-permanent water in the study area. They are self-maintaining scour features and mostly form on main channels where streamflow becomes concentrated or constricted. Permanence is influenced by depth, frequency of inundation, loss processes and groundwater interactions. In the absence of groundwater connection, waterholes generally have to be at least 3-4 metres deep to be truly permanent. Of the 830 permanent and semi-permanent waterholes documented, 260 had not been dry since European settlement. 77% of these lie within the Cooper catchment, while only 60 permanent waterholes exist across the 365 000 km^2 area of the Georgina-Diamantina catchments, where 'annually dry' is the most common permanence category.

Most waterholes occur on major channels, but their distribution is patchy. Based on the density of permanent waterholes, the Cooper catchment contains the six 'wettest' reaches in the LEB, including Cooper Creek below Windorah and the lower reaches of the Thomson and Barcoo Rivers. The Roxborough Downs-Glenormiston and Roseberth-Durrie channels are the most well-watered in the Georgina and Diamantina catchments, respectively. In contrast, the lower Cooper beyond Coongie Lakes is the driest reach in the study area, with no >70% waters along its entire 340km length. All other very dry reaches (i.e. those with <1 permanent waterhole per100km) occur in the two western catchments. Long reaches with no permanent water include the Mulligan River/Eyre Creek system in the far west, the upper Georgina River, Warburton River after Goyder's Lagoon and most of Farrars Creek.

Waterholes support a distinctive biotic assemblage and act as important refuges for aquatic and some terrestrial fauna during dry times. Unsurprisingly, they have been a focus of human endeavour over millennia, dictating settlement and travel patterns and inspiring mythology across this predominantly arid region. Sadly, a dark undercurrent lurks beneath their calm surface as waterholes provided the backdrop for much of the violence and dispossession of the frontier period. Today, human impacts are evident at many waterholes, primarily as a result of increased total grazing pressure, introduced species and some localised recreational impacts. A condition assessment framework was developed to assess these impacts, based on riparian condition and aquatic fauna assemblage. Preliminary results suggest that most waterholes are impacted to some degree by surrounding land uses, however native fish assemblages remain healthy. The general health of waterholes in the LEB can primarily be attributed to less intensive land use and relatively low levels of water extraction and flow modification compared to other catchments in Australia.

The overwhelming majority of ‘lakes’ in the study area are dry for most of the time. Only the Desert Uplands in the far north-east of the Cooper catchment and the Coongie system towards in South Australia harbour semi-permanent lakes. Three lakes in each region are considered to hold water for more than 70% of the time on average and so were mapped for this project. Despite their limited distribution, where they do occur, lakes are highly ecologically and culturally significant.

Even amongst remote and rugged inland ranges, far from major watercourses, lie small, hidden sources of water. Rockholes are small depressions, often occurring in gully heads or carved into sheer rock, that harvest local run-off when it rains. Depending on timing and amount of rainfall, and depth and shelter of rockhole, some retain water for many months. Semi-permanent rockholes are roughly clustered into six ‘provinces’, primarily on or near catchment watersheds in the north and eastern portions of the LEB. Of the 72 individual rockholes documented, only one-quarter were classified as permanent. Sheltered rockholes may support species with rainforest affinities, as well as a variety of fish, birds, bats and invertebrates. The presence of paintings and stone arrangements in the vicinity of many rockholes suggests their significance to Aboriginal people, however they have not figured prominently in European explorer or settlement patterns in the study area. Due to the remote and inaccessible nature of many rockholes, knowledge about the permanence and ecology of these features is extremely limited.

Springs occur where groundwater is pushed to the surface. In the study area, the majority of these springs emanate from the Great Artesian Basin (GAB). The major spring clusters are the Mulligan River, Springvale and Barcaldine ‘Supergroups’. GAB springs, particularly those in the western portion of the study area, provide permanent freshwater in a harsh desert environment. In terms of the distribution of water, the Mulligan River and Springvale Supergoups are especially significant, as they occur in otherwise waterless areas. The cultural significance of Queensland’s GAB springs has not been comprehensively documented, but they were significant to Aboriginal inhabitants and some played a role in early European settlement and travel patterns. Springs support a rich and highly specialised biotic assemblage, including endemic plants, fish and invertebrate. Since European settlement, groundwater exploitation has led to the drawdown of the GAB and consequent extinction of many springs, particularly in the Springvale Supergroup. In recent years, springs have been the focus of research, which continues to inform management and conservation decisions.

Springs can also form via discharge from fractures in local, shallow rock aquifers which are recharged after rain. Non-GAB springs often occur at the base of escarpments in sandstone country. 35 non-GAB springs were documented in the study area, 64% of which were classed as permanent. The major concentration occurs in the northern Grey Range, which encompasses 29 springs. They have not received the same degree of attention as GAB springs, although some are known to have comparable conservation values. Their cultural significance is probably similar to that of rockholes. A number of springs have decreased in permanence since European settlement. Some have been dynamited in an attempt to increase the volume of available water, which has universally had the opposite effect, while others have become less permanent under more ambiguous circumstances. Like rockholes, the exact location and permanence of some of the more remote springs is not known.

Overall, sources of natural water in the Lake Eyre Basin are widely spaced and unreliable. This is underscored by the fact that there are only about 500 sources of truly permanent water spread over the 661 000km^2 of the Cooper, Diamantina and Georgina catchments of Queensland and South Australia. In general, areas away from major rivers and the more precipitous ranges, with the exception of discrete and comparatively small clusters of GAB springs, would have been completely devoid of water during dry periods. In prolonged dry times, even the major watercourses would have been mostly reduced to widely-spaced, dwindling waterholes, and the remaining rockholes covered in green slime.

Since European settlement, however, the distribution and permanence of water has changed dramatically. Some water sources have declined in abundance and/or permanence, primarily through silting of waterholes and loss of springs. However, far surpassing this has been a massive increase in the distribution and abundance of permanent water. In just 150 years, the arrival of pastoralism in western Queensland has transformed the landscape from one of generally occasional water (in most areas) to a situation where permanent water is ubiquitous across much of the landscape. Today, few areas of potentially productive rangeland are greater than 3km from some source of permanent water. Numerous recent studies have suggested that the rapid proliferation of 'artificial waters' may have profound implications for the ecology of the inland, including changes in species abundance and decline of vulnerable 'decreaser species'.

It seems that we have acquired the knowledge necessary to manage point impacts *on* individual waterbodies and riparian environments (although such guidelines are not always practiced). However, we are still grappling with how to mitigate the far-reaching effects *of* permanent water across the vast expanses of the inland. Water, long the panacea of desert animals, residents and travellers, has paradoxically become perhaps the major conservation challenge for arid Australia.

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1 INTRODUCTION

Australia is the driest vegetated continent and has the smallest area of land surface covered by wetland of any continent. Inland Australia has been described by various authors as the 'dead heart', a 'wide brown land' and the 'vast central desert' (Finlayson 1943; Madigan 1948). When people imagine the interior, it is often as a dry, harsh and dusty place – the 'great grey plain' of Henry Lawson (Hirst 2007); a land of 'ever-receding horizons, lonely graves' (Durack 1959) and 'pitiless skies' (Duncan-Kemp 1934). Indeed, this is perhaps an accurate description of much of the landscape for much of the time. The climate is arid or semi-arid, temperatures high, and the erratic rainfall far exceeded by evaporation. The emptiness and distance often give rise to convincing and alluring mirages, shimmering on the hazy horizon like promised oases, only to dissipate as one draws closer. Francis Ratcliffe described inland South Australia as a 'waterless land', writing that *'I spent month after month travelling through this region, and never once did I see permanent natural water'* (1938, pp. 205-206).

However, amidst the aridity do lie vital sources of water: small, often incongruous, life-giving oases. Even in the driest regions, such places may be found: camped in the midst of a 'hideous spinifex desert' in the Hay River region near the Queensland-Northern Territory border, the indefatigable surveyor-explorer Charles Winnecke thought it *'a most discouraging country to travel over, and for which a man obtains little or no credit; and yet it is necessary to traverse and examine this country in detail, for one can never tell where and when an oasis may be found'* (1894, p.10). Many of these 'oases' are ephemeral, with surface water only present for a relatively short period of time following rainfall or flooding. Such ephemeral wetlands, including floodplains, swamps, claypans and playa lakes, are regarded as havens for biodiversity in arid Australia and drive the spectacular migratory bird breeding events that epitomise the 'boom/bust' nature of the inland (Kingsford *et al.* 1999; Kingsford & Norman 2002). Much rarer are the more stable, enduring wetlands, where water can be reliably found most of the time.

These permanent and semi-permanent waterholes, lakes, springs and rockholes provide stability in a system that is overwhelmingly characterised by aridity and variability. Their tiny surface area relative to the immensity of the surrounding landscape belies their immense ecological, cultural, economic and social significance (Box *et al.* 2008). They have been known, used and cared for by Aboriginal people for millennia. More recently, they have provided vital water supplies for white explorers and settlers and their livestock. Today, despite no longer being so directly dependent upon natural waters for survival, visitors and residents alike still gravitate towards waterholes for both physical and psychological comfort.

1.1 Project background and aims

Despite their ecological and human significance, the permanence of waterbodies across most of Australia's arid lands has never been accurately mapped or defined (with the exception of the Northern Territory; see Box *et al.* 2008). This project was funded by the South Australian Arid Lands Natural Resource Management board. It aimed to identify permanent refuge waterbodies in the Cooper Creek, Diamantina and Georgina River catchments of Queensland and South Australia, and compile an inventory of all semi-permanent and permanent waterbodies within this area. Ultimately, this will provide an understanding of the distribution and permanence of water across this vast area. Additional project aims were to record social and cultural information about waterbodies and to provide a framework for assessing the ecological condition of waterholes in the study area.

1.2 Overview of study area

The Lake Eyre Basin covers an area of 1 140 000km^2, or approximately one-seventh of the Australian continent, comprising large parts of Queensland, South Australia and the Northern Territory, and a small section of north-western New South Wales. It is one of the largest internally-draining systems in the world. The climate is semi-arid to arid, with potential evaporation exceeding actual evaporation year round, except along the north-eastern margin of the Basin (McMahon *et al.* 2008a). Average annual rainfall ranges from 400-500mm in the northern and eastern headwater regions to just 120mm in the Simpson Desert (Gibling *et al.* 1998).

The rivers of the Lake Eyre Basin are among the last of the world's unregulated large river systems. They are characterised by catchments that lie almost entirely in the arid (and semi-arid) zone, low gradients, endorheic drainage, wide floodplains, large transmission losses and extremely high flow variability (Costelloe *et al.* 2004). In fact, flow variability of Lake Eyre streams is about double the average variability found in river systems worldwide (McMahon *et al.* 2008b). This variability means that rivers exist mostly as isolated waterholes while occasionally transforming into veritable 'inland seas' of floodwaters.

The Georgina and Diamantina Rivers and Cooper Creek and their associated streams dominate the Queensland and north-eastern South Australian portions of the Lake Eyre Basin. These catchments formed the boundary of the study area for this project (Figure 1). Together, these watercourses supply the great majority of the total run-off to Lake Eyre, with the Diamantina contributing the most water in terms of volume and frequency of flow events (McMahon *et al.* 2008b). These rivers flow seasonally in response to summer rainfall in the upper catchments.

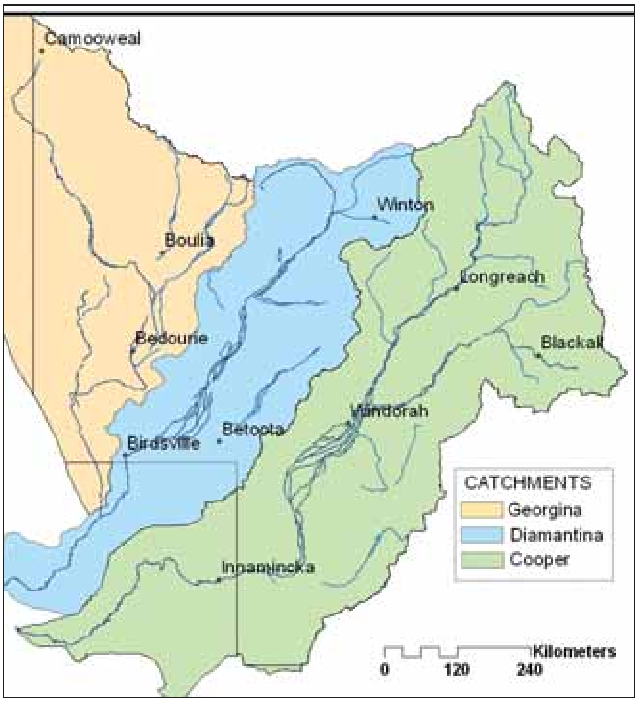

Figure 1: Catchments of study area

In their lower and mid-catchments, drainage lines spread out to form extensive anastomosing channel systems and wide floodplains. Away from the rivers, the study area is dominated by a mixture of Mitchell grass downs, stony plains, low ranges, open shrublands, ephemeral forblands and, in the higher-rainfall areas, woodland communities. Detailed descriptions of the climate, landforms and vegetation of the study area can be found in Sattler & Williams (eds, 1999), Tyler *et al.* (eds, 1990) and White (2001). A feature of the LEB is that it contains large areas that do not contribute any streamflow to Lake Eyre. These include the extensive dunefields of the Simpson and Strzelecki Deserts where uncoordinated drainage accumulates in interdunal swales, and a number of large endorheic 'sub-basins' where drainage flows into terminal salt lakes or claypans (McMahon *et al.* 2008b).

1.3 Overview of knowledge and need for an inventory

Sources of water in the study area have been known to humans for millennia. Aboriginal people had an intimate knowledge of waterholes in their areas, including their location, permanence under various conditions, quality of water, likely extent of flooding and so on (Duncan-Kemp 1934; Bayly 1999). From the 1840s, the European explorers provide the first written records and descriptions of waterholes, lakes, springs and rockholes. The early settlers used this knowledge to select pastoral properties and homestead sites, and as settlement expanded, knowledge of waterbodies and their permanence spread rapidly. Today, information on the permanence of waterbodies is readily available in the community, primarily stored in the heads of local residents who have spent many years observing them.
Over the past two decades, numerous scientific studies have looked at various aspects of ecology and hydrology within the study area. A search of the literature reveals studies of the riparian/floodplain vegetation (e.g. Bunn & Davies 2001; Bunn *et al.* 2003; Brock *et al.* 2006; Capon & Brock 2006; Phelps *et al.* 2007; Porter *et al.* 2007), waterbirds (Kingsford & Porter 1994; Kingsford *et al.* 1999; Kingsford & Norman 2002), fish (Glover 1990; Unmack 2001) and flow regimes or hydrology (Knighton & Nanson 1994; Kotwicki 1986; Puckridge 1998, 2000; McMahon *et al.* 2008a&b). A small number of studies contain specific information on waterholes, notably Wainwright *et al.* (2002), who mapped the wetlands of north-eastern South Australia from satellite and identified the more permanent waterbodies, and Costelloe *et al.* (2004), who sampled numerous permanent and semi-permanent waterholes for the ARIDFLO project. ARIDFLO focussed on waterbodies within five reaches spread across the Cooper, Diamantina and Neales catchments, and obtained detailed hydrological and ecological information for these study sites between 2000 and 2003.

There have also been studies on a handful of individual waterbodies within the Lake Eyre Basin, including Coongie Lakes (Mollemans *et al.* 1984; Reid & Gillen 1988; Reid & Puckridge 2000; Sheldon *et al.* 2002) and Goyder Lagoon (Sheldon & Puckridge 1998). Knighton & Nanson (1994 & 2000) focussed on Cooper Creek waterholes below Windorah, but provide general information on the geomorphology of inland waterholes. The Dryland River Refugia project, which ran from 2001-2003, assessed the characteristics of permanent waterholes and their importance for aquatic organisms in the Cooper, Warrego and Border Rivers systems (Cooperative Centre for Freshwater Ecology 2002).

The last two decades have also seen increased emphasis on social and anthropological research across the Lake Eyre Basin (e.g. Hercus 1990; Watson 1998; Godwin 2001; Simmons 2007). Given the centrality of water to human life in arid regions, it is hardly surprising that these studies contain some information about the more permanent waterbodies. One study (Gibbs 2006) looked specifically at the value people place on water in the LEB. Local and shire histories produced over the past two decades also contain many references to waterbodies (Moffat 1989; Kowald & Johnson 1992; Bell & Iwanicki 2002; Nolan 2003; Forrest & Forrest 2005).

Despite this wealth of information from disparate sources, there has been no attempt to compile an inventory of all permanent and semi-permanent waterbodies across the study area. As such, there is good published information on selected waterholes and river reaches, and detailed anecdotal/experiential knowledge in the local community, but no overall picture of where long-lasting water occurs across the LEB. By compiling all written and oral records of waterbodies into a single inventory, it becomes possible to gain a picture of the distribution of semi-permanent and permanent water sources across a vast area.

1.4 Report structure and contents

This report explains the methods and results from this project, and discusses the implications of the research. The Methodology section (2) outlines the key phases of the project and discusses how each was approached. Section 3 provides a broad overview of findings from the project, while Sections 4-7 present results individually for the four main sources of water: waterholes, lakes, rockholes and springs. These sections explore the distribution, permanence and ecology of each water type, as well as their cultural significance and present-day status. The final section summarises the current situation regarding permanent water in the LEB, and examines how its distribution has changed since European settlement. Finally, recommendations flowing from this research are suggested.

2 METHODS

2.1 Baseline mapping

Given the size of the study area, satellite imagery was the necessary starting point for identifying waterbodies. Baseline mapping was obtained from the Queensland Wetlands Mapping Program and the South Australian Department of Environment and Heritage. In both cases, waterbodies had been mapped from a series of satellite images. The methodologies differed in detail, however the final datasets allowed the more permanent waterbodies (i.e. those that had water in them for most or all of the images analysed) to be identified. The Environmental Protection Agency (2005) and Wainwright *et al.* (2002) provide details of these methodologies.

Rockholes and non-GAB springs are too small to show up on satellite-derived mapping. The Queensland wetlands mapping revealed many 'WR3' waterbodies (i.e. those where water was supposedly present for >80% of the time) in range systems, but preliminary ground-truthing revealed that shadows and/or ephemeral waters were showing up. Only a tiny proportion of rockholes and non-GAB springs are marked on topographic maps. In the absence of reliable baseline data for these waterbodies, all range systems in the study area were mapped as 'potential rockhole areas' and properties within these areas contacted. Great Artesian Basin (GAB) springs have been mapped and surveyed by Fensham & Fairfax (2003), and their springs database was imported into the final mapping for this project.

2.2 Expert knowledge survey

Over 170 people were interviewed about the permanence of waterbodies across the study area (Table 1). Contacts were sought through existing networks, and discussions with long-term agency staff and pastoralists in western Queensland and north-eastern South Australia. The majority of people consulted were pastoralists or retired pastoralists who had lived in one area for a number of decades, and so had long-term knowledge and observations of waterbodies. In cases where new managers (<5 years) were on a property, efforts were made to contact previous owners or managers with longer experience. For properties that had seen a succession of managers, two or three were contacted in order to build a picture of permanence over at least a decade. Appendix 1 provides the database of people consulted during the project, summarising their position, knowledge history and interview method used.

The knowledge of managers who had experienced severe drought conditions during their time on a property (e.g. early 1980s in the Diamantina catchment; early 1940s and 1960s across much of the study area) was particularly valuable, as these periods would have tested waterhole permanence. In this regard, the dry conditions experienced across much of the study area between 2001 and 2007 rendered 2008-09 an ideal time to conduct surveys of waterhole permanence. In fact, numerous waterholes that had not been dry since European settlement dried up during this time, including the Glengyle Station Waterhole on Eyre Creek.

Considerably more people were interviewed in the Cooper catchment, reflecting the smaller property sizes and greater number of waterholes (Table 1). Agency staff consulted included Queensland Parks & Wildlife Rangers, Natural Resource Officers and QDPI Fisheries Inspectors. Scientists and researchers with long-term experience of certain river reaches were also consulted. A small number of people did not fit the categories of pastoralists or agency employees/researchers. The 'other' informants were helicopter pilots, local townspeople, keen fishermen and amateur historians with good knowledge of particular areas.

Table 1: Informants by catchment and position

System*	Pastoralists (owner/ managers)	Retired graziers	Agency/ researchers	Other	*Total*
Cooper	80	15	8	3	*106*
Diamantina**	22	9	8	3	*48*
Georgina	31	4	2	0	*37*
TOTAL	*131*	*22*	*12*	*5*	*173*

* some people contributed knowledge of >1 system
** includes Warburton River, after junction with Diamantina

Where a small number of waterholes were detectable on the satellite imagery or topographic maps and minimal uncertainty existed surrounding their location or names, interviews were conducted over the phone. Where waterholes were more numerous, unnamed or not detectable on the SPOT10 imagery (as was the case for all rockholes), colour A3 map/s were sent to the relevant people. These maps were produced by overlaying the waterbody mapping discussed above with property boundaries and 1:250 000 topographic maps in ArcMap 9.0. All waterholes on these maps were highlighted and numbered, and maps were accompanied by a short cover letter explaining the project aims and information requirements. Maps were sent to informants only after an initial phone call explaining the project aims and requesting their participation. A follow-up phone call was made within a couple of weeks, and each numbered waterhole was discussed, focussing only on those that had water in for >70% of the time on average. Questions concerned the number of months a certain waterhole held water without inflow; how often the person had seen a waterhole dry and under what conditions, and any other relevant information.

In a small number of cases, difficulties were encountered in conversing with people over the phone. In these instances, face-to-face visits were arranged, either on-property or when that person came to Longreach. Face-to-face interviews were also preferred where there were a large number of waterholes that did not show up clearly on the satellite mapping, or where uncertainty still existed after the phone interview. Where possible, face-to-face interviews were preferred over telephone interviews, as the information gathered was often more detailed. In the case of rockholes and non-GAB springs, face-to-face discussions over detailed topographic maps were nearly always necessary.

2.3 Written records

Numerous explorer and early settler journals, newspaper articles and local history books contain observations about waterbodies. This is hardly surprising, given the total reliance of Aboriginal people, explorers and early settlers on natural water sources. As well as information about the permanency of waterbodies, written records often provide valuable historical information on waterbodies mentioned. Historical sources and other written records (Table 2) were used primarily to supplement expert knowledge, and to provide insights into the role of water through human history in the study area. Such records were also valuable for researching the origins of waterhole names, including their meaning or derivation.

Table 2: Written records consulted during project

Studies on Aboriginal occupation	Explorer/ surveyor journals	Early settlers/ scientists accounts	Local/regional histories	Secondary sources
Ah Chee (2002); Bandler (1995); Bayly (1999); Donovan & Wall (eds, 2004); Harris (1980); Hercus (1990); Langton (2002); Roberts (2005); Simmons (2007); Watson (1983; 1998); Wilson (2004)	Sturt (1869); Mitchell (1847); Kennedy (1847); Gregory (1856) Landsborough (1862); McKinlay (1862); Winnecke (1883)	Allen (1968); Duncan-Kemp (1934; 1968); Durack (1959); Madigan (1939); Ratcliffe (1938); Sutherland (1913); Bennett (1927)	Bell & Iwanicki (2002); Forrest & Forrest (2005) Kowald & Johnson (1992); Moffat (1989) Nolan (2003); Powell (1991); Shepherd (1994); Tolcher (1986)	Bailey (2005); Bell (2004); Cumpston (1964); Macinnis (2007); Murgatroyd (2002); Towner (1955)

2.4 Field work

As discussed above, some field work involved conducting face-to-face interviews with landholders about waterholes and rockholes. This tended to involve discussions over maps, followed by a drive (or, in one case, a flight) to look at selected waterholes with the land manager. Obviously a visit to all waterbodies mapped for this project was not feasible. Waterbodies were selected based on logistics, ease of access and prioritisation. Waterholes along each major section of river were inspected over the course of the project, with large and/or isolated permanent waterbodies especially targeted. At each waterbody, a list of common species was compiled, along with a visual assessment of condition at the time of visit. Some field work was conducted with Adam Kerezsy from Griffith University, allowing further fish surveys to be undertaken at selected waterholes and related to waterhole condition, as discussed in Section 4.7. In total, about 50 waterholes were visited across the study area, however some reaches were sampled intensively (e.g. upper and mid-Thomson) while only one or two waterholes on other reaches were visited (e.g. Mulligan River and Warburton River).

Where only rough locations for rockholes and non-GAB springs were available, some searching, combining quad bikes and hiking, was done. The Idalia and Goneaway districts (see Section 6) were most intensively searched in this regard. Each rockhole visited was assessed in a similar manner to waterholes, and accurate depth measurements were obtained. In the absence of detailed observations available for rockholes, depth was used as a surrogate for permanence.

2.5 Final database coverage

All information collected on waterholes and lakes was entered into ArcMap 9.0 Geographic Information System (GIS). For the Cooper catchment, separate shapefiles and tables were created for zones 55 and 54. The Metadata for this dataset is provided in Appendix 2. A summary of the dataset fields is provided in Table 3. The full dataset is provided in the Spatial Data CD which accompanies this report.

Permanence percentage was calculated from the information gathered about water-holding capacity, frequency of inflow, and frequency and length of dry periods. The accuracy of estimates varied between waterholes, depending upon accessibility (information for waterholes on major property tracks or near houses is more detailed than highly inaccessible waters such as remote rockholes), proximity to other sources of water (determines the importance of a water for pastoral use), and timespan and level of available knowledge. Where a cluster of permanent or near-permanent waterholes occurred within a small area, knowledge of each individual waterhole was often not as detailed as for similar waterholes on a property with only one or two long-lasting waters.

Table 3: Dataset parameters and explanation, waterholes and lakes

Dataset Field	Explanation
Location	Waterholes and lakes were mapped from Landsat imagery and are represented as polygons.
Water Name	Based on local knowledge and/or topographic maps. Where these two sources are in conflict, local names take precedence and other name/s are recorded in brackets.
Water Type	Each waterbody is classified as riverine waterhole, lake, spring or rockhole (see Duguid *et al.* 2002 for definitions of these terms).
'Naturalness'	Whether the hydrology or permanence of a waterbody has been altered by human actions, such as dams/weirs, excavation or addition of bore water. A score of 1 indicates some form of modification, while 0 indicates no anthropogenic modifications (disturbance from grazing is not included).
Property	The property (or properties) where the waterhole is located is recorded from the Pastoral Holdings Access Database.
Watercourse and Catchment	Each waterbody occurs in one of four major catchments: Cooper, Diamantina, Georgina or Warburton Creek (after the confluence of Georgina and Diamantina).
Permanence	Defined as the percentage of time a waterbody contains water.
Months	Number of months a waterbody typically holds water without some input (from local run-off or river flow)
Frequency of Drying	Records how many times a waterbody has been dry over the time of observation; ranges from 1/1 (goes dry every year) to 0/150 (has not gone dry since white settlement)
Timeframe	Timeframe spanned by observations/knowledge for each waterhole; may be continuous or discontinuous, depending on the knowledge history of informants (e.g. 1950-2008; 1950-1975, 2000-2008).
Years	Number of years of observations or knowledge for each waterbody; ranges from 5 years to 150 years, depending upon availability of sources.
Permanency Notes	Information relevant to the permanence of a waterbody, including frequency of flooding, landscape/catchment position, size and shape, and human use.
Informants	Names of people who provided information on particular waterbody. A separate Excel spreadsheet contains details and knowledge history of each informant, and the waterbodies for which they provided information.
Other Information	Any other notes about the waterhole, including ecological or hydrological information, Indigenous significance, explorer visits/camps, importance in early settlement, current use and human impacts.

Where waterholes had been de-silted or dammed, or were fed by bore drains, permanence parameters were recorded as its estimated pre-modification (i.e. 'natural') permanence. In these cases, 'naturalness' was given a value of 0, and its current permanence parameters were recorded in the notes column. If a waterbody would not have met the 70% criteria prior to being excavated or modified, it was not included in the dataset. The structure of the spatial database allows waterholes to be selected and arranged by a certain parameter, or combination of parameters, such as permanence, river system or catchment. For example, all 100% natural permanent waterholes in the Georgina catchment can be selected. Waterbodies can also be colour-coded or different symbols used to represent different characteristics.

A number of themes became evident during the project regarding social and cultural importance of waterholes; namely Aboriginal use and significance of waterholes, European explorer use and significance, importance to early settlers and pastoralists, role of waterholes in frontier conflict, and origins/meanings of names. Separate tables were created for each theme, in order to record such information for specific waterholes. Social, ecological and cultural information was recorded in brief in the 'other notes' column of the spatial database. This prevented the spatial database from becoming extremely large, as it would have done if all such information was included.

Separate Excel spreadsheets were created for rockholes and non-GAB springs. The data gathered for each was similar as for waterholes, except that permanence information (and sometimes location data) was generally not as accurate or reliable as for waterholes. In recognition of these limitations, extra data fields were created to record locational precision and confidence level of permanence data for each feature (Table 4). This spreadsheet data was imported into ArcMap 9.0 GIS to provide an overview of the spatial distribution of these water features.

Table 4: Dataset parameters and explanation, rockholes and non-GAB springs

Dataset Field	Explanation
Name	Based on local knowledge and/or topographic maps. Where these two sources are in conflict, local names take precedence and other name/s are recorded in brackets. Often rockholes are not named.
Catchment and Region	Rockholes and non-GAB springs tended to cluster in certain areas, which were called 'provinces' or 'regions'; these are more fully explained in the Results section below.
Location_1	The property (or properties) where the waterhole is located is recorded from the Pastoral Holdings Access Database.
Location_2	Directions to rockhole, as described by land managers or other informants; this information was recorded because GPS coordinates were often estimated from this
Coordinates	Latitude and longitude in decimal degrees; springs and rockholes are represented as point locations.
Coordinates Source	Either from GIS described over phone, topographic maps or GPS if visited
Precision	Accuracy of location in kilometres
Permanence	Defined as the percentage of time a waterbody contains water.
Permanence Ranking	Permanent = 100%, almost-permanent = known to have gone dry once or twice; semi-permanent = would go dry infrequently during dry periods, perhaps 1-2 times a decade
Confidence Level	High = both location and permanence data accurate and reliable; medium = location reliable, information on permanence general but reliable; low = general location known, permanence assumed from few observations; very low = known to exist, but location not known and very limited information on permanence
Other Information	Any other notes about the waterbody; some rockholes and springs had very limited information surrounding them; others had relatively rich histories or stories
Informants	Names of people who provided information on particular waterbody. A separate Excel spreadsheet contains details and knowledge history of each informant, and the waterbodies for which they provided information.

2.6 Condition assessment criteria

Numerous studies on river condition assessment have been conducted in the study area over the past decade. A review of these previous studies was used as a starting point for devising criteria for assessment of waterholes. Visits to waterholes and discussions with land managers and researchers were combined with scientific data to decide upon a set of key indicators to assess waterhole condition. Preliminary testing of this methodology was conducted on a small number of waterholes in the study area. This framework is discussed fully in Section 4.7.

3 RESULTS: OVERVIEW

3.1 Permanence definitions and types of waterbodies

'The question, 'What is *permanent water?' tormented him more insistently as the drought went on. With terrible force the answer burst on him – Permanent water can only be obtained from Nature's reservoirs under the ground'* (Bennett 1927, p.168; recounting Robert Christison's thoughts in the 1880s).

'There is no such thing as a permanent waterhole.'
(Geoff Morton, 'Roseberth', October 2008).

Geoff Morton has been observing the Diamantina River near Birdsville for the best part of 50 years, and is quick to point out that there have been much drier times in the past than have been experienced since European settlement, and no doubt there will be again in the future. During the last glacial period, about 18 000 years ago, the Lake Eyre Basin would have been extremely dry, with more irregular and less total rainfall relative to today, providing little recharge for waterholes. The current climatic conditions experienced by the LEB only settled into being a mere 1500 years ago (Simmons 2007). Coupled with the inherent dynamism of inland river systems (Knighton & Nanson 1994), labelling waterholes as 'permanent' becomes a somewhat dubious business. Obviously our ideas of permanency are couched in a timespan spanning little more than a century – a mere blink of an eye in the evolutionary time scales of inland rivers and landscapes.

However, for practical purposes, '**permanent'** waterholes are defined here as those which have not gone dry since European settlement, as far as could be ascertained through the oral and written record. Notably, the Goodberry Broadwater on the Thomson River north of Longreach has not gone dry since white settlement (circa 1870), but Aboriginal knowledge from the initial contact period indicates that it had gone dry once at an unspecified time in the past (Kate Deane, pers.comm., August 2008). Nevertheless, in the interests of consistency, this waterhole was classified as 'permanent', highlighting the mere snapshot of permanence that this project documents. A waterhole on the Diamantina was also known to have gone dry once in Aboriginal memory and once since white settlement (Robert Banning, pers.comm., November 2008). Again, only the records since white settlement were used in classifying permanence.

Another waterhole also warrants a mention in this regard. Rocky Crossing Waterhole on the Mayne River is regarded as permanent, and has not been dry or even low in the past two decades (Waddy Campbell, pers.comm., April 2009). Most people in the district consider it to be permanent, as it is deep and fills easily from the surrounding rocky country. However, two bush graves at the base of the range near this waterhole suggest that it may have been dry at least once since European settlement. In the 1880s, two men were droving cattle to Austral Downs along the Mayne River, and apparently relying on this waterhole as a stop-over. They perished just two kilometres west of the most permanent section of this waterhole, which they would have just passed (Peter Russell, pers.comm., May 2009). It seems unlikely that they would have died if there was surface water available. The 1880s was an extremely dry decade, and it appears that this usually reliable waterhole may have failed. The two lonely graves perhaps stand as testimony to the less-than-permanent nature of this waterhole. Again, in the interests of consistency, this waterhole was classified as 'permanent'.

Numerous studies have classified permanence of waterbodies (e.g. Unmack 2001; Duguid *et al.* 2002; Box *et al.* 2008). For this study, '**semi-permanent'** waterholes and lakes were split into four categories (Table 5). **'Almost permanent'** waterholes have been dry only during the most severe droughts (perhaps once or twice in 50 years). Numerous waterholes in this category had not been dry since white settlement but went dry in 2002 or 2008. '**Infrequently dry'** waterholes are dry once a decade or less, on average. '**Regularly dry'** waterholes go dry two to five times a decade, while '**annually dry'** waterholes generally go dry every year (or second year), but still generally hold water for most (>70%) of the time. Large, flat waterholes on the Mulligan River which fill infrequently but may last for >12 months (therefore having an approximate permanence of about 70%) before going dry (David Brook, pers.comm., October 2009) were classified as 'annually dry', the lowest level of permanence.

Assigning categories of permanence depends upon the years that waterhole knowledge spans. For example, some land managers interviewed had been on a property for less than a decade, but this period often coincided with extremely dry conditions (e.g. such as were experienced on the Georgina in 2007-08), which provided a 'test' of waterhole permanence. In some cases, the judgements of landholders were used to assign categories. For example, a land manager may not have seen a waterhole go dry during his or her time, but based on observations and local knowledge assumed that it would go dry in the biggest droughts.

Table 5: Waterhole and lake permanence categories

Category	Explanation	Amount of time with water (%)	Typical frequency of drying
Permanent (P)	Has not gone dry as far as could be ascertained through oral and written record; typically knowledge dates back to white settlement around 1870-1880 for most large permanent waterholes	100%	0/130-140
Almost permanent (AP)	Only dries out in the most severe droughts, in the order of once or twice in 50 years or less	97-99%	1-2/50 to 1/130
Infrequently dry (ID)	Goes dry during moderate droughts, once a decade or less	91-97%	1/10 to 3/50
Regularly dry (RD)	Dries out at least twice a decade on average	80-90%	2/10 to 3-4/10
Annually dry (AD)	Goes dry every year or nearly every year; will do dry by end of the year in average seasons but last during good seasons	70-80%	1/1, 1/2 or 2/3

Waterbodies below 70% permanence (i.e. contain water for less than 8-9 months in most years) were not included in this study. Using this cut-off, there are only four types of dependable surface water in the study area: riverine waterholes, springs, rockholes, and a small number of lakes (Table 6). GAB springs were classified as either active or inactive, while non-GAB springs and rockholes were ranked as permanent, almost-permanent or semi-permanent. This was the highest level of detail that could be gathered for these remote and seldom-visited features, and even then the confidence level on these estimates was often low. Aboriginal wells are recognised as an important source of water for people in the study area over millennia (Hercus 1990). However, they generally do not contain accessible surface water, and were therefore only documented opportunistically during this study. Likewise, soaks typically occur in the base of creekbeds, and while water can be obtained by digging and may even enhance the permanence of a waterhole, little surface water is available.

Table 6: Sources of permanent and semi-permanent water (modified from Box *et al.* 2008)

Waterbody Type	**Definition**
Waterholes	Areas within river channels where water is stored after flow has stopped; may be permanent, semi-permanent or relatively ephemeral
Springs	A groundwater discharge with visible water flow; 'mound springs' occur where discharge causes mounds to form at the spring; springs in the LEB can be classified as Great Artesian Basin springs or non-GAB springs, which emanate from local or regional aquifers
Soakage/soak	Location where shallow groundwater can be accessed by digging; surface of soil is often damp; these may access the regional watertable where it is close to the surface, or shallow, perched, often ephemeral alluvial aquifers
Rockholes	Natural hole in rock that stores water, either from local run-off or riverine rockholes (often called scour holes, including 'plunge holes' below a cliff face or other steep gradient)
Lakes	Shallow lakes, either fresh or saltwater, of widely varying sizes and permanency
Wells	Applied broadly in reference to Aboriginal water use – includes surface water in rockholes and holes dug to access a regional or perched watertable

3.2 Distribution of permanent water in LEB

The primary finding of this study was the paucity of truly permanent water, given the size of the study area. In Table 7, permanent waterbodies are shown first, with total number of permanent and semi-permanent (all >70%) waterbodies are shown in brackets. Figure 2 shows the waterbodies mapped in the study area, coded by permanence and type. Although more detailed permanence definitions are provided for waterholes in section 4, for the purposes of this overall map, semi-permanent equates to waterbodies which hold water for 70-94% of the time, almost-permanent is 95-99% and permanent is 100%.

Table 7: Permanent and total semi-permanent + permanent waterbodies by catchment

Catchment	**Waterholes**	**Lakes**	**GAB Springs†**	**Non-GAB Springs**	**Rockholes**	**TOTAL**
Cooper	200 (514)	0 (6)	150 (227)	21 (29)	6 (26)	**377 (833)**
Diamantina*	38 (209)	0 (1)	49 (50)	1 (7)	11 (40)	**99 (307)**
Georgina	22 (113)	0 (0)	33 (98)	0 (1)	1 (15)	**56 (227)**
TOTAL	**260 (836)**	**0 (7)**	**233 (350)**	**22 (37)**	**18 (81)**	**532 (1367)**

* Includes Warburton Creek after confluence with Georgina River

† Non-active springs shown in brackets

The Cooper catchment has by far the highest number and density of both permanent and semi-permanent waterbodies, particularly south of Jundah where permanent waterholes become a feature of the system. In contrast, the Diamantina and Georgina catchment are characterised by a small number of widely-spaced permanent waterholes, interspersed with clusters of semi-permanent sources of water. Rockholes, GAB springs and non-GAB springs are clustered in discrete areas, with the latter two features most prevalent in ranges on the watersheds of catchments (Figure 2). Away from spring/rockhole clusters and major drainage lines, there is very little lasting water. Interestingly, without the influence of groundwater in some form, there would only be four truly permanent waterbodies across the entire Georgina catchment: two waterholes on the Burke River near Boulia, one on Eyre Creek west of Bedourie and a remote rockhole near the north-eastern watershed. The distribution and characteristics of the four major types of surface water in the study area are discussed separately in the following sections.

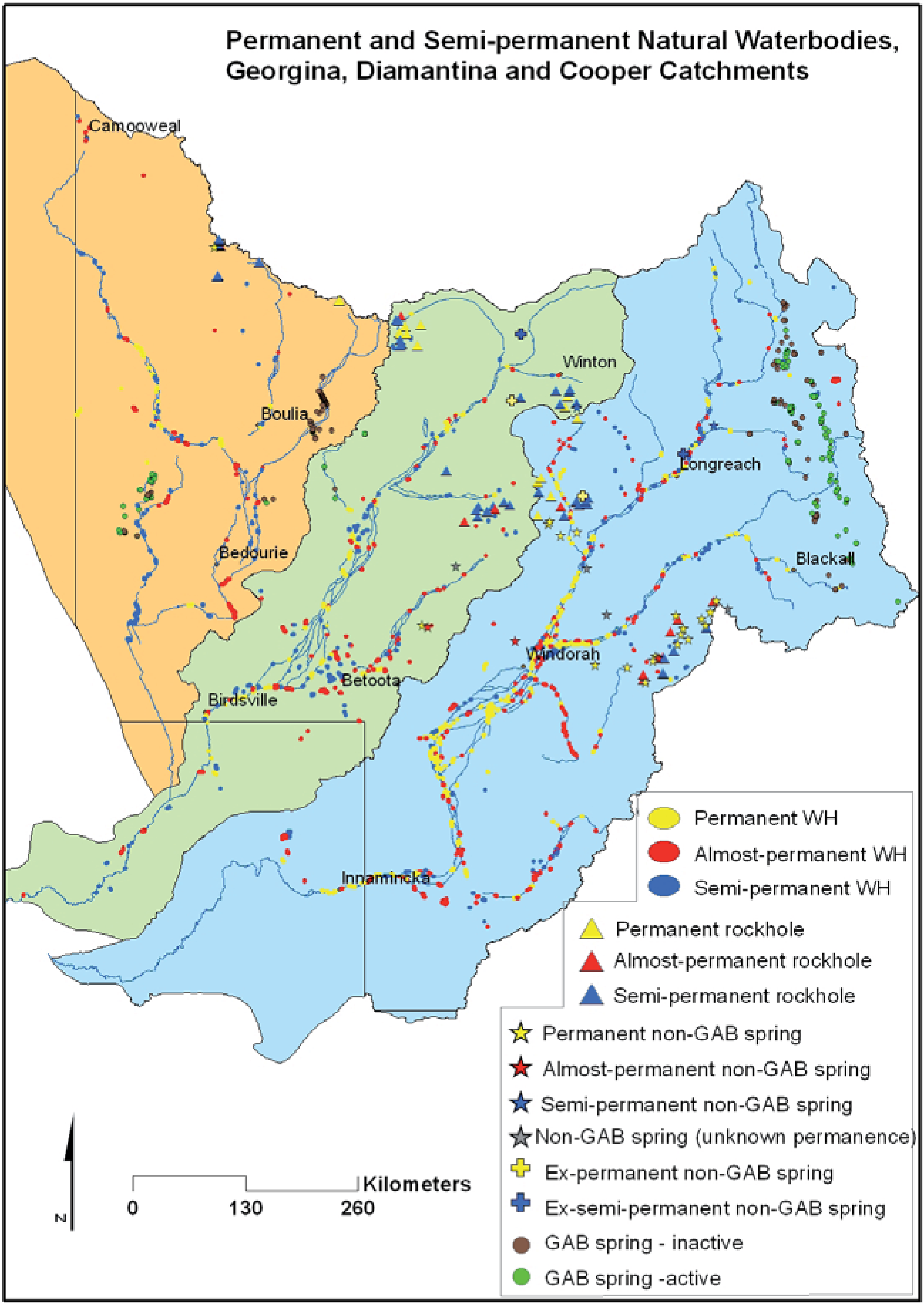

Figure 2: Overall distribution of semi-permanent and permanent water in study area

4 WATERHOLES

Waterholes are the most widespread, numerous and conspicuous source of permanent and semi-permanent water in the Cooper, Diamantina and Georgina catchments. They also represent a distinctive component of all major river and creek systems in the region. This section outlines the characteristics and distribution of waterholes found in the LEB, and explores their formation, ecology and considerable human significance.

4.1 Geomorphology and hydrology of waterholes

4.1.1 Definition of a waterhole

A waterhole is an enlarged segment of a watercourse which holds water after flow has ceased. Enlargement occurs in both width and depth: waterholes are typically two to five times wider and two to three times deeper than associated channels (Knighton & Nanson 2000). Indeed, these authors suggest that 'expansion channel' could be an alternative term for waterhole. Waterholes collect flow from both feeder channels and the surrounding landscape during both flood events and local rainfall. For most of the time, inland rivers exist as chains of waterholes, which are only connected during flood events. As such, waterholes indicate what a single continuous channel would like look if one could be maintained. In reality, aridity and insufficient energy render such a scenario impossible.

Waterholes in the arid zone vary from deep, steep-banked holes on major river channels to wide, shallow 'lakes', often situated on outer channels. They range in length from less than 50m to over 20km, with typical widths of 50 to 200m. Despite these differences, most inland waterholes share a number of broad features. There is usually a clear distinction between channel and floodplain at waterholes, partly because channel banks are formed of cohesive mud and can stand at high angles (Knighton & Nanson 2000). Tree-covered levees, which stand slightly above the adjacent floodplain, often border waterholes. While lines of trees are a feature along all sections of river, anastomosing channels have less well-defined levees than waterholes.

4.1.2 Geomorphology and formation of waterholes

The formation and age of inland waterholes has been the subject of some debate. The fact that most lie either within the active channel, or at present-day points of flow convergence, points to a contemporaneous origin, although some degree of inheritance cannot be discounted (Knighton & Nanson 1994; 2000). Evidence certainly suggests that waterholes can be formed under the present hydrological regime. The location of many waterholes demonstrates that their formation is linked to localised scour under present conditions, with the splays of sediment at their downstream ends shows that their depths can be maintained under present regimes (Knighton & Nanson 1994). Indeed some waterholes are very new in geological terms, with a small number having been formed within living memory. For example a waterhole on Roseberth on the Diamantina River near Birdsville formed after the 1974 flood (Geoff Morton, pers.comm., October 2008). Prior to this, the new waterhole had been used as a crossing place over the river, as indicated by an old wagon track.

Most waterholes occur on main channels, often forming at points where flow becomes concentrated or constricted, such as between aeolian dunes (e.g. Kingadurka Waterhole, Diamantina River; Tooley Wooley Waterhole, Wilson River), against a valley side or floodplain edge (Tabbareah and Eulbertie Waterholes, Cooper Creek) or, less commonly, in gorges (Hunter's Gorge, Diamantina River). Dune-flanked waterholes tend to be quite short, probably because they are not so deeply scoured and the cause of flow convergence – dunes that restrict flow laterally – disappear downstream (Knighton & Nanson 2000). Similarly, gorge waterholes only persist where the gorge constricts flow. Dune-flanked waterholes are generally wider and more variable in width than other waterhole types, suggesting that the sandhills through which they are cut, while focussing the flow, exert little constraint on lateral expansion (Knighton & Nanson 1994).

Flow convergence can also be brought about by the meeting of several anastomosing channels. This effect can be observed at most waterholes, but is particularly pronounced at Meringhina Waterhole, which is the only place between Windorah and Nappa Merrie where the entire flow is concentrated into a single channel. Other prime examples are the 'Innamincka Choke', which produces the deepest waterhole in the LEB, and Muttaburra Broadwater, formed where numerous northern tributaries join to form the Thomson River. Abrupt changes in flow direction also facilitates scour, and several large waterholes are located where flow changes sharply in direction (Knighton & Nanson 1994). Examples include Unthill, Wombunderry, Eulbertie and Goonbabinna on the Cooper and Camoola Waterhole on the Thomson.

The fact that waterholes have developed in the Channel Country but not in other anastomosing rivers with the ability for active scour is attributed to the alluvial history of the area, in particular the presence of a more easily-eroded sand sheet at relatively shallow depths beneath cohesive surface sediments. The formation of waterholes can be split into three broad phases: initiation, augmentation and maintenance. The following information is summarised from Knighton & Nanson (1994 and 2000), and represented in Figure 3.

Phase 1: Initiation

The major prerequisite for waterhole formation is conditions conducive to scouring. When flow volume and velocity reaches a critical level and is able to scour through the cohesive surface sediments, waterhole formation is initiated. Most commonly, these conditions occur when numerous anastomosing channels converge or where flow is constricted between an obstacle such as sand dune, gorge or rocky ‘choke’ (see above). As such, waterholes appear to indicate a spatially uneven distribution of erosive ability across a very broad floodplain.

Phase 2: Augmentation

Once initiated, waterholes become self-perpetuating. In the low-gradient settings which characterise inland rivers, the development of even a slightly deepened channel section will tend to concentrate the flow further. This in turn leads to enlargement of the initial incision through extension and deepening. The augmentation process is influenced by the underlying geology, which is usually comprised of a layer of surface mud 2-9m deep, sitting over at least two bodies of medium to coarse sand dated at 100-120 000 and 200-250 000 years before present (BP). The mud deposition dates to 85 000 years BP, and probably signifies a change to more arid conditions which decreased the river’s transporting ability. Once scouring reaches this sand sheet, more easily eroded sediments are exposed and the scouring process is enhanced. While breaching of this ‘mud-sand boundary’ is an important event in the evolution of a permanent waterhole, there are some long-lasting waterholes where the mud has not been breached. Such waterholes (e.g. North Chookoo and Tooley Wooley Waterholes on the Cooper) may be in a partial or arrested state of development.

Phase 3: Maintenance

Waterholes are regarded as self-maintaining scour features. The steepness of the reverse slope at the downstream end of most waterholes acts as a natural ‘dam’, while seepage is inhibited by a ‘bottom seal’ formed by the deposition of suspended clays. The reverse slope is a major limiting factor in determining the length of waterholes, as it causes a decline in stream power and scouring is unable to be maintained. The ‘bottom seal’ may occasionally be breached during big flood events, exposing the sand sheet to further excavation. During floods, the high velocity of water is able to maintain, and sometimes increase, existing waterhole depth.

Belying their peaceful appearance for most the time, waterholes are major foci for erosional energy during flood events. Stream power at the upper end of waterholes far exceeds that of channels and the sedate floodplain. Such movement and dynamism may be hard to imagine as you take in a serene waterhole vista. However, the abundance of sand in the waterhole, and the deposits downstream from many waterholes, bear testimony to these scouring events.

Bifurcation: A Fourth Phase?

There may be a fourth stage in waterhole evolution, whereby waterholes effectively become victims of their own success. Many large waterholes split or ‘bifurcate’ at their downstream end, with excavated sediment forming an ‘island’ between the two channels (Figure 4). This divided flow becomes unable to transport away the products of scouring, which is the primary mechanism of waterhole development. Over a considerable period of time, this sediment may infill the waterhole.

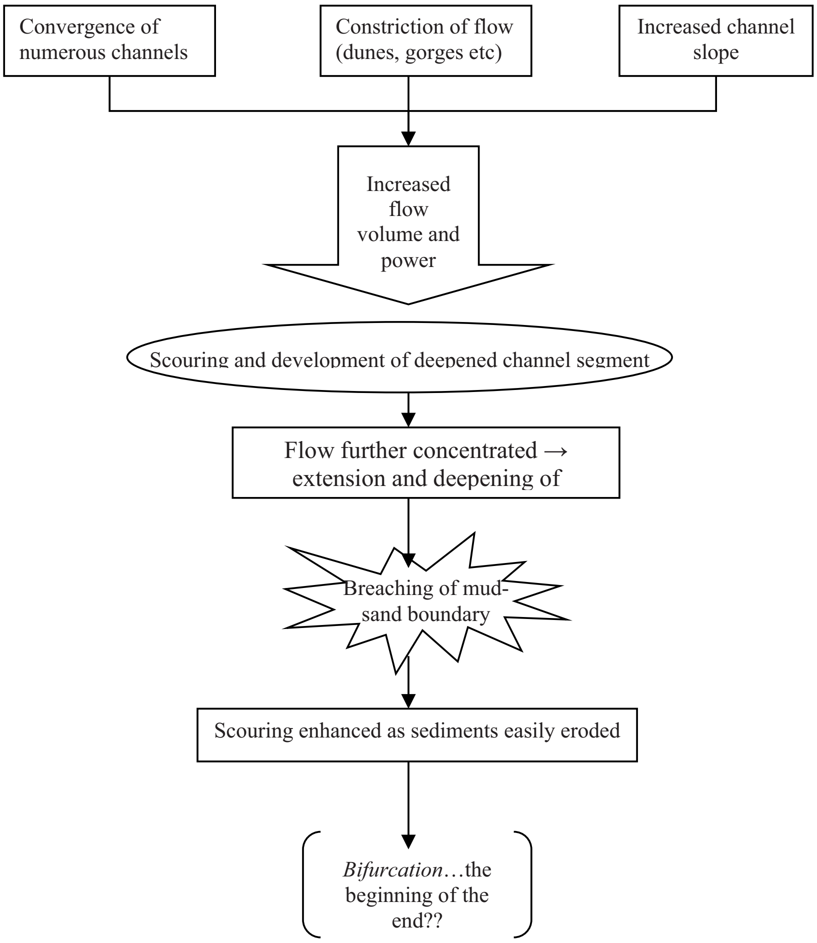

Figure 3: Waterhole Formation Process

Figure 4: Bifurcation, Gallina Waterhole, Durham Downs (SPOT10 imagery) and Birt's Dip Yard Waterhole, Keeroongooloo

4.1.3 Hydrological role of waterholes

Waterholes play a significant hydrological and geomorphologic role in inland river systems, as their fixed position and water holding capacity helps maintain the stability of the channel systems. They are points of flow convergence, and play a major role in concentrating flow from both upstream anastomosing channels and the adjoining floodplain. For example, Meringhina Waterhole, a permanent waterhole south of Windorah, is a point of flow convergence, collecting and redistributing all of the channelled flow in the area of the floodplain, and probably acting as a repository for overbank flow as well (Knighton & Nanson 2000). Similarly, Eulbertie Waterhole exerts a major control over transmission of flow in the western Cooper floodplain south of Windorah, with exit channels supplying water to Currawonga Waterhole and Lake Yamma Yamma (Knighton & Nanson 1994).

This convergence of large amounts of water renders waterholes veritable 'erosion hotspots'. Their fixed position in the floodplain landscape helps to maintain existing channel lines, as well as the downstream continuity of flow in a variable environment. They are hydraulically more efficient than anastomosing channels and floodplains for conveying flow, due to the substantially lower boundary friction. Paradoxically, then, major waterholes are simultaneously places of ferocity and intensity, but also features which provide constancy and stability in an otherwise dry, highly variable system.

4.2 Factors influencing permanence

The permanence of any given waterhole is primarily determined by four interrelated factors, which are explored below: depth, frequency of inflow, loss processes and groundwater interactions. It should be recognised that waterholes, like rivers, are inherently dynamic and their permanence varies over time depending on flood events and processes. The permanence of a waterhole in any given season will depend upon the time of rainfall, temperature and flooding regime. In general, outer channel holes are regarded as being more dynamic than in-channel holes, as they will silt up after droughts, then be cleared out by a big flood, so depth and permanency is more variable than in-channel holes.

A. Depth

Permanence of a waterhole is primarily determined by its depth when flow ceases. Four metres is a critical depth relating to waterhole permanence in the LEB. This 'cease-to-flow' depth (i.e. the depth of the waterhole when the river stops flowing) is necessary for a waterhole to retain water for two years without any input. This is because of the high rate of evapotranspiration in western Queensland, which ranges from 2-3m to 4-6m per year (Costelloe *et al.* 2004). Most waterholes shallower than this will go dry in extended droughts (although there are some exceptions). Waterholes with a cease-to-flow depth of about 3m will still retain water in the event that they miss one flow season, while 2m waterholes will generally hold water between flood seasons, but will go dry in years where no run occurs.

Depth of a waterhole is determined by the degree of scouring which, in turn, is determined by the location of a waterhole, as discussed in Section 4.1.2. In general, waterholes seem to attain more permanent status once scouring has breached the underlying mud-sand boundary. Conversely, 'silting up' of waterholes over time (discussed in Section 4.6.2) will decrease the depth and therefore permanence of waterholes. However, there are some more shallow waterholes that are close to permanent, due to the influence of other factors discussed below.

B. Frequency of inundation

Location is also paramount in determining waterhole permanence. Most truly permanent waterholes occur on main river or creek channels where they receive regular inundation. Although large off-channel waterholes may be capable of retaining water for a considerable length of time after filling, they go dry because they are not topped-up on a regular basis. In this regard, more frequent, smaller flow pulses that remain within the river channel, while not triggering the major 'boom' events associated with floodplain inundation, are important for 'topping up' waterholes (Hamilton *et al.* 2005). There are no permanent waterholes below Coongie Lakes on Cooper Creek, because floodwaters only get past these lakes every 2-3 years (Graham Morton, pers.comm., November 2008). Local run-off is also important, with some smaller waterholes, although not particularly deep, being filled by only half an inch of rain on adjacent hard ('tin roof') country, and therefore being permanent or almost so.

C. Loss processes

Once a waterhole is filled, its persistence between flow events will depend upon how quickly water is lost to the surrounding environment. In the LEB, water is lost primarily through evaporation – 'that insatiable enemy of water in the west' (Bennett 1927, p.168). Seepage into porous sediments, transpiration by fringing vegetation and animal and/or human use play relatively minor roles. The relentless inland sun is quick to 'suck up' water, with the rate of evaporation determined by the time of year, prevailing weather conditions, effective fetch for wind action, degree of channel incision below levees and the surface area to volume ratio of the waterhole (Hamilton *et al.* 2005). Water temperature and quality can also influence the rare of evaporation. In particular, the high turbidity of many waterbodies can exacerbate heating during exceptionally hot periods and contribute to higher evaporation losses (Costelloe *et al.* 2007).

In summer, waterholes can drop noticeably by the day – a harsh reality that has long dismayed people in these areas. Returning to what he considered a reliable waterhole in January 1862, the explorer John McKinlay was shocked to find that *'…rapid evaporation had taken place since we left yesterday, for then there was enough water for 100 horses, now there is not half enough for eight…'* (1863, p.38). Wide, flat waterholes such as occur on Spring Creek on Diamantina National Park or the upper Georgina near Camooweal, lose water more quickly than their deep, narrow, shaded counterparts and are therefore less permanent (Figure 5).

Figure 5: Narrow, steep-banked waterholes such as Big Hole on Vergemont Creek have much lower evaporation rates than broad, flat waterholes such as Neuragully on the Diamantina River

Percolation of water out of a waterhole depends upon nature of the bank and channel sediments and the level of the local aquifer (Costelloe *et al.* 2007). As such, the substrate underlying a waterhole is a critical factor determining its permanence. Waterholes with rocky bottoms tend to hold water the longest, while clay-based waterholes are also quite impervious. The minimal loss through seepage in clay-based waterholes is attributed to the fact that suspended clays in the water settle out to form a bottom seal (Knighton & Nanson 1994). Although this seal is breached during high flows when the sand sheet is exposed to further excavation, it is quickly re-established when flow ceases to prevent sustained water loss. Sandy rivers, such as the Burke, Field and Alice Rivers, tend to harbour very little long-lasting surface water, although water is often present just below the surface. However, clay-bottomed waterholes flanked by dunes can become more permanent than surrounding drainage lines because of the constant seepage through the dune (Simmons 2007).

Although trees provide shade and therefore can reduce evaporation, they also use water via transpiration, the magnitude of which will be a factor of the perimeter length relative to the area of the waterhole (i.e. the narrower a waterhole, the greater the potential loss by transpiration). There is limited data on water use by coolibahs, the dominant riparian species across much of the LEB, however a study on river red gum (*Eucalyptus camaldulensis*) in semi-arid Australia found that trees within 15m of a stream sourced less than 30% of their water requirements from the stream, and those more than 15m away utilised only soil water and groundwater sources (Mensforth *et al.* 1994). Assuming that these figures hold true for LEB waterholes, the increase in loss rate due to transpiration would be less than 20% of the expected evaporation rate (Costelloe *et al.* 2007). Thus transpiration is far exceeded by potential evaporation as a loss process.

Heavy use for household, garden or stock use may also test the permanence of a waterhole during dry times. With the advent of bores, stock are usually removed from a waterhole before it becomes low and boggy, while tough decisions often have to be made concerning station gardens during dry times.

D. Groundwater interactions

Discharge from shallow groundwater can mitigate evaporative losses and increase the persistence of waterbodies (Bernardo & Alves 1999). Research has found no deep waterholes with signs of groundwater inflows on the Cooper or Diamantina, suggesting these systems are mostly closed to groundwater interactions, except after large floods when bank/floodplain storage may discharge back into waterbodies (Justin Costelloe, pers.comm., July 2008; Hamilton *et al.* 2005; Costelloe *et al.* 2007). In particular, waterholes adjacent to dunes are likely to exchange water with the dune during and after flooding, when stored water seeps back into the waterhole.

There are, however, a small number of waterholes in these catchments that owe their permanence to being spring-fed. For example, the only permanent waterhole in the Farrars Creek catchment is fed by a spring, and has not been dry in the past two decades (Roger Oldfield, pers.comm., September 2008). A handful of long-term land managers in the Cooper catchment also harbour suspicions about certain waterholes being spring-fed, as they have never been dry despite not being particularly deep. This lack of groundwater interaction sits in sharp contrast to waterbodies in central Australia, where virtually all long-lasting surface water have some dependency on groundwater discharge (Box *et al.* 2008).

However, it is in the primarily arid Georgina system that groundwater interactions become the overriding factor in determining the permanence of waterholes. All bar three permanent waterholes in the catchment are spring-fed, and after >18 months with no flow in the river, the only waterholes surviving from Camooweal to Glengyle (a distance of 400km) are spring-fed. Some waterholes dry back to very small soaks in droughts, while others, including the impressive 17-mile-long Jimboola or Walkabee Waterhole south of Urandangi (Figure 6), remain sweeping expanses of water. This waterhole stays fresh in dry times; however parts of the other major permanent waterhole on the Georgina, Paravituri near Boulia, goes extremely salty and rank as it gets low.

Figure 6: Jimboola or Walkabee Waterhole: a permanent spring-fed oasis south of Urandangi

The Warburton River, formed after the junction of the Georgina and Diamantina Rivers in South Australia, also has groundwater inflows, resulting in many of its waterholes being hyper-saline and therefore less significant as biological refugia. Goyder's Lagoon marks an ecological boundary of sorts: above the Lagoon, waterholes tend to stay fresh, while below it, most go salty within 6-12 months of filling (depending on the time and height of the flow). As such, the defining factor in the 'refugial value' of these waters is not how long the water lasts, but whether it goes salty and how quickly.

The groundwater interactions in this area are not well understood. There are a series of springs and soaks under the channel and near the base of banks. These are thought to be due to water infiltrating from the floodplain back into the deeper sections of the channel. Costelloe *et al.* (2004) hypothesise that as some of the water slowly percolates back into the channel, it picks up salts. Whether or not a waterhole goes salty depends upon whether it is influenced by fresh, salty or no groundwater. These zones of saline seepages are patchy along the channel and so the salinity of waterholes varies. Intriguingly, waterholes can 'switch' after floods, depending on whether a fresh or salty spring has been 'opened up' (Sharon Oldfield, pers.comm., October 2008). It seems that fresh waterholes may have a hardpan that does not allow salty groundwater to infiltrate the waterhole, but very little is known about the underlying hydrogeology of the Warburton system.

4.3 'Inconsiderate nature': distribution of permanent waterholes

'Thus began the Big Drought, the biggest ever known since the time of white man…Waterholes and rivers that were never known to be dry, dried up in this drought; from end to end the earth cried out for moisture.'
(Duncan-Kemp 1934, p.86)

'By October 1895…the Cooper country was in a deplorable state…Waterholes supposed to be practically inexhaustible had dried up…' (Tolcher 1986, p.207)

The great majority of waterholes in western Queensland and north-eastern South Australia go dry. In drought, the dwindling waterholes become coated with green slime and the stagnant water exudes an increasingly uninviting smell. Occasionally, smaller waterholes may be obliterated by a single fierce sand storm, as recounted by Duncan-Kemp (1934) on Dickalow Waterhole on the Currawilla-Morney boundary: *'In a few short hours it blew a hurricane, lasting a day and a night. Previous to the "blow" there was plenty of water about for cattle and plant…When the storm died, there was no water…The waterhole that had contained the water-supply was a bed of soft red sand, so firm that the packhorses walked to and fro over it…'* (1934, p.165). Fortunately for human and bovine inhabitants of the region, such fierce storms are rare.

Nevertheless, the relentless sun ensures that, unless they are topped up, most waterholes dry out within 12-18 months. For example, of the 300 recognisable waterholes between Windorah and Nappa Merrie, the best-watered reach in the LEB, only 115 can be regarded as being even semi-permanent (i.e. have water in them for >70% of the time), while just 65 are truly permanent (John Ferguson, John Rickertt, Bill Scott & Sandy Kidd, pers.comm., July-August 2008; March 2009). The profusion of 'waterholes' marked on topographic maps is very misleading in this regard. Bennett (1927, p.235) cites the instance of a city-based Land Commissioner 'expiating on the nutritive properties of Mitchell grass and Flinders grass, and reciting an inventory of waterholes' as justification for raising the rents of western pastoral properties. In actual fact, this spiel was uttered at the height of the Federation drought, when 'the grasses had perished and the waterholes were dry'.

Most permanent waterholes in inland Queensland occur within the channels of major rivers and creeks. These waterholes are not only maintained by being scoured out by flooding, but also receive water more regularly than off-channel waterholes. In the Cooper Catchment, more than three-quarters of permanent waterholes occur along the three major channels (Thomson, Barcoo and Cooper), with the remainder mostly on major tributaries such as the Wilson River, Kyabra Creek and Vergemont Creek. In the Diamantina and Georgina catchments, over 70% of permanent waterholes occur along the two eponymous streams. Only a handful of substantial permanent and almost-permanent waterholes are situated off major channels. The distribution of permanent and semi-permanent waterholes is affected by the geomorphologic and hydrological factors discussed above. So where do conditions conducive to the formation of big waterholes occur? How is water distributed through the river systems and catchments? This section provides an overview of the major river systems and catchments in the LEB of Queensland and South Australia, with reference to the occurrence of semi-permanent and permanent waterholes along them.

4.3.1 Overview of hydrology and major river systems

An understanding of the nature of inland rivers is necessary to appreciate waterhole formation and occurrence. The Lake Eyre Basin system in Queensland and South Australia is comprised of three major river systems and their catchments (Figure 1): the Cooper, Diamantina and Georgina-Mulligan. All three systems are almost entirely reliant upon periodical monsoonal rain from the north, which falls over the upper catchments. As such, these three systems are influenced by the El Nino Southern Oscillation (ENSO), and are characterised by extremely high flow variability (Puckridge *et al.* 2000). Some flow occurs in most years, however long periods of zero flow are not uncommon and can exceed 21 months (Hamilton *et al.* 2005). The inter-annual hydrological variability of the LEB rivers is highest in their lowest reaches (Costelloe *et al.* 2004).

Anastomosing channel systems are prominent in the region, giving rise to the well-known 'Channel Country' (Figure 7). 'Anastomosing' is a scientific term for describing the pattern of multiple channels separated by large inter-channel 'islands' (Knighton & Nanson 2000). Main channels are relatively narrow and deep and are conduits for flow during smaller flow events and the initial stages of flooding. Networks of broader, shallow channels only carry flow at higher levels, including when the main river channel breaks its banks. Their development appears to be a response to conditions of low flow strength, low bank erodibility and a moderately high relative rate of sediment supply, which in combination force flow out of a single channel and leads to cutting of new channels. A flow regime characterised by isolated events of large magnitude is an important contributory factor (Knighton & Nanson 1994). Wide floodplains are often a feature of extensive anastomosing channel systems – such floodplains in the Channel Country can exceed 60km in width.

Figure 7: Anastomosing channels, Cooper Creek south of Windorah

The **Cooper** system is the most easterly catchment in the LEB. Cooper Creek is formed by the confluence of two river systems from central Queensland: the Thomson and Barcoo. South of Windorah, it is joined by two other major tributaries in Kyabra Creek and the Wilson River. Despite carrying the largest volume of water of all the systems in the LEB, it rarely reaches Lake Eyre, having to fill so many large waterholes and negotiate the maze of lakes and dunefields of the Coongie system north of Innamincka. It has reached Lake Eyre only 11 times since 1880 (representing about once every 10 years, and just 16% of total flow to the Lake over this period).

The **Diamantina River** heads in the remote rocky ranges south-west of Kynuna, and flows in an easterly 'horseshoe' before assuming its general south-westerly course west of Winton. It is joined by the Mayne River and then Farrars Creek, both of which channel water from the extensive range systems east of the river, as well as numerous smaller tributaries. In its lower reaches, it becomes a wide maze of channels and flood-outs – the classic 'Channel Country' morphology – before reforming to become a well-defined channel south of Birdsville.

The **Georgina River** begins in the vast open downs of the Barkly Tableland north-west of Camooweal, and follows a predominantly south-south-east course. Near Boulia, the Burke and Hamilton Rivers flow in from the north, and the main watercourse becomes known as **Eyre Creek**. South of Bedourie, it turns sharply west to meet the **Mulligan River**, which flows south along the edge of the Simpson Desert. Eyre Creek (Mulligan River) joins the Diamantina near Goyder's Lagoon in South Australia, and the combined waters of these two systems form the **Warburton River**, which channels water to Lake Eyre. The channel flood reaches Lake Eyre approximately every second year, and runs for several months.

4.3.2 Distribution of waterholes by river system

There are around 830 permanent and semi-permanent waterholes across the three catchments. Of these, only 260 (about 30%) have never been dry since white settlement, and so are regarded as permanent. The great majority of these permanent waterholes (77%) occur in the Cooper catchment, which also contains over 60% of all documented waterholes. Across the entire 365 000km^2 area of the Georgina-Diamantina Catchment in Queensland and South Australia, there are only 60 truly permanent waterholes: 38 in the Diamantina catchment and 22 in the Georgina catchment. Less than 20% of documented waterholes in each of these two catchments are permanent, compared to 40% in the Cooper catchment. The most common permanence category of waterhole in the Diamantina and Georgina catchments is 'annually dry'. Inventories of all the permanent (100%) waterholes in each catchment are provided in Appendices 3-5. Table 8 gives an overview of waterholes by major catchments and watercourses. In general, only those tributaries with more than five waterholes are considered separately; others are lumped in the table.

Waterholes are too irregularly distributed to be part of some orderly bed sequence. This is reflected in the fact that some reaches have large concentrations of waterholes, while others have no permanent waterholes. The patchy distribution of waterholes was much lamented by early pastoralists, as it precluded large areas of prime grazing country from being opened up to stock on a regular basis: 'It seems a pity that nature was not more considerate and generous in her distribution of waterholes' (Duncan-Kemp 1934, p.53). Table 9 summarises the 'wettest' and 'driest' reaches across the study area on the basis of density of permanent waterholes.

Table 8: Permanent and semi-permanent waterholes by catchment and watercourse

Major Streams	Permanent	Almost-permanent	Infrequently Dry	Regularly dry	Annually dry	TOTAL
COOPER CATCHMENT	**200**	**37**	**86**	**114**	**77**	**514**
ThomsonCatchment	***70***	***14***	***28***	***44***	***21***	***177***
Thomson River	*40*	*5*	*18*	*24*	*8*	*95*
Upper tributaries*	12	7	4	5	4	32
Mid-tributaries**	3	1	5	5	7	21
Vergemont Creek & tributaries	15	1	1	10	2	29
Barcoo Catchment	***28***	***7***	***13***	***16***	***27***	***91***
Barcoo River	*22*	*6*	*8*	*10*	*23*	*69*
Ravensbourne Creek & tributaries	0	0	2	1	3	6
Powell Creek & Tributaries	6	1	3	5	1	16
Cooper Creek Catchment	***102***	***16***	***45***	***54***	***39***	***246***
Cooper Creek	*90*	*10*	*21*	*23*	*19*	*163*
Kyabra Creek	3	5	14	2	0	24
Wilson River & tributaries	7	1	10	28	9	55
Other tributaries***	2	0	0	1	1	4
DIAMANTINA CATCHMENT	**38**	**21**	**35**	**55**	**60**	**209**
Diamantina River	*27*	*12*	*17*	*23*	*28*	*107*
Mayne River	1	1	1	1	2	6
Spring Creek	5	0	2	0	6	13
Farrars Creek	1	4	7	10	10	32
Morney Creek	2	1	0	3	0	6
Browns Creek	0	0	3	3	3	9
Other tributaries^†	2	3	3	10	6	24
Warburton River	*0*	*0*	*2*	*5*	*5*	*12*
GEORGINA CATCHMENT	**22**	**5**	**16**	**16**	**54**	**113**
Georgina River	*16*	*1*	*9*	*11*	*27*	*64*
Upper tributaries ^	0	0	2	2	0	4
Burke, Wills & Hamilton Rivers	3	1	1	0	8	13
Eyre Creek	*1*	*1*	*0*	*1*	*3*	*6*
King Creek	0	1	3	0	4	8
Mulligan River	*0*	*0*	*0*	*0*	*9*	*9*
Pituri & Linda Creeks	2	0	0	2	0	4
Sylvester Creek	0	1	1	0	3	5
TOTAL	**260**	**63**	**137**	**185**	**191**	**836**

* Includes Bullock, Cornish, Clunie, Prairie, Reedy, Torrens and Towerhill Creeks

** Includes Aramac Creek, Darr River, Katherine Creek, Maneroo and Alice Creeks

*** Includes Cunnavulla, Curalle and Whitula Creeks, all of which enter the Cooper south of Windorah

† Includes Cadell and Wockingham Creek (one permanent waterhole each), Carbine, Cobbonderre, Gidya, Kell's, Middleton, Saville, Umpadiboo, Whistling Duck and Whitulania Creeks and Western River

^ Includes Buckley River, Moonah Creek, Limestone and Sulieman Creeks; all enter above Urandangi

Table 9: Wet and dry: river reaches at opposite extremes

River/ System	Reach	Approx. Length (km)*	No. permanent waterholes**	Permanent waterholes per 100km	Max. distance between perm. WHs (km)
WET					
Cooper Creek (Cooper)	Keeroongooloo-Tanbar reach	180 (150)	51 (77)	**28.3** (42.8)	26
Thomson River (Cooper)	Lower Thomson, south of Stonehenge to Barcoo junction	105 (100)	20 (31)	**19** (29.5)	11
Barcoo River (Cooper)	Lower Barcoo, Jedburgh to Thomson junction	70 (65)	8 (16)	**11.4** (22.9)	11
Cooper Creek	Nappa Merrie & Innamincka (to north-west branch junction)	130 (120)	13 (28)	**10.8** (21.5)	20
Vergemont Creek (Cooper)	Mid-lower reach, from Vergemont to Thomson junction	110 (100)	11 (16)	**10** (14.5)	18
Powell Creek (Cooper)	Upper Powell Creek (Gooyeah to Hell Hole Gorge)	50 (45)	5 (6)	**10** (12)	15
Georgina River	Jimboola WH to Glenormiston eastern boundary	115 (100)	11 (18)	**9.6** (15.7)	15
Diamantina River	Diamantina Lakes (Hunters Gorge) to Monkira homestead †	150 (135)	10 (17)	**6.7** (11.3)	45
Diamantina River	Diamantina channels on Durrie and Roseberth	150 (130)	9 (32)	**6.0** (21.3)	45
DRY					
Cooper Creek (Cooper)	Lower Cooper, from Coongie Lakes to Lake Eyre	340 (260)	0 (0)	**0** (0)	340
Mulligan/ Eyre Creek system	Mulligan headwaters to junction with Diamantina	470 (400)	0 (9)	**0** (1.9)	470
Georgina River (Georgina)	Upper Georgina, headwaters to Jimboola	385 (320)	0 (13)	**0** (3.4)	385
Warburton River (Diamantina)	Goyder's Lagoon to Lake Eyre	240 (190)	0 (10)	**0** (4.2)	240
Farrars Creek (Diamantina)	Headwaters to Morney-Currawilla boundary	195 (190)	0 (15)	**0** (7.7)	195
Georgina River/ Eyre Creek	Marion Downs homestead to Mulligan River junction ^	300 (210)	1 (23) □	**0.33** (7.6)	240
Hamilton River (Georgina)	Entire length	240 (220)	1 (4)	**0.4** (1.7)	160
Diamantina River	Upper Diamantina, headwaters to Tulmur	240 (120)	2 (4) ††	**0.8** (1.7)	150
Burke River (Georgina)	Entire length	260 (220)	2 (7)	**0.8** (2.7)	250
Thomson River	Strathmore to Lochern NP northern boundary	100 (95)	1 (10)	**1** (10)	70

* Distance measured along watercourse; straight-line distance given in brackets

** Total number of permanent and semi-permanent (>70%) waterholes given in brackets; only includes waterholes on river or creek channel, not tributaries

† Includes waterholes on Spring Creek that are fed from Diamantina

^ Also includes Georgina River/King Creek complex, which flow parallel to Eyre Creek in this area

□Includes almost-permanent Glengyle Station WH, which has been dry once since white settlement

†† Includes permanent Conn Hole, which is at junction of the Diamantina and Wockingham Creek

4.3.3 Summary of individual catchments

The following section provides a summary of the major creeks and rivers of the Lake Eyre Basin, with reference to the major waterholes that occur along them. It is necessarily quite lengthy, however is arranged so that those interested in a specific river system or reach will be able to easily locate the relevant section. All information has been compiled using the methods discussed in Section 2. Figure 8 shows the distribution of waterholes (including Desert Uplands Lakes) in the Thomson and Barcoo catchments, while Figure 9 is the Cooper Catchment. Figures 10 and 11 show the distribution of waterholes in the Diamantina and Georgina catchments respectively.

4.3.3.1 Cooper catchment

Thomson catchment

The headwaters of the Thomson's major tributaries – Torrens, Prairie, Towerhill and Bullock Creeks – begin to the north. **Bullock Creek** heads on the southern side of the sandstone wall that divides the Thomson and Flinders catchments, and flows south to join Prairie Creek. There are narrow gorges and small rockholes with permanent water along sections of this creek, including in Moorinya National Park. **Prairie Creek**, which heads near the township of Prairie, in turn meets Torrens Creek on Prairie Vale. There apparently used to be more semi-permanent water on this creek system, but most waterholes have silted up and now last only 6-7 months, although an almost-permanent hole remains on Rainsby.

Torrens Creek heads in the Great Dividing Range and runs through the gap in sandstone wall. There are very few holes of any permanence on upper Torrens Creek. The first semi-permanent hole is the Hopewell/Wowra Hole near Hopewell House. The only permanent holes on Torrens Creek are on Aberfoyle, just before it is joined by Prairie Creek – these have not been dry in the past two decades. **Reedy Creek** overflows from Lake Dunn and flows east. The Four Mile Waterhole is the only permanent waterhole on this system. It joins Torrens Creek on Woolthorpe to form **Cornish Creek,** which flows west to join Landsborough Creek. There are numerous semi-permanent waterholes along Cornish Creek, and Buckleseas Waterhole is considered permanent, not having been dry in 60 years.

Towerhill Creek is the northern Thomson tributary with the most permanent water. Lammermoor has the greatest concentration of permanent water along Towerhill Creek, with four permanent holes (and a waterfall!). Downstream, many holes that were 6-8 feet deep had never gone dry in the past 100 years have silted up and went dry in the 2002 drought. Kirby's Waterhole on Biricannia, however, has not been dry in the past 90 years. Towerhill Creek joins Cornish Creek just before its junction with Landsborough Creek north of Muttaburra. **Landsborough Creek** is a wide, flat creek that flows through downs country and has no waterholes that last more than a few months.

The combined waters of these two tributaries forms the **Thomson River**. The Thomson runs most years, although sometimes very late (occasionally not until April). Between Muttaburra and Longreach, there are many semi-permanent waterholes but only four truly permanent ones: the Muttaburra Broadwater, Camoola Waterhole, Goodberry/Dilullah Broadwater and the Longreach Waterhole. In the 1902 drought, these were the only remaining water along this 100km stretch of river. **Aramac Creek** flows into the Thomson from the east, just below the Camoola Hole. It drains a large area, including the overflow from Lake Mueller. Water from Lake Dunn may even flow into it in wet years, via Lake Barcoorah overflow, Sandy Creek and finally Bullock Creek. There are numerous semi-permanent waterholes south of Aramac and some close to its junction with the Thomson, but the only natural permanent waterhole in the system is on **Rodney Creek**, near where it runs into Aramac Creek. This has not been dry in the past 15 years, including very dry times in early 2000s.

South of Longreach, there are three permanent waterholes between town and the Darr River junction: Rio and 8 Mile Waterholes in the main channel and the Kateroy Lagoon. The **Darr River** heads in downs country on Marita Downs east of the Landsborough Highway between Longreach and Winton. It flows south-south-east, but there are no natural semi-permanent waterholes. At Dahra, where it crosses the Landsborough Highway, there is a large permanent waterhole. From here, the river runs south-west until it joins Maneroo Creek just north of the Maneroo boundary. **Maneroo Creek** heads in the Selwyn Ranges south-west of Winton, and flows south-east. There is no permanent natural water on Maneroo Creek, although good semi-permanent holes occur from the Hartree Pump Hole (on **Alice Creek**) downstream. The Darr then flows south through Maneroo, a stretch with numerous semi-permanent waterholes, to the Thomson River.

Katherine Creek, which flows to the west of Maneroo Creek, heads on the range country on Melrose/Corona, flowing south-east, and meeting the Thomson on Rosabel. There are only a couple of small semi-permanent waterholes on this system. Between Longreach and Lochern, numerous small creeks flow into the Thomson from the south, draining the gidgee and downs country in this area. These include Ernistina, Four Mile and Tocal Creeks. There is no permanent or long-lasting water along these shallow creeks. From the Darr junction to Lochern, there are no permanent waterholes on the Thomson (although there are good semi-permanent holes around Bogewong). With a straight-line distance of 75km between the 8 Mile and Lochern, this is the longest stretch on the Thomson with no permanent water. There are two permanent waterholes on Lochern National Park, and a large off-channel permanent waterhole on Waterloo, just above where the Vergemont enters.

Vergemont Creek runs fast and often (3-4 times a year), and as a result there is water along the length of the river for many months of the year, and it contributes a lot of water to the Thomson. There are numerous small, semi-permanent waterholes near its headwaters on Fermoy. Once it gets down to Vergemont, the creek is constricted by range country, and there is a concentration of permanent and semi-permanent waterholes, both on the Vergemont and its tributaries. In fact, Vergemont Creek has one of the highest concentrations of permanent waterholes in the Thomson catchment. Permanent waterholes become less common heading south – the lower Vergemont is characterised by well-spaced permanent waterholes, interspersed with other less permanent ones.

From Stonehenge to the Barcoo junction, the Thomson is characterised by numerous long permanent waterholes, the largest of which are the Goon Goon, Carella and Jundah Waterholes. The 'Junction Hole' marks the southern extremity of the Thomson River – the Barcoo joins the Thomson at this point and it becomes Cooper Creek.

Barcoo catchment

The **Barcoo River** begins in the downs country just east of Tambo, with major tributaries Windeyer Creek and Birkhead Creek heading on the western slopes of the Great Dividing Range. This section of mountains is often referred to as the 'home of the rivers', representing the watershed dividing four major river systems: the Barcoo, Warrego, Fitzroy and Burdekin. From their common beginning, these rivers trace vastly different paths. The Barcoo first flows north-westerly through Tambo, where it is little more than a small coolibah-lined channel, dry for most of the year.

The first permanent waterhole in the system is at Swan Hill, which has not been dry in the past 80 years. In the Blackall district, there are a number of small permanent waterholes. However, it is not until after the junction of Ravensbourne Creek that the long waterholes for which the Barcoo is renowned become prevalent. **Ravensbourne Creek** heads in the Gowan Ranges, and therefore has a good catchment despite being a relatively short watercourse. It runs north to meet the Barcoo on Moorlands, west of Blackall. There are numerous semi-permanent waterholes along the creek, although many owe at least part of their permanency to historical excavation.

The river between Avington Station and Oma is known as the 'Fisherman's Highway'. There are large permanent waterholes at Avington and Coolagh. Near the Coolagh Hole, the **Alice River** flows into the Barcoo. The Alice flows south from its headwaters near Jericho, and its sandy bottom means that there is little semi-permanent surface water along its course. (In fact, the only two Barcoo tributaries with major waterholes on them are **Ravensbourne Creek** and **Powell Creek**.) After the Alice junction, the river turns south, and hereafter follows a general south-westerly course.

The 50km stretch of river that flows through Isis Downs is characterised by numerous small, semi-permanent waterholes. The next permanent waterholes are Killman and Oma Waterholes west of Isisford. Between here and the Jedburgh Waterhole, there are just three permanent waterholes spread over 100km: 30 Mile Waterhole on Gydia Park, Big Bull Waterhole on Mt Marlow and Stony Channel on Sedan. The latter is possibly spring-fed, as there is always some water in it when all other holes are dry. There are also numerous semi-permanent to almost-permanent waterholes along this reach.

Powell Creek heads in the Grey Range on Gooyea, near the southern boundary of Idalia National Park. Its major tributaries are **Nutting Creek** and **Spencer Creek**, both of which contain permanent waterholes. It flows south-west through Bulloo Lakes, filling numerous permanent waterholes, to Hell Hole Gorge National Park, where there are two permanent waterholes. Here it turns to the north-west and flows through Budgerygar and Wandsworth, receiving numerous other creeks which also channel run-off from the hard range country. There are numerous almost-permanent to semi-permanent waterholes along this reach, the most permanent of which are Muddingunyah and Lindfield Waterholes. Powell Creek usually runs at least once every year, but has gone for almost three years without a decent run. It runs into the Barcoo on Wandsworth/Sedan.

For its last 50km before the Thomson junction, the Barcoo consists of a series of long, deep permanent waterholes, including Jeburgh, Trafalga, Shed and Boomerang Waterholes. There are also numerous semi-permanent to almost-permanent waterholes. Holes in this area can get filled from local run-off as well as from the river, while the Thomson can also back up for some distance in floods.

Cooper Creek Catchment

The Cooper is Australia's largest braided stream and inland floodplain and harbours the most permanent waterholes of any stream in the LEB. Most of major waterholes are on western side of river. The Barcoo and Thomson Rivers meet to form the Cooper north of Windorah in the Haughton Vale/Coniston/Hammond Downs area. The Thomson can back the Barcoo up 20 miles, filling waterholes in this area, while the Barcoo can back about 14 miles up the Thomson when in flood. The confluence of these two rivers gives rise to a concentration of permanent waterholes. Although perhaps not as deep as waterholes in other stretches of river, they are filled regularly by one of the two rivers. There are numerous semi-permanent waterholes on Hammond Downs, and two large permanent waterholes near Windorah: Currareva and Mayfield, which have not been dry since white settlement.

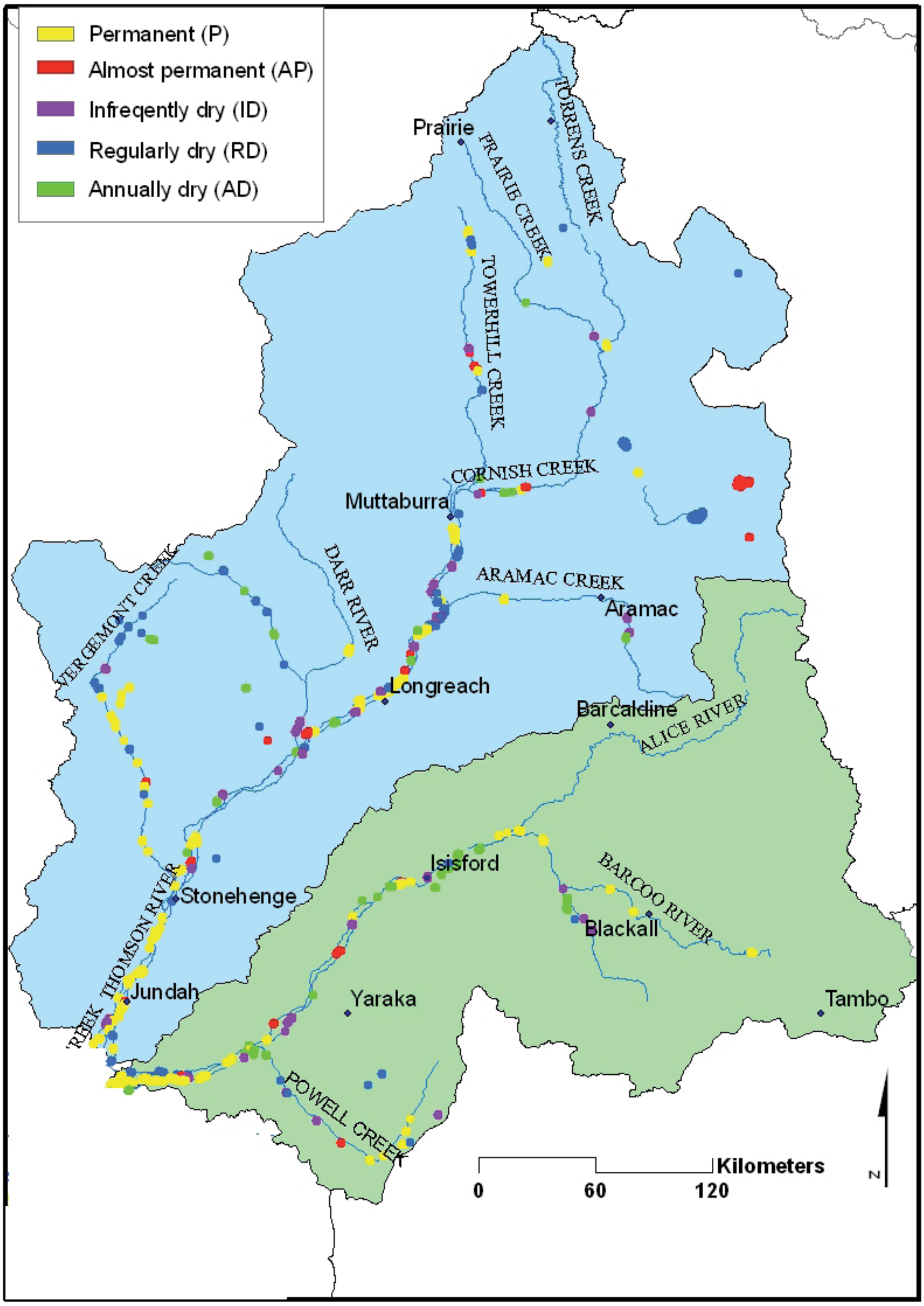

Figure 8: Waterhole permanence in Thomson and Barcoo River Catchments

Kyabra Creek runs into the Cooper from the east just south of Windorah on South Galway. It heads in the Grey Range on Thylungra, and flows south for about 100km before doing an abrupt 'U-turn' to the north at Kyabra. It flows easily off this rough country, and may run 4-5 times in a year. The waterholes at Thylungra, Bodella and Springfield are permanent, while there are good semi-permanent waterholes along its length, particularly downstream of Kyabra.

There are only four permanent waterholes on South Galway, plus one large permanent hole on Whitula Creek at the South Galway house. Keeroongooloo and Tanbar have the largest number of permanent waterholes in the LEB (>50), the longest of which is the 20km-long Eulbertie Waterhole. This preponderance of waterholes is a distinctive feature of the Cooper floodplain south of Windorah. Permanent waterholes become less common on Durham Downs. There are many small waterholes on Durham Downs, but all are shallow and go dry within 3-6 months of the river not running. There are only five holes that have never gone dry, and by November-December, there is very little water left across the property.

The **Wilson River** heads in the Grey Range on Mount Margaret and flows through Nockatunga and Naryilco, before joining the Cooper just before the South Australian border on Nappa Merrie. There are many small semi-permanent waterholes in the upper catchment, as it only takes a few millimetres to top waterholes up and two inches on Mt Margaret to run the river. Therefore, although the holes are small and relatively shallow, they usually have some water in them, either from local run-off or the Wilson River. The Wilson River often runs twice a year, however in 2002 (driest year on record) it did not run at all. In this year, waterholes such as Conbar that had not been dry in living memory dried up, and the only water left on Nockatunga were the three major permanent waterholes: Nockatunga, Noccundra and Nocoura. Further up on Mt Margaret, only Belalie, Mt Margaret house and Tooldoodoo Waterholes have not been dry in the past 14 years. The lower Wilson is characterised by a series of broad, semi-permanent waterholes on Naryilco and Nappa Merrie.

There are numerous permanent waterholes on the Cooper on Nappa Merrie, extending across the border into Innamincka Station. The Cooper crosses the border as a single channel with a number of deep permanent waterholes. At 18 metres cease-to-flow depth, Cullyamurra is the deepest waterhole in the Lake Eyre Basin. Other waterholes in the area are also permanent or almost so, including Nappaoonie, Burke, Mulkonbar, Queerbidie, Minkie, Tilcha and Maapoo Waterholes.

After these waterholes, the Cooper branches: most water travels along the north-west branch, and it is only in large floods that water begins to travel down the 'main channel' towards Lake Eyre. The north-west branch feeds the almost-permanent Scrubby Camp Waterhole, the permanent Tirrawarra Waterhole (has not been dry since white settlement) and, south of Coongie Lakes, the almost-permanent Kudriemitchie Waterhole, which has not been dry in the past 16 years. The channel becomes less defined in a maze of swamps, shallow lakes and dunefields in the

Coongie Lakes area (see Section 5). Heading west, the 'main channel' to Lake Eyre also morphs into shallow lakes and floodplains. Although it reforms into a channel closer to Lake Eyre, there are no more waterholes of note in this section. **Strzelecki Creek** is situated south of the Cooper, however its sandy bottom does not harbour any lasting waterholes. In times of high flood, water overflows from the Cooper into the Strzelecki.

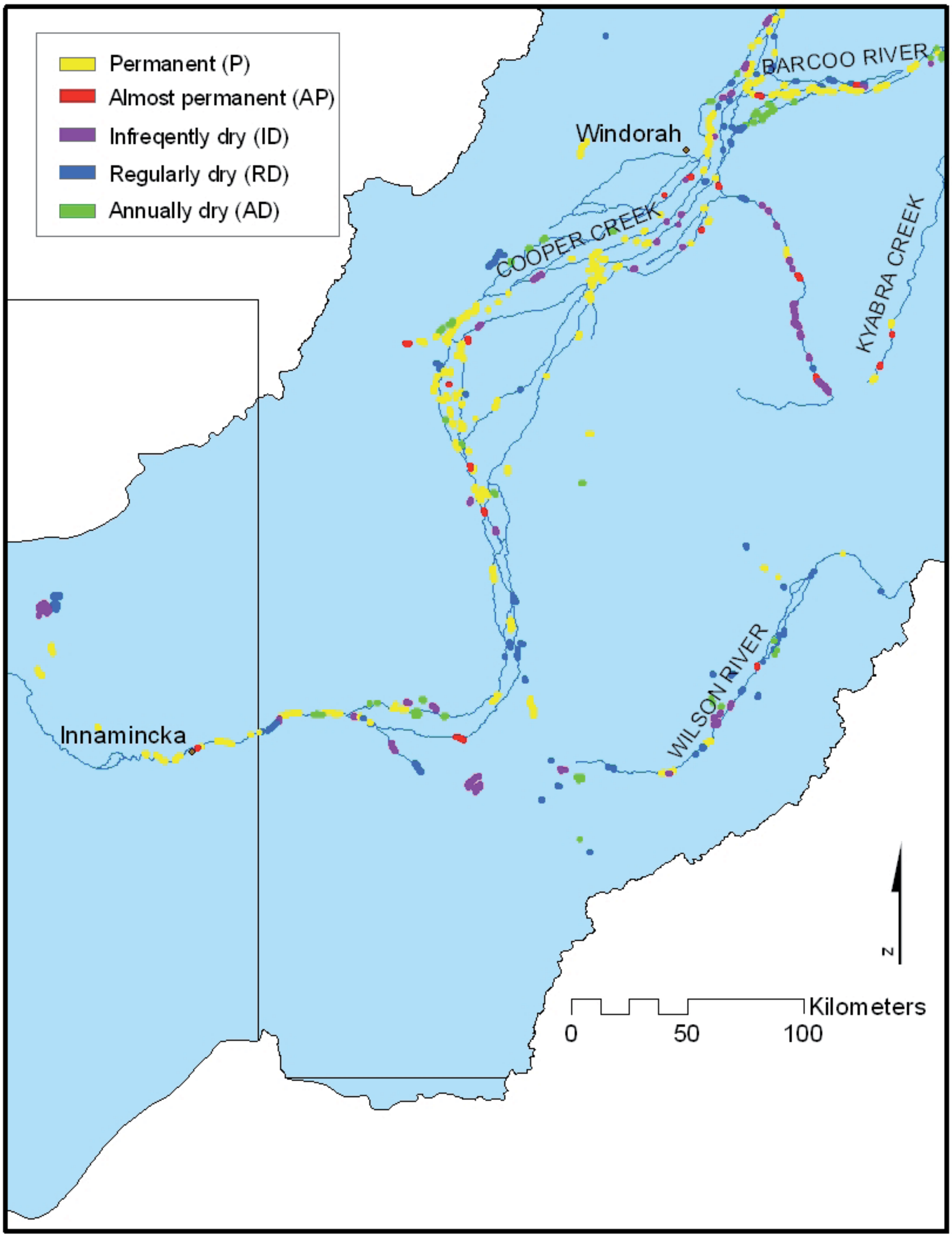

Figure 9: Cooper Catchment Waterholes (n.b. no >70% waterholes occur west of Coongie Lakes)

4.3.3.2 Diamantina catchment

Upper catchment (headwaters to Brighton Downs)

The Diamantina River heads in the remote and rugged ranges of the Kynuna Plateau, and flows north-west for a short distance, before turning to the south and ultimately assuming its general south-westerly course. The range country of the upper Diamantina on Brackenburgh hides many small but permanent rockholes (Section 6), and a couple of waterholes. After this, however, there are no permanent natural waterholes on the upper Diamantina – the most permanent ones are generally dry by June/July, although can be topped up and last longer in good seasons. Combo Waterhole is the most well-known and permanent hole in this reach, however without the overshots it would also only last for about six months. As such, there is a huge 'waterless triangle' from the Diamantina headwaters to Conn Waterhole across to the Darr River and north towards Julia Creek.

The first major permanent waterhole in the Diamantina system is the Conn Hole west of Winton, at the junction of Wockingham Creek, Western River and the Diamantina. The Diamantina from here to Diamantina Lakes is characterised by well-spaced permanent waterholes (the largest of which is Old Cork), interspersed by smaller, semi-permanent to almost-permanent waterholes. From Old Brighton Waterhole on Verdun Valley to Diamantina Lakes there are no permanent waterholes >100km, and only scattered semi-permanent holes. Numerous creeks flow in from the ranges in the north, including Cadell, Middleton and Mackunda Creeks. Although they run fast and contribute substantial volumes of water to the Diamantina, they do not generally harbour lasting water.

Cadell Creek flows into the Diamantina on Cambeela, upstream of Old Cork Waterhole. It heads in the range/ridge country on Boolbie, then flows south through Woodstock, picking up tributaries such as Middleton and Fletcher Creeks, which channel water from similarly hard country. Cadell Creek feeds the Gin Holes (Big Gin Waterhole is permanent) on Cambeela. A creek known locally as the 'Two-way Creek' connects Cadell Creek and Diamantina River – it runs either from Cadell Creek into the Diamantina or vice versa, depending on where rain has fallen and which watercourse is running. As a result, the waterholes on the outer channels of the Diamantina on Cambeela (including permanent Mundurin and Tail Yard WHs) can fill from either Cadell Creek or the Diamantina River, increasing their permanence. The **Mayne River** enters from the east just above the Diamantina National Park boundary. There is a permanent waterhole near its headwaters at Rocky Crossing, but only occasionally semi-permanent holes along the remainder of its 120km length.

Mid-reaches (Diamantina Lakes to Birdsville)

The mid-Diamantina reach, between Diamantina Lakes and Birdsville, contains classic "Channel Country" morphology, and the majority of the catchment's permanent waterholes. Near the Diamantina NP homestead, the channels are constricted between the Goyder and Hamilton Ranges, forming two major permanent waterholes (Mundaweira and Wangrei). A smaller hole between them seems to be almost permanent – no one has seen it dry, but all those interviewed suspected it would go dry in big droughts. This was a common theme where a relatively small waterhole occurred very close to major permanent waterholes – it was often not observed as closely as isolated waterholes of a similar size.

Spring Creek heads near the Georgina watershed, and flows south from Elizabeth Springs. Warracoota Waterhole on the Diamantina Lakes/Springvale boundary is the first permanent waterhole on this creek. Downstream, there are many relatively shallow, flat waterholes on Spring Creek to the west of the Diamantina, where the creek winds between sand dunes. These are generally semi-permanent, and last between 6-10 months of the year. However, Paraputcheri Waterhole is permanent, as are Coota, Mooradonka and Peleenah Waterholes on Davenport Downs. All these waterholes receive water from the Diamantina in moderate flows. After the junction of Spring Creek, there are no lasting waterholes until Mackara Waterhole near the Monkira house.

Numerous creeks head in the hard country on Tonkoro near the Diamantina-Cooper watershed, and join to form **Farrars Creek**. Farrars Creek flows through Connemara, Davenport Downs, Currawilla, Morney Plains, Mooraberrie and the northern end of Mt Leonard. In the upper catchment, most waterholes last 6-8 months, and are not regarded as reliable waters. There are, however, a scattering of small semi-permanent waterholes that get filled easily from run-off on the hard country. On Davenport Downs, there are numerous semi-permanent waterholes, the biggest of which is Big Booka Waterhole. On Currawilla, all waterholes on Farrars and Cudgebulla Creeks are semi-permanent. Although there are no deep holes (they last between 4-11 months), it only takes an inch of rain on the hard country in the catchments of these creeks, or local rainfall, to fill these waterholes. There is one permanent spring-fed waterhole on Spring Creek, a tributary of Cudgebulla Creek.

The far north-eastern corner of South Australia (Cordillo Downs) is dominated by small, stony creeks with many small waterholes that last between 3-6 months (some have been excavated). Only two holes could be classed as semi-permanent: Jurie and Cadelga Waterholes. These last for 12 months, and dry out about 3-4 times a decade. All creeks run from local rainfall, so the permanency of the waterholes in any year depends upon timing and amount of rainfall. These creeks run north into Queensland, and after making their disparate way through sandhills and small, semi-permanent waterholes on Mt Leonard, they form **Browns Creek**. Flowing north through Betoota, it meets the Diamantina after filling a series of large, almost-permanent waterholes west of Betoota.

The drainage around the Mt Leonard area is particularly perplexing: many waterholes can fill from either the Diamantina River, Farrars Creek or Brown's Creek depending on flooding, and if rain falls to the south, creeks can run 'backwards' from Durrie. Farrars Creek meets a similarly confusing end in this quagmire of drainage, flowing north-west into Mooraberrie and filling Kingadurka Waterhole before spreading out onto the Diamantina floodplain. In big Farrars floods, this water can run back down to waterholes on Mt Leonard. On topographic maps, many waterholes are marked on Durrie and Roseberth. In reality, all but a handful of these go dry: there are only seven permanent waterholes across both properties, with most waterholes considered semi-permanent at best.

<u>Lower Diamantina (Birdsville to Goyder's Lagoon)</u>

The Diamantina is a single channel south of Birdsville. This deeply incised main channel is known as the 'Pandie Channel', and contains good permanent water, particularly south of the Pandie Pandie homestead. These holes are not particularly deep, but receive water every time the river runs (i.e. yearly since 1950, as even a storm on Durrie can send water down to top these waterholes up). There are numerous other sizeable waterholes on Pandie Pandie, but these are off the main channel and require a decent flood to fill them (although they can be topped up from local rainfall). Such a flood occurs once every 3-4 years, after which Dickeree and Eight Mile Waterholes hold water for 12-18 months. Without rainfall, they can then be dry for over 12 months, or until the next flood comes. For example, Appamurra WH can last 18 months to 2 years, but only gets filled irregularly because the river has to be quite high to run into this waterhole. As a result, it is probably dry for about 50% of the time.

The Pandie Channel then flows down to the permanent Yammakira Waterhole at Clifton Hills Outstation, which has not been dry in the past 80-100 years. After this, the channel spreads out and the only other semi-permanent waterhole is Koonchera Waterhole at the northern end of Koonchera dune, which goes dry every year. The Andrewilla Channel has a small sill at the upper end of it, but has still received water nearly every year since 1950. However, anecdotal evidence suggests that it has been dry once in the past 80-100 years (Costelloe *et al.* 2004). The 1974 flood scoured out the channel, so now the river only has to run at 3m to fill Andrewilla Waterhole. There are no other lasting waterholes between here and the Eyre Creek junction.

<u>Warburton River (Goyder's Lagoon to Lake Eyre)</u>

The Diamantina joins Eyre Creek (Georgina catchment; see below) just above Goyder's Lagoon, an extensive ephemeral wetland of some 1300km^2. Here the channel becomes the Warburton River, which is a well-defined channel that usually runs every 12-18 months. Goyder's Lagoon marks an ecological boundary of sorts – above the Lagoon, waterholes tend to stay fresh, while below it, most go salty within 6-12 months of filling (depending on time of flow, height of flow etc). As such, the defining factor in the refugial 'value' of these waters is not how long the water lasts, but whether it goes salty.

The only significant freshwater waterhole between the semi-permanent Goyder's Lagoon Waterhole and the 'junction' is Yelpawaralinnia WH, which forms the boundary between Clifton Hills and Cowarie. It is relatively long and deep, and holds water for many months with no input. Opinions differ regarding its pastoral utility, as it tends to go salty, and it was mapped as 'infrequently dry' for this project. There is one branch before Lake Eyre is reached – Kallakcopah, which runs to the west of the main channel, is only filled in high flows. When the Warburton gets to half a channel flow, most of the water is directed down Kallakoopah channel. This branch is not regarded as a good flow. Normally all the water goes down the Warburton, as the main channel is filled after the branch. There are two waterholes, one just above the junction and one below, both of which go salty after 9-12 months.

After the junction, on the Kallakoopah channel, there lies perhaps the most reliable fresh water on Cowarie: between 'Top Hole' and Kuncherinna WH there is a 10km waterhole, although it is very flat bottomed and only about 20ft deep. It retains water for 12 months and usually gets topped up before this time, but it has been dry for more than 50% of the past three years (prior to this it was only completely dry once in 20 years!). Further down, Lumbkin's Hole (Anarowidinna WH on topos) is also fresh, and lasts 9-12 months without input. It has been dry a few times in the past 25 years. The other waterholes in the cluster in this area go salty before drying up, and you can really only rely on 6-9 months of fresh water after a good flow. Emu Bone is regarded as the most 'useful' waterhole on the main channel. There are numerous other small waterholes in the area, but none which can be regarded as semi-permanent as they are not filled as often and/or go salty, so many are effectively dry for about half the time.

Further south along the Warburton, Yellow and Stony Crossing Waterholes usually have water in but it goes salty. To the south, freshwater Tarawillinna Waterhole is on Derwent Creek, which flows north from Mungerannie and can be filled from 1.5 inches on Mungerannie hard country. This creek then flows into the Warburton. Both these holes would make it into the semi-permanent category, but as they are filled from local run-off, they have both been dry for the past 2.5-3 years. The final lasting waterhole on the system, Wild Dog Hole on Kalamurina, seems to last quite well and contained fresh water throughout winter 2007, despite very dry conditions. The current managers have only been on the property for two years, so permanence data is inconclusive for this waterhole. It is mapped as 'infrequently dry' pending further information.

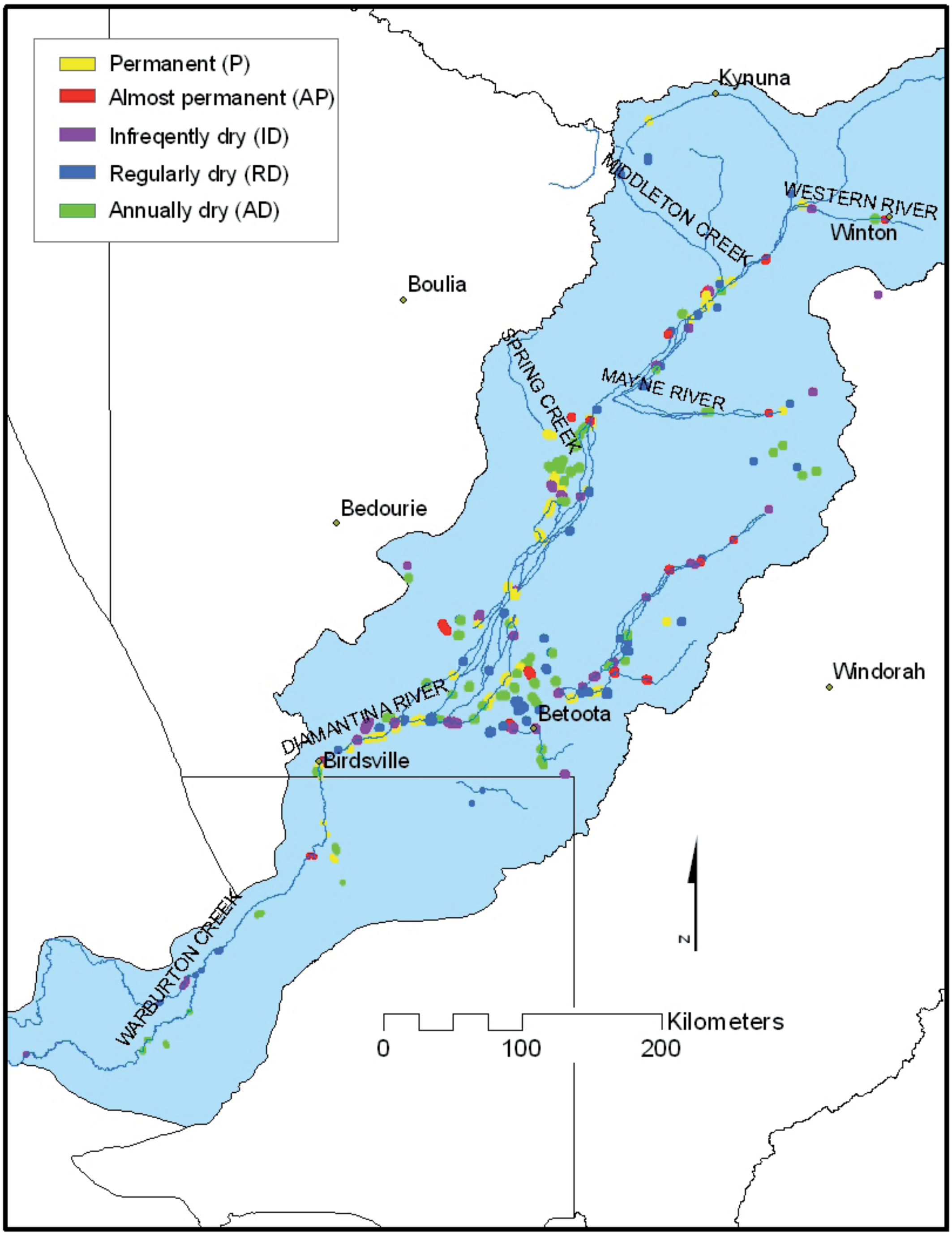

Figure 10: Diamantina Catchment showing waterhole permanence

4.3.3.3 Georgina catchment

The **Georgina River** begins in the Northern Territory on Rocklands, and flows into Queensland north-west of Camooweal. Three large, flat semi-permanent lakes dominate the Georgina in the Camooweal district. Lakes Mary, Francis and Canellan will all go dry if there is no run in the river or rainfall to top them up by December (although Mary and Canellan have been dug out, increasing their permanency). They can also be topped up from **Chester Creek**, which runs off hard country to the east of the river north of Camooweal. There are two semi-permanent waterholes on Chester Creek, while there are a couple of large semi-permanent waterholes (less permanent than the Lakes) on the Georgina on Rocklands.

South of Camooweal, the Georgina flows west into the Northern Territory for some 100km (the largest waterhole in this section is Lake Nash). It flows back into Queensland on Barkly Downs, and there are numerous semi-permanent waterholes and off-channel lagoons on Headingly, most of which go dry by the end of the year. Lake Marian is the most permanent of these, and will only go dry if the river doesn't run for more than 12 months. The **Templeton River** flows into the Georgina just north of Headingly homestead, and can contribute a substantial volume of water from the hard country around Mt Isa and May downs. Downstream, there is an almost-permanent waterhole near Mungala Yards, which has only been dry once in living memory (1986). **Moonah Creek** flows in from the north-east just below this waterhole. There is a semi-permanent spring-fed waterhole on Moonah Creek, near its headwaters in the ranges south of Mt Isa.

The first 100% permanent waterhole in the Georgina system is the impressive, 17-mile-long Jimboola or Walkabee Waterhole. Like many waterholes from here south, it is spring-fed, and has never been dry. Roxborough Downs has numerous permanent spring-fed waterholes, which turn clear and foul-smelling towards the end of the year. The largest of these are Lake Katherine, Lemo Waterhole and Smokey Waterhole. Glenormiston has the most permanent and semi-permanent water of any property in the Georgina catchment, with numerous spring-fed waterholes on the river. Some of these, such as Basin and Midgingar, are large waterholes, however most dry right back to small spring-fed puddles during dry times. **Pituri Creek** heads in the ranges on Linda Downs near the NT border, and joins the Georgina just east of the Glenormiston homestead. There are two semi-permanent lakes (Wonditti and Idamea) on the creek, which runs easily from rainfall in its hard catchment.

One of the most geographically isolated and interesting permanent waters in the catchment lies within Toko Gorge on the NT border. This narrow gorge on Linda Creek harbours pools of permanent water, which is 60km from the nearest semi-permanent water (Lake Wonditti) and over 85km from the nearest permanent water (Basin Waterhole), across inhospitable arid range country. It is probably spring-fed, but very little is known about this oasis amongst the extremely rugged and inaccessible arid ranges on the Queensland border. Groundwater contributes to waterhole permanence in the NT section of the Toko Range (Box *et al.* 2008).

There is a large concentration of semi-permanent to almost-permanent waterholes on the Georgina on Marion Downs. However, Paravituri Waterhole on Badalia, Marion and Wirrilyerna, is the only permanent waterhole along this reach of river. It is spring-fed and, although it has never been dry, it becomes extremely salty. The **Burke River** flows into the Georgina just below this waterhole, however it can also back up and feed Paravituri. The Burke heads in the stony ranges near Duchess and follows a southerly course, receiving numerous creeks from the system of ranges in this district. The largest of these are the **Mort River**, which begins in the ranges on Chatsworth, and **Wills River**, which runs from south of Mt Isa (**Sulieman Creek** is also a major feeder stream of Wills Creek). There are numerous waterholes marked on the Burke River. However, the sandy nature of the river means that very few of these waterholes could be classified as semi-permanent, although water is present underground for most of the time. Munuka, Barracks and Beantree Waterholes are notable exceptions; the latter two have not been dry in the past 60 years.

The **Hamilton River** heads in the rocky hills around Cannington, and follows a general south-west course to meet the Georgina south of the Marion Downs homestead. There are some semi-permanent waterholes on the lower reaches of the Hamilton, and Bulla Bulla Waterhole has not been dry in the past five decades. There are numerous springs in this area, and higher up on the Hamilton (mostly inactive), and it is possible that this waterhole is spring-fed.

Much of the Hamilton water gets channelled down **King Creek**. The sections of the Georgina and King Creek on Coorabulka have no permanent water. The ashy soil means that creeks need a big run to get into the waterholes, and most of them are quite flat and shallow. Most waterholes along King Creek on Cluny only get filled once every 2-3 years, and although they may hold water for 8-14 months, they don't have water in them for >70% of time overall. The exceptions are a cluster of semi-permanent holes on the main channel (Cluny House, 3 Mile and 5 Mile Waterholes). These don't need a big flood to fill, as they can receive water from relatively local rainfall. King Creek flows into Eyre Creek on Cluny, south of Bedourie.

Just north of the Coorabulka/Marion Downs boundary, the Georgina splits: from here on, **Eyre Creek** flows to the west of the Georgina River, following a course slightly west of south through Coorabulka, Sandringham and Kamaran Downs to Bedourie. There is very little semi-permanent water on this portion of Eyre Creek, with only two holes (Taradi on Coorabulka and Moorabulla on Sandringham) holding water for any length of time (although both go dry regularly). It then flows south through Cluny (where King Creek joins) and Glengyle, where if fills the major almost-permanent waterhole of the system at Glengyle Station – it went dry for the first time since European settlement in late 2008.

Eyre Creek turns abruptly to the west, flows though two shallow Lakes (Mipria and Koolivoo) and on through a series of semi-permanent waterholes. Floods rarely make it past Pampra Waterhole and as such, most waterholes only fill once every three years (although they may then hold water for between 6-12 months). Pampra, Bunk and Tomydonka waterholes are the only >70% waterholes in this section. Pampra and Bunk are both filled in ordinary floods (i.e. most years), however Tomydonka waterhole is permanent, despite only being filled once every three years. This is the only permanent waterhole in the Eyre Creek system, and is isolated from other permanent water by almost 100km (Beppery springs on Kamaran Downs); it is 185km 'as the crow flies' to the nearest permanent waterhole, Paravituri on the Georgina. It is apparently not dependent upon groundwater flows to maintain its water level.

Eyre Creek then flows into the north-eastern corner of Adria Downs. After flowing through a series of small, excavated (naturally <70%) waterholes then into Taranga Waterhole (<70%) it turns south and flows into Muncoonie Lakes. If the flood is big enough, it backs up to the north-west into Kuddaree Waterhole.

The **Mulligan River** is the most westerly of the major drainage lines in the Georgina Catchment. (The more westerly **Field River** and **Gnallan-a-gea Creek** get soaked up in the sand dunes of the eastern Simpson Desert, and contain no permanent or semi-permanent waterholes). The Mulligan system begins on Cravens Peak, where Ripunthala Creek heads near the Northern Territory border, flowing south-west through Glenormiston to meet Sylvester Creek and form the Mulligan on the boundary of Marion Downs and Ethabuka. There are numerous large semi-permanent waterholes in this area, on Kamaran Downs and the northern half of Adria Downs, from Pulchera to Kuddaree Waterhole. These generally wide, flat holes are 6-8 feet deep and hold water for between 8-12 months. They are mainly filled from local rainfall on claypans in their small catchments, as the Mulligan only floods once every 4-5 years (or 5-6 times in 30 years). As a result, they can be completely dry for years at a time. David Brook estimates that waterholes such as Pulchera are completely dry for 1-2 years out of five. All of these waterholes can go a bit salty, but Kalidewarry on Adria Downs is the only one that goes extremely salty.

In big floods, Eyre Creek flows into the Mulligan (or vice versa, according to the topographic maps, which mark Eyre Creek as continuing south after this confluence) north of Kalidewarry. However, water rarely continues south of Muncoonie Lakes/Kuddaree Waterhole to reach waterholes further south. This happens about once a decade, most recently in the May 2007 floods. There is no permanent water on Eyre Creek south of the border, as floods only make it down that far irregularly (9 times in past 60 years). Holes on Alton Downs hold water for 12-13 months after filling, but may be dry for years at a time. These holes don't fill from local rainfall, as the ground is so deeply cracking. The series of small waterholes on Clifton Hills receive water only about one in four years on average.

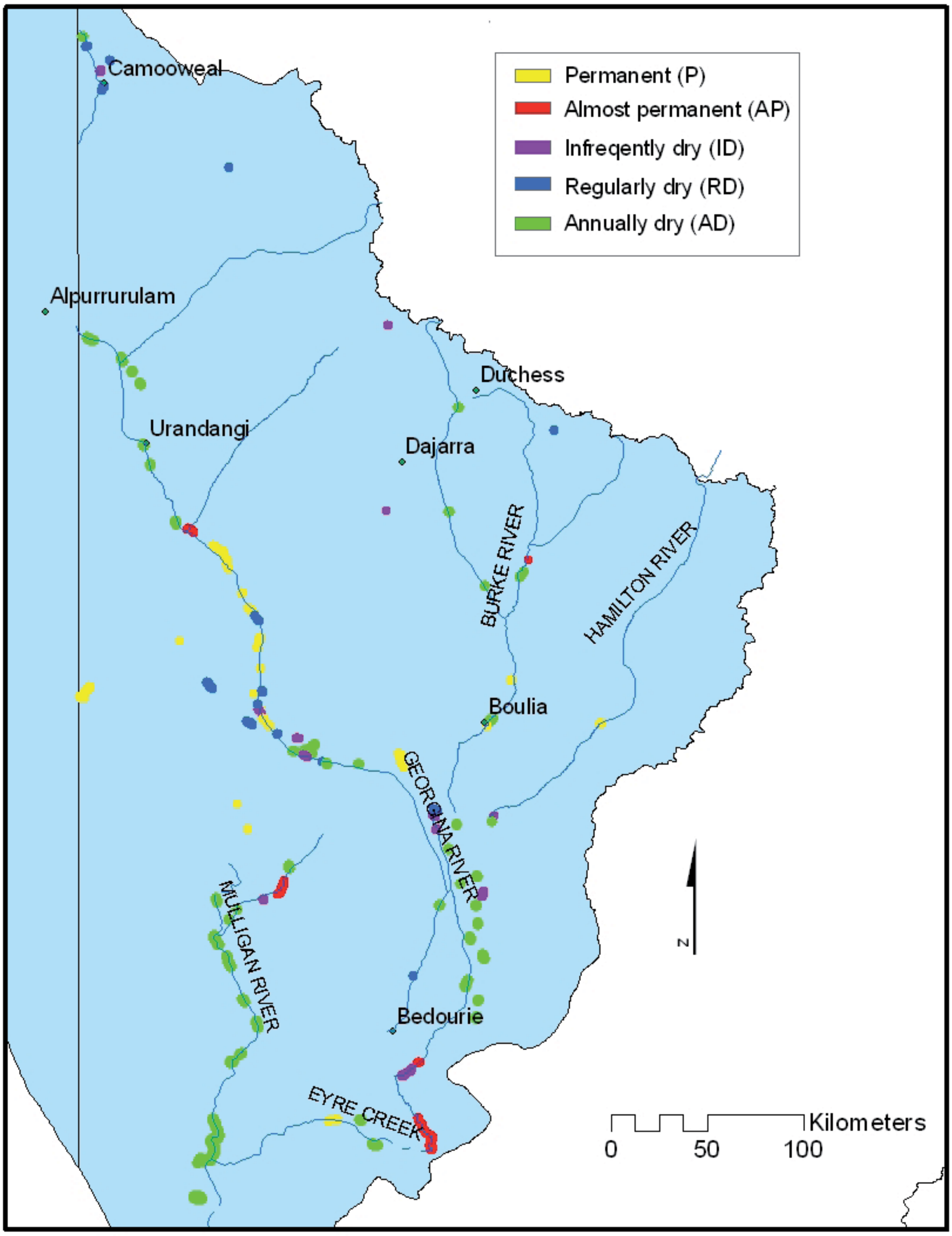

Figure 11: Georgina-Mulligan Catchment, showing semi-permanent and permanent waterholes

4.4 Waterhole ecology

LEB waterholes provide long-term storage in a highly variable and overwhelmingly arid environment, and thus have ecological implications that far exceed the tiny surface area which they occupy. They give rise to a distinctive biotic assemblage, and function as 'refuges' for a variety of fauna species. The following section explores the ecology of LEB waterholes with respect to general character, vegetation and fauna.

4.4.1 General character

The 'dirtiness' of waterholes is often commented on by uninitiated visitors, and many are reluctant to plunge into such an apparent quagmire, even on a hot day. Most waterholes in the LEB have clay banks and their catchments lie in clay soil country. The major rivers transport predominantly clay-rich mud loads with high suspended sediment contents (McMahon *et al.* 2008b), explaining the opaque or brown water. Bunn *et al.* (2006) report that mean photic depth (i.e. 1% of ambient light) was less than 23cm in 30 western Queensland waterholes measured.

There is an assumption, probably correct in the LEB, that high turbidity levels are 'natural'. However, Reid & Odgen (2006) suggest that there is some evidence that waterholes may not have been as turbid prior to European settlement. Travelling along the Darling near Bourke in 1831-2, Thomas Mitchell wrote that 'The water being beautifully transparent, the bottom was visible at great depths, showing large fishes in shoals, floating like birds in mid-air' (Mitchell 1939). Later in his travels, he remarked on the 'sparkling transparency' of the water. Waterholes in this area are certainly not sparklingly transparent today, and there would be no chance of seeing any fish in the turbid water (pers.obs.). However, the earliest observations available in the LEB suggest that the turbidity of waterholes preceded widespread pastoral use of the area.

Waterholes along creeks and rivers that begin in, and pass primarily through, sandy or rocky country and those that are spring-fed are notable exceptions. The Burke River (and its tributary the Wills River) stands out in this regard: it heads in the ranges south of Mt Isa, and its sandy bottom gives rise to relatively clear water along its length. 'Outsider', a prolific correspondent to newspapers in the 1870s, likened his arrival at the Burke to finding an oasis in the middle of the African Desert, describing the water as 'splendid': *'All the water in the Diamantina, Hamilton and Herbert – and in fact all the rivers in the Far West except the Burke – is a sort of pea soup colour…whereas the water in this river is most beautifully clear and remarkably nice tasted'* (cited Nolan 2003, p.45). However, there is a considerable trade-off at play here, as permeable sandy bottoms don't hold water like their clay-bottomed counterparts, and while the water may be clear, it doesn't tend to last very long (Figure 12a) – only two waterholes along the length of the Burke are regarded as permanent (Figure 12b), and even semi-permanent waterholes are few and far between. Indeed, 'the greedy sand soaks up every drop of water' (Carnegie 1898).

Figure 12: (a) wide, sandy bed of Burke River east of Phosphate Hill and (b) Barracks Waterhole north of Boulia, one of only two permanent waterholes on the Burke

Visitors to the Georgina River may be surprised by the clear, aqua-tinged water in waterholes such as Jimboola, Lake Katherine and Paravituri, given that it rises on the vast clay plains of the Barkly Tableland. This clarity is due to the springs that characterise the permanent waterholes of this system, filling them with clear subterranean water. Upper-catchment waterholes in rocky situations, such as those found on the upper Mayne River, are surrounded by stony country and have rocky substrates. The water in these holes tends to be clearer than clay-soil waterholes.

Figure 13a-d: Contrasting waterholes: (a) spring-fed Mt Guide waterhole, Moonah Creek, upper Georgina tributary; (b) spring-fed Georgina waterhole; (c) typical clay-soil waterhole on upper Thomson River; (d) rocky waterhole on Mayne River

4.4.2 Vegetation

The vegetation surrounding waterholes, and indeed all creek and river systems in the LEB, contrasts sharply with the surrounding landscape. This contrast becomes increasingly marked in the harsh, arid environments in the western and southern portions of the study area, where tree-lined oases are nestled somewhat incongruously amongst sand dune deserts and stony plains. In effect, rivers represent small 'corridors of verdure' amidst the desert. Despite being widely-spaced along numerous disparate river systems, waterholes across the Lake Eyre Basin are remarkably similar in terms of vegetation. The major exceptions to the general discussion below are the broad, semi-permanent waterholes along the Mulligan River, where the adjacent environment is more saline. Coolibahs are not as closely-spaced along these waterholes, and the fringing vegetation is often an open herbfield of sedges, samphires and other forbs (Figure 14).

Figure 14: Pulchera Waterhole, Mulligan River

In general, however, a distinct vertical zonation of the common riparian species can be observed around waterholes in the study area: the coolibah zone occurs around bank-full depth, while lignum tends to grow lower down at the cease-to-flow depth. Where river red gums are present, they tend to occur just above the cease-to-flow depth. More ephemeral vegetation such as sedges, grasses and herbs often occupies the area between the current water level and lignum level, suggesting that these species are able to retreat and advance as the water level varies (Costelloe *et al.* 2004).

Visually, waterholes are dominated by one or both of two representatives of the quintessential Australian gum tree – coolibah (*Eucalyptus coolabah*) or river red gum (*E. camaldulensis*) (Figure 15). Coolibahs, the tree that so epitomises respite from heat and holds such a central place in inland folklore, tend to occur where soils are more clay-dominated, and can spread back from the river to cover vast floodplains. It is the species that is most characteristic of the permanent and semi-permanent waterholes across the LEB. River red gums tend to dominate in sandier situations.

Despite being the most widely-distributed of Australia's >500 eucalypts (Brooker & Kleineg 2007), it is mostly restricted to waterholes on the lower Thomson and Cooper, and the upper catchments of other tributaries across the Basin. River red gums require seasonal flooding for their survival, and can tolerate being inundated for several months. They produce seed freely, and dense thickets of saplings may appear after floods, which gradually thin themselves out. River red gum has one of the fastest growth rates for a tree – with a good water supply, a tree can attain a height of 12-15m in just a few years.

Riparian plant communities in desert river ecosystems represent the most structurally complex plant communities in these ecosystems, and provide critical fauna habitat (Brock *et al.* 2006). In the absence of macrophytes in the turbid waterholes of the LEB, riparian vegetation types provide important aquatic habitat for a range of biota (Costelloe *et al.* 2004). The dominant eucalypts, along with other riparian species, play a vital role in maintaining riparian ecology. Standing trees provide bank stability, while fallen trees and branches slow the flow or water, trap sediment and nutrients and create ponds. This extends the period that water is available, and provides a feeding ground and protection for aquatic fauna. Mature trees may provide shelter and nesting sites for many species of birds, mammals, reptiles and frogs, as well as thousands of invertebrate species.

Figure 15: Coolibah (left) and river red gum (right): the two trees which epitomise LEB waterholes

Tea-trees (*Melaleuca* species) are also a distinctive component of many waterholes, often forming clumps in relatively sheltered areas where stream flow is not so vigorous. Tea-trees seem to prefer perpetually 'wet feet', so rarely grow far from permanent or semi-permanent water. Black tea-tree (*Melaleuca trichostachya* var. *linariifolia*) is by far the most common species throughout the LEB, occurring across all river systems (Figure 16). Silver paperbark (*Melaleuca argentea*) grows to an impressive stature along the Georgina River waterholes, while the similarly umbrageous *M. fluviatilis* lines creeks in the Desert Uplands in the north-east of the region (Figure 16).

Figure 16: *Melaleuca trichostachya* thicket on Longreach Waterhole, Thomson River (left) and *Melaleuca fluviatilis* on Four Mile Waterhole, Reedy Creek (right)

Bauhinia or bean tree (*Lysiphyllum gilvum*) is scattered along the banks of many waterholes, as is sally wattle (*Acacia salicina*). The root-parasite true sandalwood (*Santalum lanceolatum*) is often hidden beneath the canopies of other trees. Creek wilga (*Eremophila bignoniflora*) and belalie (*Acacia stenophylla*) are two distinctive tall shrubs of waterholes and surrounding floodplains. Gidgee (*Acacia cambagei*; *Acacia georginae* on the Georgina system) occurs in patches adjacent to the river, usually where the soil is sandier and/or with surface pebbles. Mistletoes go unnoticed for much of the year, but become conspicuous when flowering. Along waterholes, they seem to have a particular penchant for red gums and tea-trees (Figure 17).

Beneath this riparian forest, the tangled mass of lignum (*Muehlenbeckia florulenta*) often extends down to the water, in some cases lining much of the bank. Lignum persists through dry times as dormant stems, producing leaves and flowers in response to flooding (Brock *et al.* 2008). The permanent waterholes of the Georgina River are home to perhaps the largest lignum clumps in the Lake Eyre Basin (Figure 18). Queensland bluebush (*Chenopodium auricomum*) is often dominant on adjacent floodplains, but also occurs along the banks of waterholes. The prickly vine wait-a-while or split-jack (*Capparis lasiantha*) occurs across a variety of habitats, but seems to be particularly common near rivers and creeks, in season providing tasty fruits for the keen-eyed waterhole visitor (Figure 17).

Figure 17: Mistletoe on river red gum and wait-a-while on coolibah, Rocky Crossing, Mayne River

Figure 18: Dense lignum community, Jimboola Waterhole, Georgina River

The ground flora surrounding most waterholes is relatively floristically depauperate. Perennial grasses and forbs are naturally rare on the portion of the bank that is regularly scoured by flood waters. Where grazing pressure is not heavy, perennial grasses such as the stoloniferous rat's tail couch (*Sporobolus mitchellii*) and the tussocky Warrego grass (*Paspalidium jubiflorum*) often dominate further back (Figure 19). Most plants managing to survive in the path of fast-moving flood waters are short-lived 'pioneer' forbs, such as joyweed (*Alternanthera* spp.), cudweed (*Pseudognaphalium* spp.) and sneezeweed (*Centipeda* spp.), which colonise bare channels after floods and rapidly complete their lifecycle. Bare-foot waterhole visitors may unwittingly discover the common black roly poly (*Sclerolaena muricata*) or, perhaps more unpleasantly, the dried spiny fruits from old plants. Ground flora composition will vary with season, with summer floods tending to promote grass growth and winter rainfall or flooding producing herbage (Brock *et al.* 2006).

Figure 19: Grassy riverbank, Jundah Waterhole, Thomson River: *Paspalidium jubiflorum* dominant, with some *Sporobolus mitchellii* and nardoo in foreground

Sedges (mostly *Cyperus* species) commonly line the banks of more permanent waterholes (Figure 20). After floods, nardoo (*Marsilea drummondii*) may be very common in the riparian zone and across extensive areas which have been inundated. Nardoo is a semi-aquatic fern, and begins its life floating on the surface of shallow water, supported by long, spaghetti-like roots. Other semi-aquatic plants include knotweed (*Persicaria* spp.), which can extend out into a waterhole for a considerable distance, and is often perceived to be 'choking up' the waterhole (see Section 4.6), and water primrose (*Ludwigia peploides*).

Figure 20: Knotweed or smart weed (*Persicaria* sp.), Noccundra Waterhole (left) and sedges (*Cyperus dactylotes*) lining Belalie Waterhole, Wilson River

Water lilies put on spectacular displays after floods in more sheltered waterholes, hence the numerous 'Lily Lagoons' across the LEB. Lilies are perennial aquatic forbs, with thick creeping rootstocks buried in mud and the leaves and flowers floating on the water surface. The most common species seen in the LEB are the white or lilac-flowered *Nymphaea gigantea, N. georginaea* and the yellow-flowered *Nymphoides crenata*. Conversely, duckweed, although common in many situations, is inconspicuous and rarely noticed. Duckweeds (*Lemna* and *Spirodela* species) are tiny, aquatic monocots that float on the surface of still water, spreading vegetatively across the water. It is often seen on the edges of water, or in stagnant areas, and, as suggested by its common name, provides important waterfowl food as well as habitat and food for fish. Ten species of duckweed occur in Australia, grouped into three genera, however there is little in the way of observable morphological differences between species (Les *et al.* 2002).

Unfortunately, rivers act as corridors for weed dispersal, meaning that waterholes are often characterised by the presence of significant weed species. Parkinsonia (*Parkinsonia aculeata*) and noogoora burr (*Xanthium occidentale*) are the two most serious and conspicuous weeds of waterholes and channels, while the odd mesquite (*Prosopis* species) and prickly acacia (*Acacia nilotica*) may also rear their ugly heads. Rubber vine (*Cryptostegia grandiflora*) is common in waterholes of the upper Thomson tributaries, extending as far south as the Muttaburra Broadwater. Weeds are discussed in Sections 4.6-7 on waterhole condition. No listed rare and threatened species are known to occur around permanent or semi-permanent waterholes in the study area. This seems surprising given the pressures on this habitat (Section 4.6), however probably reflects the resilience of a flora assemblage that has evolved to withstand large-scale natural disturbances.

In general, the diversity of vegetation around waterholes seems to increase with increasing sand and rock content. Clay waterholes in Mitchell Grass Downs, such as those found along the Thomson, Barcoo, Cooper and Diamantina, tend to be dominated by a handful of species, while rocky waterholes in the upper Catchments have relatively more species present. This probably reflects little more than the comparative floristic diversity of the habitat surrounding these waterholes. Many other species may also occur next to waterholes, ranging from mulga to spinifex, but these essentially represent 'interlopers' from the surrounding landscape, growing on the waterhole more by virtue of serendipity than any specific habitat preference.

Table 10: Common Plants of LEB Waterholes

Trees	Shrubs/climbers	Forbs	Graminoids	Aquatic/ sedges
Eucalyptus camaldulensis	*Eremophila bignoniflora*	*Alternanthera* spp.	*Sporobolus mitchellii*	***Nymphoides/ Nymphaea* spp.**
Eucalyptus coolibah	*Acacia stenophylla*	*Marsilea* spp.	*Paspalidium jubiflorum*	***Spirodela/ Lemna* spp.**
Lysiphyllum gilvum	*Acacia salicina*	*Pseudognaphalium luteo-album*	*Panicum laevinode*	***Cyperus* spp.**
Melaleuca trichostachya	Mistletoe species	*Sclerolaena muricata*	*Eulalia aurea*	***Eleocharis* spp.**
***Melaleuca* spp.**	*Muehlenbeckia florulenta*	*Centipeda* spp.	*Leptochloa digitata*	***Persicaria* spp.**
Acacia nilotica*	*Parkinsonia aculeata**	*Ludwigia peploides*	*Echinochloa turneriana*	
	Clerodendrum floribundum	*Cullen cinereum & australasicum*	*Cenchrus ciliaris**	
	Cryptostegia grandiflora*	***Xanthium occidentale****	***Cyperus & Eleocharis* spp.**	

4.4.3 Algae

The green-tinged 'bathtub ring' of algae is noticeable around most permanent and semi-permanent waterholes. Aside from presenting a slippery safety hazard to the unwary swimmer, research shows that rates of primary production in this zone are among the highest recorded for rivers in Australia, and remain high even during the winter months. In fact, this seemingly unremarkable 'ring of slime' is the major source of energy driving the food web in permanent waterholes, supporting large populations of snails, crustaceans and fish (Bunn & Davies 2001). In the high turbidity waterholes that characterise the LEB, the food web is driven by this productivity at the waters edge (Bunn *et al.* 2006). Recent and current flow has a major influence on the richness of algal assemblages in a given waterhole, through transport of planktonic algae from upstream refugia and in situ algal germination from resting spores in water and sediment (Costelloe *et al.* 2004). River connectivity and aquatic refuges are critical to maintaining algal diversity in a river system.

4.4.4 Aquatic fauna – flexible but dependent

The aquatic fauna of waterholes is distinctive. Most organisms have flexible life history strategies to cope with the variable and extreme nature of their habitat, but remain fundamentally dependent upon refuges during the dry times. Most people have some awareness of fish assemblages in waterholes, while amphibians, birds, turtles and mammals are also conspicuous. In contrast to this 'charismatic megafauna' of desert rivers (Kingsford *et al.* 2006), much less is known about the invertebrate fauna.

4.4.4.1 Waterholes as refuges

Surface water persistence has a huge influence on biodiversity across the LEB. In the short to medium-term (i.e. 1-5 years), the persistence of semi-permanent waterholes determines the distribution of species, and is important to the maintenance of biodiversity (Costelloe *et al.* 2004). The major rivers across the LEB typically flow each year, but it is the irregular extreme flood and drought events that have the most widespread and long-lasting effects on the system and its biota (Costelloe *et al.* 1990; Stafford-Smith & Morton 1990; McMahon & Finlayson 2003). Occurrence of extended droughts means that survival of the Basin's biota is critically reliant on the persistence of 'drought refuges'. Costelloe (2008) defines a 'refugium' as a waterbody with a maximum cease-to-flow depth of 4m and an approximate annual flow frequency. As discussed above, such permanent waterholes are extremely rare throughout the Lake Eyre Basin, with the exception of some reaches of Cooper Creek and the lower Thomson and Barcoo Rivers.

These rare, often isolated features are of vital importance as biological refugia and underpin the health and viability of the aquatic fauna (Morton *et al.* 1995; Hamilton *et al.* 2005). For individuals, populations and communities to persist in variable environments, they must have refuge from disturbance. As such, refugia convey spatial and temporal resilience in the face of natural disturbances such as drought (Magoulick & Kobza 2003). They function to reduce population losses and as sources of recolonisation after drought – permanent waterholes are in essence the colonisation epicentres of desert rivers (Kingsford *et al.* 2006). During the extended 2002/2003 ('Millennium') drought, biota were still found to be thriving in refuge waterholes (Costelloe *et al.* 2004). Populations of aquatic organisms which lack desiccation-resistant life-stages are reliant on refuges during drought, as are wetland-dependent organisms which do not readily disperse, or which cannot move long distances between isolated habitat fragments (Costelloe *et al.* 2004). Such fauna include all fish, some macroinvertebrates, the Cooper Creek turtle (*Emydura macquarii* subsp. *emmotti*) and water rat (*Hydromys chrysogaster*).

Refugial waterholes are not the comfortable 'safe havens' that the name implies. The contraction of large populations to remaining habitat in dry times results in intense competition for limited resources, accompanied by increased predation pressure. In addition, the habitat itself becomes increasingly harsh, due to depleted dissolved oxygen, high temperatures, pH changes and altered water chemistry (Magoulick & Kobza 2003). The crowded individuals in a waterhole refuge become more susceptible to mortality from these additional stresses. Such pressures tend to wipe out many less tolerant species, and thus exert a substantial effect on aquatic faunal assemblages throughout a river system.

Although environmental conditions within refugia vary substantially, both spatially and temporally, most refugia seem to undergo a similar sequence of events leading to harsh abiotic and biotic conditions (Magoulick & Kobza 2003). In severe dry times, even permanent waterholes, whilst retaining considerable volume of water, can turn 'rank'. In the 1940s drought, the deep, permanent Mayfield Waterhole turned green and fish died in their thousands; the stench wafted into Windorah township on the breeze (Sandy Kidd, pers.comm., February 2009). As such, even waterholes mapped as permanent may have dubious 'refuge' value during occasional severe dry periods. Waterholes south of Goyder's Lagoon that become increasingly salty with time since flow have even less value as biological refuges during drought, even though considerable amounts of water may remain.

Permanent waterholes also tend to have consistently higher species diversity than more ephemeral waterholes (Box *et al.* 2008). From the perspective of inland ecosystems, ephemeral wetlands provide the 'pulses' or 'booms' while permanent waterholes provide constancy and stability in a highly variable system. This reduction of rivers to a handful of waterholes during drought highlights both the importance and vulnerability of these refuges. As such, it is critical to ensure the biotic integrity of refuge waterholes is maintained. Current knowledge suggests that the effective conservation of permanent waterholes could protect more native biodiversity than conserving non-permanent features (Box *et al.* 2008). Isolated refugia are particularly vulnerable to catastrophic events, which can have implications for biodiversity across wide areas. The most isolated permanent waters (i.e. those separated from the nearest permanent *waterhole* by more than 40km straight-line distance) in the study area are outlined in Table 11. Isolated refugia are sorted by distance to waterholes because other sources of water are often small and/or inaccessible rockholes and springs that may have limited refugial value.

Table 11: Isolated refugia and distance to other water sources

Name & Property	Creek/ Catchment	Nearest Permanent Waterhole	Nearest Permanent Waterbody	Notes
Tomydonka Waterhole, Glengyle	Eyre Creek (Georgina)	**120km** (Nerathella WH, Diamantina R, Roseberth)	**95km** (Beperry Springs, Kamaran Downs	Nearest permanent WH in Georgina catchment is Paravituri near Boulia (190km)
Toko Gorge, Glenormiston	Linda Creek (Georgina)	**85km** (Lake Katherine, Roxborough Downs)	**50km** (Dignum WH/soak, Pituri Creek, Glenormiston)	Dignum WH dries back to a small soak in dry times; there is quite permanent WH across the NT border in the Toko Range
Conn Hole, Elderslie	Western Creek (Diamantina)	**75km** (Mitta Mitta WH, Diamantina River, Wyoming)	**70km** (Cave Hole & Man Hole Rockholes, Bladensburg – both inaccessible to animals)	40km from both Fig Tree Hole and Carisbrooke Spring, both of which apparently used to be permanent or almost so
Poural Waterhole, Currawilla	Spring Creek (Diamantina – Farrars Creek)	**65km** (Big Moorathulla WH, Morney Creek, Morney Plains)	**65km** (Big Moorathulla WH, Morney Creek, Morney Plains)	Poural WH is spring-fed
Rocky Crossing, Mt. Windsor	Mayne River (Diamantina)	**65km** (Billa Billa & Vergemont House Holes, Vergemont Creek)	**50km** (Policeman's Rockhole, Vergemont)	90km to nearest permanent WH in Diamantina catchment (Old Cork WH)
Kirby's Waterhole, Biricannia	Towerhill Creek (Cooper)	**60km** (Kooroorinya WH, Towerhill Creek, Lammermoor)	**60km** (Kooroorinya WH, Towerhill Creek, Lammermoor)	Closer waterholes along Towerhill Creek in this area apparently used to be more permanent but have silted up
Swan Hill Waterhole, Swan Hill	Barcoo River (Cooper)	**60km** (5 Mile WH, Barcoo River, Norwood)	**30km** (Putora Spring)	Within 5km of two inactive GAB springs on Swan Hill and The Springs
4 Mile Waterhole, Reserve	Reedy Creek (Cooper)	**60km** (Bucksleas WH, Lilyarea)	**10km** (Sumana Spring)	Although isolated from permanent waterholes, 4 Mile is within a large cluster of Desert Uplands springs and lakes
Tirrawarra Waterhole, Innamincka	Cooper Creek (north-west branch)	**50km** (Marpoo WH, Cooper Creek, Innamincka)	**50km** (Marpoo WH, Cooper Creek, Innamincka)	20km south of semi-permanent Coongie Lakes
Bulla Bulla Waterhole, Warra	Hamilton River (Georgina)	**50km** (Barracks WH, Burke River)	**1km** (Bulla Bulla Spring)	Most springs in this area are now inactive
Paravituri Waterhole, Marion Downs	Georgina River	**45km** (Bean Tree WH, Burke River, Boulia)	**45km** (Bean Tree WH, Burke River, Boulia)	Closest WH on Georgina River is Midgningar WH on Glenormiston (65km)
Whitula Waterhole, Sth Galway	Whitula Creek (Cooper)	**40km** (Tub Hole, Cooper Creek, Tanbar)	**40km** (Tub Hole, Cooper Creek, Tanbar)	Nearest semi-permanent WH is also >40km away

4.4.4.2 Fish

The waterholes of the LEB support a diverse and abundant assemblage of native fish, which is considered indicative of good ecological health of the river systems. About 104 000 native fish were caught over seven surveys spanning five reaches during the ARIDFLO project. Bony bream, carp gudgeon, rainbow fish, smelt and the Lake Eyre hardyhead are the five most common species in the Basin (Costelloe *et al.* 2004). Exotic fish (mostly plague minnow, *Gambusia holbrookii*) constitute only a minute fraction of the fish community in LEB rivers. It is well-documented that floodplains and ephemeral waterholes can harbour almost as many species as permanent waterholes. Even extremely shallow, temporary and isolated pools can have fish present, especially the hardy spangled perch (*Leiopotherapon unicolour*) (Adam Kerezsy, pers.comm., November 2007). However, despite the productivity and breeding opportunities afforded by ephemeral habitats, fish run the risk of being stranded when they dry out.

The LEB fish assemblage has no capabilities for aestivation, although spangled perch may persist in wet sand for an unknown length of time after surface water has dried up (Box *et al.* 2008). Therefore, during drought, the persistence of the entire LEB fish fauna is reliant upon permanent waterholes. Such refuges are essential in maintaining fish community integrity through extreme hydrological variability, and allow fish to recolonise less permanent waterholes during flow events following drought (Unmack 2001; Magoulick & Kobza 2003). Fish either select refugia in response to drying or are trapped within the habitats where they are found at the onset of drought (Magoulick & Kobza 2003). Very little is known about these population movement processes. As well as being permanent, deeper waterholes have a greater complexity of microhabitat and harbour the largest proportion of regional diversity of native fish. The Cooper catfish is associated only with deeper, more permanent waterholes regardless of the season (Costelloe *et al.* 2004).

4.4.4.3 Turtles

The Cooper catchment is home to the endemic Cooper short-neck turtle (*Emydura macquarii* subsp. *emmotti*). Recently, two turtles were captured at Yammakira Waterhole in South Australia as part of the ARIDFLO project – the first recorded turtles in the Diamantina (Costelloe *et al.* 2004). The eastern snake-necked turtle (*Chelodina longicollis*) is established in the headwaters of the Cooper catchment, but has not extended its range into drier areas, presumably because it is unable to move between habitats – the large spatial and long temporal scales of inhospitable desert pose too great barriers to survival (Kingsford *et al.* 2006).

To persist in dryland rivers, Cooper Creek turtles have evolved special traits which allow them to survive the unpredictable and extreme flow fluctuations (White 2002). They do this by congregating in permanent waterholes, only migrating to semi-permanent waters during flood events. As it does not possess specific adaptations to the vicissitudes of life in ephemeral habitats, it seldom moves overland in search of water and is tied to reliable waterholes (Kingsford *et al.* 2006). Permanent waterholes are therefore highly sought-after, and genetic data show that turtles in these habitats exhibit high site fidelity, retreating back to the same permanent waterhole as floodwaters recede (Costelloe *et al.* 2004).

White (2002) found that permanent waterholes on the Cooper were consistently dominated by adult turtles in very high densities, while semi-permanent holes provided habitat to juveniles at much lower densities. Ephemeral waterbodies supported no turtle populations. During periods of no flow in permanent waterholes, turtles go into a sort of 'shut-down' mode, where energy is no longer directed towards reproduction and growth. Hence the choice between waterholes involves a trade-off for individuals: they can either remain safe in permanent waterholes but with reduced opportunities for breeding, or disperse to less reliable habitats and risk death but enjoy enhanced breeding prospects. Turtle populations are sustained by mass recruitment during 'boom' periods and persisting through dry times by virtue of low metabolic rates and longevity (up to 80 years!) (Kingsford *et al.* 2006). On longer time scales, their persistence probably relies upon a pattern of local extinction and reinvasion over century timescales. What is certain is that without some permanent refuge waterholes, turtles would not exist in the Lake Eyre Basin.

4.4.4.4 Water rats

The water rat (*Hydromys chrysogaster*) is, apart from the platypus, the only amphibious Australian mammal. It occurs patchily throughout most of the study area, and also extends throughout large areas of Australia and New Guinea. Water rats tend to occur in the vicinity of permanent waterbodies, although may make occasional forays to more temporary sources of water (Strahan (ed.) 1998). They make nests at the end of tunnels in banks or occasionally in logs. Although they can climb hollow trees, they take most of their food from the water, searching among vegetation and submerged logs around waterhole edges for insects, fish, crustaceans, mussels, frogs, lizards, small mammals and waterbirds (Strahan (ed.) 1998). Most activity takes places around sunset, but water rats are rarely seen in the LEB.

Although water rats have not been intensively studied, it has been suggested that they may adopt a similar life history strategy to turtles (Costelloe *et al.* 2004), rendering permanent waterholes vital refuges for this poorly-known mammal. The distribution of water rats across their range is patchy, and their occurrence in waterholes in the LEB seems to be similarly unpredictable. The permanent Ouimmanroo Waterhole on Cooper Creek south of Windorah is home to a large population of water rats – apparently the only waterhole in the area where this enigmatic mammal occurs in abundance (Sandy Kidd, pers.comm., February 2009).

4.4.4.5 Frogs

Many frogs successfully inhabit the LEB. All are dependent upon free-standing water for breeding, as tadpoles require water for their development. However, most cope with unpredictability in the availability of permanent water by employing a range of morphological, physiological and behavioural adaptations, and thus do not depend upon permanent refuge waterholes. For example, the water-holding frogs (*Cyclorana* species) escape desiccation by burrowing beneath the soil during dry times, conserving water by enveloping their bodies in an epidermal cocoon (Tyler 1978). They emerge briefly after heavy rains to quickly feed and reproduce.

Some frogs, however, inhabit creek beds and soaks associated with more permanent waterholes. *Crinia deserticola* inhabits creekbeds and soaks associated with river channels, while *Litoria rubella* seeks refuge in trees and shrubs beside permanent and semi-permanent waterholes. Some *Limnodynastes* species also occur at the edges of more permanent waterholes (Kingsford *et al.* 2006). Unfortunately, the introduced cane toad (*Bufo marinus*) also a relish the reliable water supplies provided by rivers in the upper LEB, and is spreading down the Thomson River. As a result, campers along waterholes from Muttaburra to Stonehenge will often hear only sporadic native frog calls, as they are drowned out by the insistent drones of the fiendish toad.

4.4.4.6 Other aquatic fauna

The native blue-claw and introduced red-claw crayfish are present in all three catchments in the study area. Red-claw are native to Cape York and Gulf Rivers, and have been translocated into the LEB as escapees from live fishing bait and stocked farm dams. They were actively promoted by the Queensland DPI in the early 1990s as an aquaculture species, and appear to be expanding their range in the LEB (Adam Kerezsy, pers.comm., November 2008). It is possible that red-claw have a detrimental impact on native yabbies, as well as other species of crabs, fish, shrimps, prawns and mussels. However, little is understood of these interactions.

Macroinvertebrates include aquatic insects, freshwater molluscs, bivalves and gastropods. Over 130 species of macroinvertebrates are recorded from the LEB, with diversity primarily driven by habitat diversity (Costelloe *et al.* 2004). Box *et al.* (2008) report a distinct lack of taxonomic knowledge for most major macroinvertebrate groups found in central Australia, making any critical examination difficult. Most macroinvertebrate assemblages in the LEB are opportunistic and tolerant of a wide range of conditions and their life histories are linked to flow conditions (Boulton *et al.* 2006). Relationships between waterhole permanence and macroinvertebrate persistence are not well known. Some insects are capable of active dispersal to permanent waterholes as temporary pools dry out, however they often have life history strategies such as desiccation-resistant eggs or aestivation that allow them or their progeny to persist in non-permanent waterbodies (Box *et al.* 2008).

Microfauna (zooplankton) were virtually unstudied in the LEB prior to the ARIDFLO project, which identified 423 taxa of microfauna from the waterbodies sampled, including at least 21 new species (Costelloe *et al.* 2004). It seems that these microfauna are capable of surviving extended dry periods in sediments, diminishing the importance of refugial waterholes for their persistence.

4.4.4.7 Birds

Two broad groups of birds depend upon permanent and semi-permanent waterholes in the LEB: waterbirds and 'terrestrial' bird species whose life cycles depend upon aquatic systems (Kingsford *et al.* 2006). Although the ephemeral, shallow saline lakes and claypans are more productive in terms of density, number of species and abundance of waterbirds than perennial waterbodies (Kingsford *et al.* 1999), and provide the spectacular influx of the feathered races after floods, permanent waterholes act as refuges for waterbird populations during dry periods. By drought times, most migratory waterbirds have completed their breeding cycles and vacated the drying waterbodies of the LEB. However, any remaining waterbirds are forced to retreat back to deeper waterholes, demonstrating their refuge value (Costelloe *et al.* 2004). Waterholes are also home to a distinctive assemblage of non-migratory aquatic birds. Specialised body forms and feeding structures allow waterbirds to occupy specific aquatic habitats, feeding on different foods. Some spend most of their time around the edge of waterholes or on land adjacent to waterbodies, while some are almost completely aquatic (Kingsford *et al.* 2006).

All terrestrial bird species require drinking water, even if only occasionally, while some depend upon other resources of aquatic habitats such as food, nesting sites and nesting materials (Kingsford *et al.* 2006). Many of these are commonly observed in other habitats. Nevertheless, waterholes and their associated habitat are often preferred nesting sites due to the relative high densities of tall, nesting trees in otherwise treeless landscapes, as well as providing food and water. As such, they are foci for a variety of bird life. Birds of prey, including wedge-tailed eagles, black kites and whistling kites are often seen in large numbers around waterholes, where they are attracted by the abundance of waterbirds, fish and carrion, and nesting sites. The elusive grey falcon also tends to make its nests in large riparian trees, sometimes near permanent waterholes. Table 12 summarises some common birds of waterholes in the study area. Information is taken from Morcombe (2003), Pizzey & Knight (2005) and Kingsford *et al.* (2006).

Table 12: Common Waterhole Birds

Name	Notes
AQUATIC SPECIES	
Grebes (Australasian and hoary-headed)	Almost completely aquatic, diving and feeding on mostly fish and invertebrates up to 3m below the surface; usually in areas with abundant fringing vegetation.
Australian pelican *(Pelecanus conspicillatus*)	Almost completely aquatic; glide gracefully along water while feeding on fish – have a large bill with sack-like pouch to temporarily store food; sometimes seen high in the sky, circling over waterbodies
Ibis *(Threskiornis* spp.)	Often roost in trees along waterhole banks, feeding on edges of waterhole; nest following widespread flooding; spend most of time on floodplain adjacent to WH; straw-necked and Australian white ibis most common in LEB.
Herons *(Ardea* spp. & *Nycticorax caledonicus)*	White-necked and white-faced heron commonly seen – wading birds; spend most of time on edge of WH, feeding in shallows, flying gracefully when disturbed; enigmatic Nankeen night heron is mostly nocturnal, but is often flushed by those exploring dense tea-tree thickets and other thick vegetation along waterholes
Cormorants (*Phalacrocorax* spp.)	Four species in LEB; almost completely aquatic, feeding on fish and large crustaceans, catching prey under water; breed on islands or riparian trees
Spoonbills *(Platalea* spp.)	Often roost in trees along waterhole banks, feeding on edges of waterhole on amphibians, crustaceans and insects – any small creature that touches inside of broad bill tip triggers it to shut instantly; breed in colonies on platforms made from vegetation; royal and yellow-billed spoonbills both occur in LEB
Darter *(Anhiga melanogaster)*	Sleek, cryptic birds, which float very low, often with only head and neck visible; ducks beneath surface with scarcely a ripple; almost complete aquatic, preferring deeper stretches of water with logs, limbs and aquatic vegetation
Egrets (*Ardea* spp.)	Great, intermediate and little egrets can all be observed at LEB waterholes; forage on edge of water and glide gracefully when disturbed
Clamorous reed warbler *(Acrocephalus stentoreus)*	Amongst reeds/knotweed near edge of waterhole; heard more often than seen with metallic, powerful song; occupy dense reedbeds around swamps and waterholes, feeding on insects in wetlands and building nests in vegetation; generally moves south to breed in summer
Native hens (Purple swamp-hen and black-tailed native hen)	Large flocks can be seen scurrying along banks; purple swamp-hen is aggressive towards other waterbirds and kill ducklings; have strength to pull up reeds as food; black-tailed native hens are particularly seasonally irruptive
Ducks, teals and shovelers	Variety of species, most commonly Australian wood ducks, hardheads, pink-eared ducks, grey teal and Pacific black duck, patrol inland waterholes; variety of feeding strategies
Black-fronted dotterel *(Charadrius melanops)*	Often observed running swiftly along water edge, stopping abruptly to peck prey, flittering over water when in flight; red-kneed dotterel also occurs on LEB waterholes but generally not as common
Brolga *(Grus rubicunda*)	Usually found near water in dry season, congregating in flocks on remaining waterholes; seasonally migratory; well-known elegant dancing display and far-carrying bugling call
Black swan *(Cygnus atratus)*	More common in more shallow, well-vegetated waterbodies, but occasionally graces permanent and semi-permanent waterholes; feeds on underwater vegetation; nomadic
Gull-billed tern (*Sterna nilotica*)	Nomadic and highly dispersive; forage from air, flying gracefully over waterholes
TERRESTRIAL	
Grey shrike-thrush *(Colluricincla harmonica)*	Most often in wooded areas, e.g. where gidgee or other woodland comes near waterhole; rich, varied song
Crested bellbird *(Oreoica gutturalis)*	Similarly attracted to dense stands of timber such as gidgee; also nests in bauhinias along Diamantina River; its deep mellow call echoes across waterholes
White-plumed honeyeater *(Lichenostomus penicillatus)*	Noisy, gregarious birds; extremely common in riparian trees and shrubs of many LEB waterholes

Whistling and black kites	Nest in coolibahs fringing waterholes, and their harsh, penetrating whistles are often heard as they hover over waterholes searching for prey
Eagles	Nest in trees along waterholes; little eagle is uncommon, but in 2007, three pairs nested along the Longreach WH; wedge-tailed eagles may also nest in coolibahs beside waterholes; white-bellied sea-eagles are occasional but striking visitors to LEB waterholes
Budgerigar *(Melopsittacus undulates)*	Highly migratory; in good seasons, waterhole habitat provides drinking water and tree hollows for nesting, with flocks alighting from edge of waterhole
Red-tailed black- cockatoo *(Calyptorhynchus banksii)*	Seasonal visitors to inland after good rains/flooding; nest in hollow limbs of river red gums and coolibahs; Aboriginal people held them sacred, using only discarded feathers for ceremonies, and not touching the birds or their nests; harbingers of water, as only fly relatively short distances from water to forage, flocks returning noisily every morning and evening; sporadically common on Longreach Waterhole
Peaceful dove *(Geopelia placida)*	Small, active dove with lilting, musical voice; often seen flying from tree to tree across waterholes
Fairy martin *(Hirundo ariel)*	Tiny birds dipping and swaying above water; bottle-shaped nests can be seen under many bridges over waterholes
Woodswallows *(Artamus* spp.)	Six species occur in LEB; black-faced, white-breasted and masked woodswallows may all soar in gregarious, conspicuous, noisy groups above waterholes.
Dollarbird *(Eurystomus orientalis)*	Regular breeding migrant to Australia over spring-summer; conspicuous on trees above waterholes along the Thomson River during this time; short, metallic call

4.4.4.8 Terrestrial fauna and waterholes

Waterholes provide a vital resource for wildlife during dry times (although their importance has declined as permanent sources of water have proliferated; see Section 8). Riparian areas and waterholes are regarded as 'corridors' for wildlife movement, and contain populations of species that don't occur anywhere else in the LEB. Gliders nest in old tree hollows along rivers, while koalas have been recorded as far west as Kyabra Creek in the LEB (Peter McRae, pers.comm., July 2008). Although few mammals are aquatic, most have to drink, even if only infrequently (Kingsford *et al.* 2006). The fact that herbivores, both native and introduced, use waterholes as vital sources of drinking water means that their effects on the landscape extend beyond their small area. Total grazing pressure is often higher in the vicinity of waterholes, and this effect may extend a considerable distance back from the waterhole. Such impacts are discussed further in Section 4.6 and Section 8.

4.5 Human significance

'Water is the indispensable, limiting factor of man in the desert' (Adolph *et al.* 1969).

All human activity in inland Australia has been, and continues to be, completely dependent upon reliable sources of water. The significance of waterholes – the most common source of water and soothing oases in the midst of an often hostile, arid land – to human populations cannot be underestimated. For thousands of years, waterholes have been vital focal points for survival, activity and spirituality across western Queensland – a fascination and reliance which continues to this day. This section is split into five sections, beginning with an exploration of the naming of waterholes. Their role in Aboriginal society, white exploration and early settlement is then examined. Lastly, the present use and management of waterholes is considered. It becomes clear that the distribution of reliable waterholes has been the overarching factor dictating travel and settlement patterns throughout the LEB over millennia.

4.5.1 Naming

The desire to name and classify the natural world and its component parts is deeply ingrained in the human psyche. Waterholes, for the most part well-defined features in an otherwise seemingly featureless landscape, have long been the focus for these nomenclatural tendencies. The fact that all major waterholes across western Queensland are named and known reflects their significance to people in a dry environment.

Aboriginal people had names for all the waterholes, which were often descriptive of the particular place (e.g. clear water, good water, bad water). A 1900 list of Aboriginal words and their meanings in the Bedourie district compiled for the Royal Anthropological Society of Australasia included many words for water, including over 15 different words for 'waterhole' (Nolan 2003, p.142). Eyre wrote that 'The infinity of the native names of places, all of which are descriptive and appropriate, is of itself a *prima facie* evidence of their having strong ideas of property in the soil' (Eyre, *Manners and Customs of the Aborigines of* Australia, cited in Bennett 1927, pp.94-5). As Alice Duncan-Kemp mused, 'What a wealth of poetry lies hidden in these names!' (1934, p.49). The pioneer Robert Christison used the Aboriginal names for the string of permanent waterholes that form the head of Tower Hill Creek: 'the Falls – Koo*roor*inya, like the roar of its waters in flood; above, *Tee*ka*loon*da, of the sheep washing; *Tee*kala*mung*ga; *Mat*tamun*duk*ka, which stockmen call the Four-Mile; homestead waterhole; *Nar*kooroo; Marri*kan*na and Ba*roo*ta, where blue water-lilies grow; Pil*mun*ny, near Ironbark Camp, a favourite camp, where once the Dallebura had used to old their bora ceremonies' (Bennett 1927, p.265).

The majority of names in the Birdsville region and north-eastern South Australia have their origins in Aboriginal languages. Within these names, the ubiquity of phrases such as 'appa', 'nappa', 'anna', 'mannie', 'ninna' is unsurprising, given that these all refer to places where water is to be found (Donovan & Wall (eds) 2004). European explorers attempted to retain these names, as much for convenience and ease of communication than out of any inherent respect for the indigenous culture. And so these 'long complex names which tumbled so musically from the lips of the first people' were slurred by unaccustomed white tongues into 'slipshod imitations' (Tolcher 1986, p.134). Unsurprisingly, the spelling has often changed numerous times since white settlement, with the Aboriginal 'Kulyumaru' morphing from Callieoumarou, Culemuray, Coolumuray and Callamurra. Many remain on maps, but the meanings have often been lost. Hercus (2004) points out that the 'oral literature' that has been recorded for the LEB represents only a portion of an earlier wealth.

Other waterholes have been comparatively recently 'christened' in honour of events, people or topography over the past 150 years. The origins of some waterhole names are obvious; it does not require too much imagination to deduce the meanings of 'Windmill Hole', 'House Hole', 'Pump Hole' or the ubiquitous 'Big Holes' and 'Long Holes'. Many are even less cryptically named after the properties on which they occur. The origins of some names are common knowledge. For instance, the numerous 'Garden Holes' across the region refer to the Chinese gardeners who established their enterprises on the banks of certain waterholes (see below). The 1, 5, 12 (insert number here) Mile Waterholes are ubiquitous, and perhaps reflect some lack of imagination on behalf of the settlers. However, these waterholes provide useful landmarks for navigation away from stations, towns or other defined points.

There are many waterholes whose nomenclatural origins are unknown, including some which hint tantalisingly at a lost meaning and time (for example, Melancholy Waterhole, Gallows Waterhole, and the relatively common Dismal Waterhole). Given the violence, fear and isolation of the frontier period (Hercus & Sutton (eds) 1986; Watson 1998; Roberts 2005), perhaps not too much elucidation is required for waterholes such as 'Lake Massacre', 'Nigger Hole' or 'Suicide Hole'. Some waterholes are known by more than one name, such as the large permanent waterhole at Diamantina National Park, which has been variously known as Mulca Mulca-Wercoolah, Hunter's Gorge and Diamantina Lake (Nolan 2003). A selection of some of the more interesting names and the stories behind them are summarised in Table 13.

Table 13: Selection of Waterhole Names and their Origins

Waterhole Name	River System	Derivation

Barrioolah Waterhole	Cooper Creek	Derived from the Aboriginal name *Badribarcoola*, meaning ‘place of two grubs’ (Tolcher 1986, p.134)
Ben Knot Waterhole	Thomson River	Named after a drover who used to camp on this waterhole north of Longreach (Kate Deane, pers.comm., August 2008)
Bimbah Waterhole	Thomson River	Reportedly means ‘big fish’ in Aboriginal language (Moffat 1987)
Camoola Waterhole	Thomson River	Camoola is an Aboriginal word meaning place of waterlilies or ‘big waterlily’ (Moffat 1987)
Cullymurra Waterhole	Cooper Creek	Howitt camped here in 1861 and named it from the Aboriginal name ‘Kaliumaru’ or ‘wide lake’ (Murgatroyd 2002); its name has changed spelling numerous times since then (Tolcher 1986)
Dillula Broadwater	Thomson River	Reportedly means ‘big waterhole’ in Aboriginal language (Moffat 1987)
Goongoon	Thomson River	Recorded by Christison of Lammermoor as an Aboriginal word meaning ‘bone’ (Bennett 1927)
Jardine’s Waterhole	Diamantina River	After James Jardine, manager of Carcory in the early 20th century for Jack Gaffney, the Qld representative for Kidman (Nolan 2003)
Kooroorinya Waterhole	Torrens Creek	This permanent waterhole was a favoured camping spot of local Aborigines, and the name means ‘the rainbow’, which could be seen through the spray rising from the water as it fell over the falls (Bennett 1927; Donovan & Wall (eds) 2004)
Lake Teeta	Diamantina River	Aboriginal word for ‘little black ants’ which swarm around the claypans and edges of the water (Duncan-Kemp 1934)
Lakes Mary and Francis	Georgina River	Named by Landsborough in 1861, after his nieces; the exploration party spent Christmas Day of 1861 at Lake Mary
Nappa Merrie Waterhole	Cooper Creek	Aboriginal, probably derived from Wongkumara words ngappa = water and merrie = sandhill (Historical Research Pty Ltd *et al.* 2002)
Parapitcherie/ Paravituri Waterhole	Georgina River	Aboriginal word for salt-water hole (Royal Anthropological Society 1900, in Nolan 2003)
Pulchera Waterhole	Mulligan River	‘Pulchra’ reported to mean ‘waterhole frequented by pelicans’ (Royal Anthropological Society 1900, in Nolan 2003)
Queerbidie/ Quibberty Waterhole	Cooper Creek	Derived from the Aboriginal *Quia-pidrie*, meaning ‘origin of fishes’ (Tolcher 1986, p.134)
Toko Gorge	Linda Creek	‘Toko’ is Aboriginal word for ‘small range’ (Royal Anthropological Society 1900, in Nolan 2003)
Yuranigh Ponds	Barcoo River	After Mitchell’s Aboriginal guide on his 1845-6 expedition (Mitchell 1847)

4.5.2 ‘Living water’: Indigenous people and waterholes

Naturally, permanent and semi-permanent waterholes in the arid zone were vital places for Aboriginal people over thousands of years. Their centrality to survival gave rise to their immense significance as habitation sites and ‘nodes’ on trading and travel routes. Duncan-Kemp mused that ‘The Georgina and the Diamantina are to the back country and its inhabitants what the Nile is to Egypt and the Egyptians’ (1934, p.49), while Sturt also invoked a comparison with the Nile to underscore the importance of inland river systems to the first Australians.

4.5.2.1 Waterholes through time

There have been numerous models put forward to explain colonisation of Australia's interior (e.g. Ross *et al.* 1992; Smith 1989; Veth 1993). Whilst these theories are the source of some contention, the availability of water is fundamental to all models. At a broad level, areas with coordinated drainage and reliable water are viewed as the least marginal environments for occupation in the arid zone. Sandy deserts such as the Simpson are the most marginal and were therefore the last to be successfully occupied.

Archaeological work has confirmed Pleistocene occupation of the arid zone lowlands, including the LEB (Simmons 2007). However, the onset of the Last Glacial Maximum (LGM) around 18 000 years ago posed a major challenge for these desert people. During this period, the LEB would have been much more arid than it is today, and the catchments of the Channel Country rivers would have fallen completely within the arid zone. Waterholes became much more widely spaced and less permanent. As such, people were forced to abandon much of the area, retreating to key refuges with permanent water – Veth's (1993) 'islands of the interior'. With climatic amelioration, people would have been able to reoccupy deserted areas as more surface water and food resources became available. The archaeological record suggests intensive reoccupation of many areas, particularly those with coordinated drainage, during the late Holocene. Hence during the massive climate changes over the past 20 000+ years, permanent waterholes have provided stability and refuge.

While it is impossible to reliably estimate the number of people living across the LEB at the time of settlement, all evidence suggests that the country was well occupied prior to European settlement. The accounts of explorers point to a thriving Aboriginal society in the Channel Country. Furthermore, we now know that the Aboriginal population seen by the earliest European travellers from the 1840s onward was already depleted by a wave of smallpox which had swamp through eastern Australia prior to European forays, perhaps in the 1830s (Bell & Iwanicki 2002).

Many explorers expressed surprise at the large numbers of Indigenous inhabitants in the 'wilderness' they were 'discovering'. Sturt provides the first descriptions of Aboriginal numbers on the Cooper in 1844-5. Approaching Cooper Creek, he wrote: *'Notwithstanding the misgivings I had as to the creek, the paths of the natives became wider and wider as we advanced. They were now as broad as a footpath in England, by a roadside, and were well trodden; numerous huts of boughs also lined the creek, so that it was evident we were advancing into a well peopled country…'* (Sturt 1849). In the space of less than five miles (≈8km) along the Cooper, they saw four different groups, whose collective numbers amounted to 71. Then: *'…on gaining the summit, [we] were hailed with a deafening shout by three or four hundred natives, who were assembled on the flat below…The scene was of the most animated description, and was rendered still more striking from the circumstance of the native huts, at which there were a number of women and children, occupying the whole crest of a long piece of rising ground at the opposite side of the flat'*.

Almost two decades later, Wills also wrote of well-worn paths and heaps of shells along a waterhole on the Diamantina, and the party saw Aboriginal people in all the landscapes they traversed in their dash to the coast. Davis, a member of McKinlay's 1861 'rescue' expedition, went so far as to say that blacks 'seemed to pour out from every nook and corner where there was water' (quoted in Watson 1998), leading McKinlay to write 'Go where you will, you will find them in groups of fifties and hundreds, and often many more' (1863, p.33). Throughout their 3-month stay in north-eastern South Australia, the party was visited by large numbers of Aboriginal people – accounts of encountering groups of 80, 90 and 150 were almost a daily occurrence in some areas. To the north-west on the Mulligan River, Hodgkinson encountered 200-300 people camped near Can-tan-era WH in 1876, while both Cornish (1879) and Winnecke (1883) referred to large encampments on the Mulligan, including Bindiacka Waterhole on Sylvester Creek.

A settler on Coongie Lakes remembers that, at one time, it was possible to see Aboriginal women 'as thick as sheep grazing' as they searched for seeds and roots. By 1880, over 1000 people lived in the vicinity of the Kopperamanna Lutheran Mission on the lower Cooper (Watson 1998). On the other side of the LEB, Sutherland (1913) reported that Aboriginal tracks were 'plentiful at almost every waterhole' as they journeyed west from Hughenden to the Georgina River in the 1860s. Landsborough met with relatively small groups of people on the upper Thomson River in 1862, but the permanent waterholes of the Lammermoor area where Christison settled in 1863 were home to large numbers of people (Bennett 1927).

Many of the writings of early settlers indicate that large numbers of people were camped on waterholes across the Lake Eyre Basin. Alice Duncan-Kemp claims that about 3000 people had their hunting grounds between Daru on Farrars Creek and Dangeri Waterhole on the western side of the Diamantina in the 1880s. On Mooraberrie, she writes of the Aborigines '…one meets them everywhere in all capacities…twenty years ago and less, it was almost impossible to ride or even walk over the station horse-paddock, creek or plains, without meeting some portion of a tribe' (1934, p.186). They made their homes on reliable waterholes: 'One met twenty to fifty on almost every waterhole of size on the runs. A familiar site they were with their bough or sand-built gunyahs perched on the highest ground surrounding the water' (p.186).

4.5.2.2 Knowledge of waterholes

Aboriginal people had an encyclopaedic and intimate knowledge of waterholes in their areas, including their location, permanence under various conditions, quality of water, likely extent of flooding and so on (Box *et al.* 2008). Oral instruction and stylised mapping of traditional knowledge regarding the type and location of water supplies was of key importance (Bayly 1999). This knowledge was inculcated from a very early age. Gould (1969) describes how the sequence and location of Western

Desert water sources were memorised, and adults would instruct children as groups passed along a chain of waterholes.

In the Channel Country, elders drew 'sand maps' – huge drawings covering an acre or more, which the elders drew on cleared sand patches outside their gunyahs for the instruction of children (Duncan-Kemp 1934). Waterholes were a feature of these maps, and information included 'whether deep or shallow, permanent, or of poor holding capacity' (p.284). Knowledge of name sequence and approximate location of waterbodies would often extend beyond the regions a person had actually visited. Much of this knowledge is restricted to oral tradition, and the majority is not in the public domain (Box *et al.* 2008).

4.5.2.3 Waterholes, habitation patterns and survival

Aboriginal people relied directly upon permanent (and, in most seasons, semi-permanent) waterholes as sources of water and food. Waterholes were the vital element within territories of different clans, and ensured the survival of the large populations observed by early explorers (Tolcher 1986). The journals of explorers and early settlers indicate that large encampments of Aborigines almost always occurred around waterholes, while the archaeological record shows that habitation patterns were intimately tied to the availability of water. Burke and Wills found distinct dialect groups on the Cooper, with each group's territory centred on a large waterhole, including the Parlpanadramadra Yandruwandha who lived around the Baryulah Waterhole, and the Nirrpi people on Cullymurra Waterhole (Murgatroyd 2002). The Boontamurra people camped on the big Kyabra Waterholes, where there was fish and game all year round (Durack 1959).

On the Diamantina, the permanent Wangrei Waterhole on Diamantina Lakes was an important camp for Aboriginal people in the 1890s (Heber-Percy 1892, cited in Simmons 2007). Further south, Duncan-Kemp writes of 'big encampments of blacks' on Milkerey (Milkara) Lagoon (1934, p.137). Simmons (2007) found that dunefields in the well-watered floodplains were favoured camping places in the mid-reaches of the Diamantina. The number of hearths associated with a single dune in this area can exceed 450, indicating use as a 'core camping area', and part of a larger or denser occupation of that area compared with other landforms (Simmons 2007, p.102). Semi-permanent to permanent waterholes on Spring Creek, including Lake Constance and the impressive Paraputcheri Waterhole, are a feature of this dunefields country.

Movements of people were dictated by seasonal availability of water. After rainfall, people would generally move out to exploit smaller bodies of less permanent water, foraging around one of these before moving onto the next (Bayly 1999). This would maximise resource use, as well as giving the permanent waterholes and their surrounding area time to recover. This strategy would have involved using the most ephemeral water sources first, then retreating to the more permanent waterholes as the country dried out. The 'pulse' nature of the Channel Country rivers necessitated such an adaptable foraging strategy in order to utilise resources in all land zones. In fact, Simmons (2007) found that most camp sites occurred in association with dune and pan features away from permanent or semi-permanent water, implying that people made good use of more ephemeral water sources wherever possible. Waterless areas such as Cordillo Downs in the north-eastern corner of SA could only have supported a transient Aboriginal population, with occupation and foraging only possible after good local rain (Tolcher 1986).

As the country dried out, people would be forced to retreat to the larger and more permanent sources of water. In dry seasons in the upper LEB, Aboriginal people retreated to the permanent waterholes on Towerhill Creek, so that about 300 people might be living on Lammermoor for months on end until the rains came (Bennett 1927). Permanent refuges were vital to survival during dry times and would have seen intensive use until rain or flooding allowed people to disperse once again.

Waterholes, riparian corridors and the variety of landforms that typically surround them (especially dunefields) provided perhaps the richest environment in the Lake Eyre Basin for food resources, including seeds, grass, fish, mussels, frogs, reptiles and birds (Simmons 2007). Watercraft was part of the curriculum from very early in life (Duncan-Kemp 1934), enabling Aboriginal inhabitants to make the most of the resources harboured by the big waterholes. Fish were particularly important in the Aboriginal diet, constituting the main source of protein for groups along major rivers (Simmons 2007). Explorers and early settlers made reference to enormous nets, capable of netting up to 150kg of fish. Duncan-Kemp writes that ‘They were huge contraptions, the largest measuring fifty feet in length, with a width of twelve to fifteen feet; top and bottom edges were threaded on half-inch thicknesses of twine rope, which were fastened into a loop on each side…’ (1934, p.121). As such, it took four ‘hefty warriors’ to net a deep waterhole, which resulted in huge hauls of fish. Young fish were always thrown back so there would be plenty for the following year.

Fish could also be speared, stunned with poison (often the leaves of *Duboisia hopwoodii*) or caught by hand. ‘Swimming fish’ was a favoured means of catching them in a stagnant waterhole. It involved two people swimming among the fish, bamboozling them, and then scooping them up in a large, flat kind of coolamon, used especially for that purpose (Duncan-Kemp 1934). Aborigines in north-western Queensland threw coolibah boughs and leaves into waterholes, causing the water to become progressively darker and stronger-smelling. The following morning, fish would be found panting at the surface, and were easily caught (Roth 1897). In addition, ‘fish pens’, made of stone or woven reeds, were conspicuous on many waterholes. Such fish traps have been documented in detail on the Barwon River at Brewarrina in northern NSW (Bandler 1995). This complex maze of weirs and pens stretched about 750m along the river. In the spawning season, as vast numbers of fish travelled upstream, the openings of the tear-drop shaped enclosures were closed behind them. The fish were then herded into smaller enclosures, where they could be speared, clubbed or caught more easily. Stone walls of varying heights came into operation in sequence, as the water level fluctuated.

In the Channel Country, fish traps were used to feed the huge influx of people who came from far and wide for ceremonies. Fish could be stored for later consumption, either by sun-drying or grinding into 'fish flour' and packaged in woven grass wrapping. Groups living on 'big (i.e. permanent) waters' made crude 'fish flour' from dried pulverised fish (Duncan-Kemp 1934). Intriguingly, early in white settlement, Davis recorded what he considered to be ephemeral waterholes brimming with fish, suggesting some form of fish breeding or farming was taking place (Watson 1998). Shellfish and mussels were considered a delicacy, while water-holding frogs were also captured by digging down into the mud of dry waterholes (Mitchell 1847; Duncan-Kemp 1934). Along the Diamantina, there were 6-9m wide alleyways or 'yelka-yelkas' constructed with stone axes through heavy timber around waterholes, in order to catch birds and animals as they came in to drink.

Aboriginal people also utilised many of the plants growing in and around waterholes, including nardoo (Figure 21), waterlilies and various tubers. On the Cooper waterholes near Innamincka, Sturt wrote that: *'…they sat up to a late hour at their own camp, the women being employed beating the seed for cakes, between two stones, and the noise they made was exactly like the working of a loom factory. The whole encampment, with the long line of fires, looked exceedingly pretty, and the dusky figures of the natives standing by them, or moving from one hut to the other, had the effect of a fine scene in a play'* (Sturt 1849).

At Dickerrie Waterhole on the Mulligan River, Hodgkinson (1876) writes of females grinding nardoo while the men trapped pigeons around the waterhole. Seed-processing seems to have been an important dry-time or winter food source, focussed on the more reliable waterholes (Simmons 2007). Hunter-gatherer societies have been called 'the original affluent society' (Lourandos 1988), and much of this affluence in interior Australia is due directly to reliable sources of water, primarily waterholes. However, smaller amounts of water or moisture could be obtained from rain water in tree hollows, excavated from tree roots, water-holding frogs, dew and edible tubers (Kavanagh 1984; Bayly 1999; Noble & Kimber 1999).

Figure 21: Nardoo (*Marsilea drummondii*) adjacent to Lochern Broadwater, Thomson River. Nardoo was a vital wintertime food source processed close to shrinking waterholes

4.5.2.4 Trading and travel routes

Prior to European settlement, the Lake Eyre Basin was intersected by routes of trade, exchange and communication. In the LEB, reciprocal trade routes stretched from the volcanic hills of the Mt Isa district, following the major watercourses into north-eastern South Australia, and on into the Flinders Ranges. These lines of travel are often called Dreaming Tracks or, if associated with a particular mythology or sone cycle, Story or Song Lines (McBryde 2000). Sometimes great distances were travelled, and expeditions could take up to two years (Donovan & Wall (eds) 2004). Exchanges were both material and ceremonial. Ochre from the Flinders Ranges was much-prized and traded widely, as were stone axes from the Mt Isa area and pituri from the Georgina-Mulligan area. Walter Roth wrote that '..ideas are interchanged, superstitions and traditions handed from district to district…and corroborees are learnt and exchanged…'. These routes are among the world's most extensive systems of human communication recorded in hunter-gatherer societies (McBryde 2000). River and creek courses provided natural routes or corridors for people to travel through the area (Simmons 2007), and reliable waterholes acted as vital nodes along these routes. Many song cycles and 'dreaming tracks' followed lines of permanent waterholes along the major rivers (Hercus 1990).

The Georgina and Diamantina Rivers were both well-used trade routes, as was Strzelecki Creek. The routes taken were proscribed by convention, as were the camping spots along them, where ceremonies would be held (McBryde 2000). The Maiwali people of the mid-Diamantina travelled up the Diamantina to Cork, before heading east to Acheron Creek to meet the Thomson around Tocal, following it down to Carella Creek, then returning the same way (Simons 2007). Pathways across the Simpson Desert allowed contact with groups to the west, and relied upon hidden wells in the desert. Travel was undertaken during good seasons, usually in late winter, by clan-sized groups. As well as fulfilling trade and ceremonial purposes, the establishment and maintenance of long-distance alliance networks served to minimise risk in a highly variable climate (McBryde 1987; Simmons 2007).

The narcotic plant pituri (*Duboisia hopwoodii*) was widely distributed along a major trade route running from Cape York to SA, spreading out from a focal point in Georgina-Mulligan River area, reaching as far as the Gregory and Flinders Rivers, Alice Springs, Winton, the Flinders Ranges and the Darling River. Expeditions may have been quite large, and each member returned home with up to 32kg of dried, packaged drug. It was the ecological system of superabundance at times that made the large-scale production and use of pituri possible, as labour could be diverted away from gathering food. Urandangie, Kudaree Waterhole (south-west of Bedourie), Carlo, Bedourie, Kopperamanna and Goyder's Lagoon were centres for pituri distribution. George Aiston, a policeman in northern SA around the turn of the century, wrote '…I have seen over 500 Aborigines waiting at Goyder's Lagoon', which gives some idea of the scale of trade (cited in Watson 1983).

This vast network of trading routes later became the passages of explorers. Hodgkinson referred to using native pathways to navigate down the Diamantina, which he described as 'large, well-beaten and numerous' (1877, p.9). These well-worn pathways then became the droving runs of the early settlers, and were formally declared as 'stock routes'. Today, many highways and main roads follow ancient pathways, providing tangible and continuous evidence of the influence of water on travel and settlement patterns throughout the LEB.

4.5.2.5 Spiritual nourishment

'Aboriginal waterscapes are constructed not only as physical domains, but also as spiritual, social and jural spaces.' (Langton 2002, p.44).

Unsurprisingly, given their immense value, waterholes were also rich in mythology and regarded as places of spiritual, as well as physical, nourishment. The ubiquity of artefacts, scar trees and, in some places, rock art (e.g. Cullymurra Waterhole, Hunter's Gorge) at permanent waterholes is testimony to their central place in the lives of Aboriginal Australians over thousands of years. The term 'living water' is frequently used to describe permanent waters, conveying 'the sense of water having its own life, and also of offering life to others' (Rose 2004, p.39).

Naturally, in a predominantly arid climate, water was viewed as being sacred. People were required to be extremely circumspect in their behaviour to any body of water: they had to speak in quiet voices before squatting to have a drink; they could not foul the water, nor could they tramp angrily around its banks (Duncan-Kemp; cited in Watson 1998). 'Water people' had to see that suitable corroborees were performed to maintain water supplies, and water spirits had to be honoured with certain gits. Rain-making ceremonies were performed by dissolving a 'kopi' (gypsum) ball in a waterhole (Wells 1893, cited in Simmons 2007). Water totems related to specific bodies of water, and all bodies of water were 'owned' by particular individuals or groups (Duncan-Kemp 1934).

Waterholes also formed the backdrop for many spectacular corroborees and ceremonies. Duncan-Kemp (1934, 1966) provides perhaps the most evocative first-hand accounts of such events, which they were permitted to observe when camped on waterholes during mustering. On one occasion, the party observed a corroboree on Wantata Waterhole on the southern end of Mooraberrie. The music, wailing and dancing went on well into the night: *'The glamour of our surroundings was almost irresistible. The stillness of the atmosphere and the relaxation after days of hard riding, conduced to enhance the spell upon us of the primitive, almost savage, drama'* (1934, p.150). She also recalls approaching Kingadurka Waterhole (Figure 22), a large semi-permanent waterhole nestled amongst the Mooraberrie sandhills, on the night of a planned corroboree: *'On top of a far sandhill peak, etched sharply against a flaming sky, stood a black lookout, leaning on his spear, with one leg resting against the inside knee of the other'* (1934, p.201). Toonka Waterhole, a semi-permanent waterhole in the south-eastern corner of Monkira, was the site for the Naiari ceremonies, which honoured the mythologically powerful thorny devil (*Molloch horridus*).

Figure 22: Kingadurka Waterhole – once the site of impressive corroborees, it remains a beautiful place, but also one tinged with a silent sadness. Sitting by the waterhole at dusk, it is not beyond the realms of the imagination to glimpse a black figure silhouetted against a fiery red sunset, and recall the words of Duncan-Kemp*: 'As the heels and toes of a hundred and fifty warriors hit the ground, the earth trembled and shook in the vicinity and the sound rolled like thunder over the gravel plains for miles*' (1934, p.220).

Duncan-Kemp (1962) writes particularly beautifully of the magpie goose ceremony on Pitchuricoppa Waterhole, with 200 blazing torches, much chanting and stamping of feet reverberating across the plains. This 'goose crying' went on until nearly sunrise, and the Aboriginal people were richly rewarded with thousands of geese – old residents claimed it was one of the biggest flocks seen in living memory. Unfortunately for the geese and the Kurawali people, the nesting birds were trampled underfoot by cattle and horses, dying in their thousands. For months afterwards, a mess of blood and egg yolk clung to the boots of stockmen and the chests and legs of stock – yet another example of the irreconcilable clash of cultures and land management practices.

On the Thomson River, the Longreach Waterhole was considered to be a sacred site, and Mrs N. Button recalled, as a child, seeing a large number of Aborigines in tribal costume passing through 'Dundee' station on their way to a ceremony at the waterhole (Moffat 1987). Further up the catchment at Lammermoor, Narkool Waterhole on Tower Hill Creek provided the backdrop to a 'koroborees'. One of these was observed by Christison in the mid-1860s: a dazzling display of 'stamping, shouting, grunting…the eerie tapping and chanting like violins wailing', with the elaborately-painted dancers silhouetted in the firelight. Beyond that, 'the white immemorial bloodwoods seemed to gather round like watchers evoked by the firelight from the surrounding darkness and silence' (Bennett 1927, p.65). Also along this creek, there is a fall of about 4m over a rocky bar. This permanent waterhole was a favoured camping ground and was called 'Kooroorinya', meaning the rainbow, which could be seen through the spray rising from the water as it fell over the falls (Donovan & Wall (eds) 2004).

It was believed that Balleroo, the Rain God, resided in some of the deeper waterholes such as Monte-pi-eer-ree on the Mooraberrie/Durrie boundary – '…he dwells only in deep waterers and passes from waterhole to waterhole in the form of a rainbow' (Duncan-Kemp 1934, p.130). Duncan-Kemp writes of finding Billy, the Medicine-Man, camped alone by Monte-pi-eer-ee Waterhole, meditating in an attempt to regain his magical powers from the all-powerful Balleroo. Fear of the legendary evils that lurked beneath the water in the deepest, darkest recesses of the big waterholes also played a major part in Aboriginal mythology (Duncan-Kemp 1934), and no doubt contributed to the sacred, sublime and unfathomable esteem in which waterholes were held.

4.5.3 Exploration and waterholes

The journals of explorers provide the first written records of waterholes in the Lake Eyre Basin. While most explorers noted the perceived quality and permanency of waterholes, these observations depended largely upon climatic factors and time of year. For example, the first white men to record the nature of the Diamantina River country, McKinlay (1862) and Hodgkinson (1876), travelled through the area when the river was in flood, so were unable to provide any reliable estimates of permanency. Aware that they were merely glimpsing a snapshot of a particular area, explorers often used the presence of certain animals or plants and Aboriginal tracks or campsites as indicators of the permanence of water. However, even with these clues, assessments of permanency were usually inaccurate. In central Australia, Stuart initially thought that the majority of waterbodies he encountered were permanent, only to discover on subsequent trips that most had dried out. Both Gosse and Giles travelled after extensive rains, and many major waters they assessed as 'permanent' were later found to be temporary (Box *et al.* 2008).

The search for water in this dry and difficult climate, both for immediate use and possible future development, was a constant theme of exploration. As articulated by Ernest Giles (1889, p.292), 'Life for water he [the explorer] will at any moment give, for water cannot be done without'. Numerous themes are evident in the story of waterholes and exploration, as discussed below.

4.5.3.1 Seach for and methods of finding water

The search for water formed a grandiose goal of early explorations: 'An inland sea and a great internal river were continuously present as persistent and elusive mirages throughout the whole history of Australian exploration, and they provide the main theme for the story of that exploration' (Cumpston 1964, author's note). This conviction was especially ardently held by Captain Charles Sturt on his 1844-5 expedition into the interior of Australia, even as evidence mounted against such a possibility. Sturt carried a wooden boat (and two sailors) on his entire journey, through dunefields and gibber plains, only discarding the useless vessel at 'the Depot' (near the present-day site of Tibooburra) on his return journey. Sturt wrote forlornly that 'The boat was launched upon the creek, which I had vainly hoped would have ploughed into the waters of a central sea' (Sturt 1846). John McDouall Stuart lacked the resources necessary to cart such a vessel, but was still optimistic about finding 'Wingillpin' (Aboriginal place of water in central Australia) on his 1858 journey around central and southern SA (Bailey 2006).

However, the desert is quick to crush such extravagant hypotheses, and the reality of the inland soon forced explorers into a more modest, but no less fervent, search for water. And so it was that these men, their heads filled with dreams of vast seas and great rivers, became completely dependent upon, and eternally grateful for, small waterholes and muddy puddles – the 'dubious oases in the shimmering plain of motion', that simultaneously succoured and haunted Voss in Patrick White's classic exploration novel. To many explorers, it seemed as if the whole inland landscape had been constructed in order to defend the distance and the solitude. Exploration was only made possible by the presence of waterholes – and the assistance of local Aborigines in finding these vital oases.

Explorers, out of necessity, followed chains of waterholes as they pushed further inland. Waterholes harbour everything the explorer requires: 'feed, water, wood and shelter from the broiling sun' (McKinlay 1863, p.37). Horses require huge amounts of water, and even camels must drink sometimes, while the 'living larders' brought by the explorers also required regular water (Macinness 2007). It is not surprising that the journals of all explorers are dominated by the continuous quest for water. While most experienced bushmen used 'signs' such as certain trees and birds to indicate the presence of water, other, less savoury, techniques were also used. The practice of kidnapping an unfortunate 'native' and forcing them to reveal water sources appears to have been embarrassingly widespread – less scrupulous explorers such as David Carnegie even fed salt beef to their captives 'both to cement our friendship and promote thirst…' (Carnegie 1898).

In the Lake Eyre Basin of Queensland and SA, Aboriginal people usually provided invaluable local knowledge to explorers generously and willingly. The first white man to enter the LEB, Edward Eyre, wrote of the kind, friendly and cheerful people he met, describing how '[I] had them accompany me for miles to point out where water was to be procured (by digging) and [have] been assisted by them in getting at it, if from the nature of the soil or my own inexperience I had any difficulty' (Eyre, *Manners and Customs of the Aborigines of Australia*, cited in Bennett 1927, p.93). On the Cooper, the friendly people that Sturt encountered not only explained the nature of the drainage to him, but also brought water to the men and their horses upon arrival at a large camp on a waterhole (Sturt 1849).

Thomas Mitchell employed Aboriginal 'guides', in various guises, on all of his inland expeditions between 1828 and 1848. These people, male and female, young and old, proved invaluable to Mitchell in terms of safety, navigation and locating reliable waterholes along the inland rivers (Baker 1992). He was amazed at their detailed knowledge of the country. The intelligence and judgement of Yuranigh were so valued by Mitchell on his 1846-7 expedition into central Queensland that he kept him by his side when travelling and trusted his advice above that of any white man in the party (Baker 1992). In recognition of his 'guide, companion, councillor and friend', he named the party's final camping spot before turning to retrace his steps along his imagined 'Victoria River' (actually the Barcoo): *'At dusk, I met with one containing a fine lagoon and near this I fixed my bivouac. Yuranigh most firmly objected to our sitting down close by the water, saying that we might there be too easily speared by the wild natives who were then, probably, on our track; but he did not object to my bivouac on the more open plains adjacent, one man keeping a good look-out. I called these, Yuranigh's ponds'* (Mitchell 1847, 26/10/1846).

On Christmas Day 1861, camped on a lake in north-eastern South Australia, McKinlay set off a rocket to deter the 'natives prowling around camp'. It had the desired effect, but he was exceedingly glad when they returned the next morning as if nothing had happened: '…better it should be so, as no doubt I shall find them of great use in pointing out the principal waters…' (p.31). Even Burke and Wills, who regarded the natives with a mixture of derision and anxiety and believed they had nothing to learn from the 'ignorant blacks', were assisted by Aboriginal people as they headed north. On the Diamantina River, John King was amazed to find that some of the Aborigines were generous enough to point out the best waterholes: '…when the saw us, they kept going away & point(ing) to where the water was' (Murgatroyd 2002, p.194). Even Hodgkinson's quick-moving party of 1876 pursued and interrogated local Aboriginal people for information on the location of waterholes and the distances between permanent water (Simmons 2007).

The key importance of Aboriginal knowledge in the exploration of the region, primarily by assisting in the crucial search for water, cannot be underestimated. There is a certain irony in the way that Aboriginal people assisted the explorers in 'opening up' the country. Unwittingly, these helpful, generous people were assisting the spread of European settlement and pastoralism, which within two decades would wreak devastation on their traditional way of life.

4.5.3.2 Dictacting, making or breaking journeys

The journeys of all explorers were fundamentally dictated by the availability of water en route. All explorers knew that their expeditions would succeed or fail based on the presence and reliability of waterholes, and their ability to find them. Prior to setting out on his ill-fated second expedition, Ludwig Leichhardt, perhaps the most enigmatic and mythologised explorer in Australian history, wrote: 'As I depend completely upon water I can advance only where I find it' (quoted in Lewis 2006, p.6). This dependence is demonstrated by the fact that all major expeditions in the

Georgina, Diamantina and Cooper catchments followed watercourses, and that water is mentioned at least once a day in nearly all journals.

Numerous expeditions were forced back for want of water: Eyre by his 'impassable horseshoe' of salt lakes; Sturt as he attempted to penetrate the stony desert and sea of fiery sand dunes; Landsborough on his initial push down the upper Georgina River. Despite obviously travelling in a favourable season (most of the seasonal lakes in the Coongie region were full of fresh water), McKinlay was as bound by the availability of water as those who had gone before him. Whilst waiting for the return of Hodgkinson, whom he sent to Adelaide for provisions, he wrote: 'Should any rain fall…I will go over to Cooper's Creek Depot; but the country is so exceedingly dry in this region at present, that unless I can make out to hit upon these places where water has been left by the last flood, it would be quite impossible to travel with anything like safety (p.21). To this end, he spent long days searching for water east of his 'Wantula Depot'. After being deceived and frustrated by convincing and alluring mirages shimmering between the dunes, he concluded there was 'not the slightest appearance of water anywhere' (p.23).

Contrary to most expeditions, which are characterised by thirst and the constant desperate quest for water, the otherwise hapless Burke & Wills must have travelled in a very good season, and were short of water for just one day on their entire journey (Murgatroyd 2002). Their surprise discovery of the Diamantina River, just south of the present-day township of Birdsville, after days of trudging through sand dunes in the December heat, was perhaps the pivotal moment in their journey north. It led them to the Georgina system and then onwards to the Gulf. Paradoxically, it was not the waterless desert that defeated Burke and Wills; rather, it was too much water that took a heavy toll on the men and their animals at various stages of their journey.

4.5.3.3 Quest for understanding of hydrology

Grasping the nature of the drainage was a matter of grave importance for explorers in arid regions, as the success of their expedition and the very survival of their party depended upon being able to find reliable water sources. The complex network of streams and channels in the LEB has perplexed explorers and settlers from the outset. Both Mitchell and Kennedy struggled to decipher the hydrology of the upper Barcoo in the Great Dividing Range (Mitchell 1847; Kennedy 1847).

On the opposite side of the Basin, Sturt was confounded by the 'channel country' he encountered: *'The singular and rapid succession of these water courses exceedingly perplexed me, for we were in a country remote from any highlands, and consequently in one not likely to give birth to such features, yet their existence was a most fortunate circumstance for us'* (Sturt 1849). Two decades later, McKinlay was regularly 'astonished' by various aspects of the hydrology of north-eastern South Australia.

These explorers were not alone: all the early explorers were perplexed by the hydrology of the country they traversed. They were particularly dismayed at the speed with which apparently large waterholes dried up. McKinlay and Kennedy both found waterholes which they used dried up upon their return, days or months later, while Wright, leading a relief party north to meet Burke at the Cooper Creek Depot, rued the drying up of waterholes on the Strzelecki Creek. The waterholes which had sustained Burke's initial party had shrunk to undrinkable sludge by the time the unfortunate Wright stumbled past (Murgatroyd 2002).

4.5.3.4 Psychological comfort in an otherwise harsh landscape

In 1939, Cecil Madigan became the first white man to finally 'conquer' the waterless Simpson Desert from west to east. He wrote, in tones reminiscent of Joseph Conrad, that *'There are other barren and silent places, but nowhere else is there such vast, obtrusive and oppressive deadness…the ghostly spirit brooding of the past is inescapable, haunting, menacing. Death seems to stalk the land…Thirst can never be quenched here, it can only be aggravated; eyes are blinded by the flare, throats parched by the bitter dust. All signs of life cease as the dead heart, the lake, is approached…It is like entering a vast tomb. Gaiety is impossible… There is the indefinable feeling of the presence of death'* (Madigan 1940).

While Conrad was sailing up large rivers into the 'heart of darkness', surrounded by water, thick vegetation and the shadowy presence of aggressive natives, Madigan's 'dead heart' is characterised by openness, blinding sunlight, overriding aridity and a humming silence. While Conrad's expeditioners followed the river towards the inevitable chilling horror, Australian explorers tended to view the environment along watercourses as benign, even beautiful. Waterholes in particular provided much-needed psychological comfort to the explorers, who were pushing both mind and body to the limit in a strange, unfriendly land.

The most positive and effusive journal passages were often written by explorers besides picturesque waterholes. These journals, penned by men conventionally viewed as stoic, utilitarian gentlemen (Macinness 2007), provide an unlikely insight into the psychological succour provided by waterholes. Whilst obviously vital to the explorer's push inland, waterholes were also places of mental respite, inspiration and muse. There was something in their unruffled calm and contrasting coolness that stirred the imaginations of explorers and seemed to awaken their more philosophical and poetical natures.

Charles Sturt was especially partial to some metaphysical musings as he made his arduous journey towards his imagined inland sea. At one riverside camp, early in the journey, he ruminated at length on the necessity of the Murray River to human beings, and comfortingly concluded that *'…so it is, that in the wide field of nature, we see the hand of an over-ruling Providence, evidence of care and protection from some unseen quarter, which strike the mind with overwhelming conviction, that* *whether in the palace or in the cottage, in the garden, or in the desert, there is an eye upon us.'*

After a long, trying and ultimately unfulfilling journey, Sturt sat by a waterhole on Cooper Creek and considers his position: '*When I sat down beside the waters of this beautiful channel to which Providence in its goodness had been pleased to direct my steps, I felt more than I had ever done in my life, the responsibility of the task I had undertaken.'* In the midst of fiery sand dunes and unforgiving stony desert, Sturt was prone to feelings of melancholia, which spawned numerous impassioned meditations on mortality and human failing. These passages often verge on the melodramatic, which is understandable under the circumstances. In contrast, the waterhole setting seemed to impart calmness to his psyche, and he was able to assess his situation with considerably more perspective and benign resignation.

Thomas Mitchell is perhaps the only other inland explorer to match Sturt in terms of eloquent, if somewhat histrionic, prose. Many of his most lyrical passages were composed overlooking inland waterholes. One spring morning beside a 'fine pond of water' on the Barcoo River, Mitchell imagined he had attained a 'sublime position…between earth and heaven where a man…hears nothing but the thoughts of the Almighty'. Other explorers were less effusive, but the importance of waterholes to these men and their parties, over and above their palpable survival value, is evident in nearly all published accounts. Even the usually solemn Wills was suitably enamoured by the waterhole on Gray's Creek where the explorers spent Christmas to enthuse that '…never in our most sanguine moments [had we] anticipated finding such a beautiful oasis in the desert' (cited in Murgatroyd 2002, p.188).

However, even when water was found, it was not always the imagined oasis. Water was often of questionable quality, and nearly every journal contains some 'horror story' about muddy, contaminated or otherwise dubious water that the party was forced to drink. For example, heading through the barren white dunefieds into the southern Simpson Desert, Winnecke and his party did not see water for a fortnight. On reaching the Mulligan, the party was exceedingly glad to find a 'waterhole' containing 'an inch of liquid and putrid mud', despite the fact that it had 'a most vile taste, and caused us all to vomit violently' (1884, p.3).

4.5.3.5 Waterholes as backdrop for despair, boredom and horror

Despite providing vital life-giving water, waterholes also formed the backdrop for excruciating experiences of tedium, sickness and, sometimes, death. After establishing his Depot in the Grey Range of north-western New South Wales, Sturt explored every creek and gully in the area, becoming increasingly desperate as he realised the party was trapped by lack of water 'as effectively as if they were wintering at the Pole'. He described in horrified language the gibber plains and sand dune desert during the very dry years of the mid-1940s, and wondered 'Was it instinct that warned the feathered races to shun a region in which the ordinary course of nature had been arrested, and over which the wrath of the Omnipotent appeared to hang?' (Sturt 1849). Kennedy was similarly 'imprisoned' at waterholes, left behind to establish depots as Mitchell pursued glory and discovery in the Queensland interior. During his subsequent expedition to trace Mitchell's 'Victoria River', Kennedy expressed mixed feelings upon returning to these places that harboured memories of boredom and anxiety (Kennedy 1847).

Burke & Wills selected the magnificent Bullah Bullah Waterhole on the Cooper as their Depot prior to their push north: 'an exuberant slice of park-like beauty that obliterates the desert beyond' (Murgatroyd 2002, p.161). Not surprisingly, it soon felt more like a prison to Brahe and the two other men left behind. For four months and one week they remained at this dubious oasis in the oppressive desert, haunted by boredom, sickness, lethargy and the unnerving presence of the local Aborigines, with whom relations swung between grudging tolerance and outright hostility. In ill-health and believing that the exploration party had perished in the desert, Brahe was certainly not disappointed to leave Camp 65 and head south.

Later, this picturesque camp and its ancient coolibah tree became the backdrop for a tale of despondence, disappointment and excruciatingly bad luck that is unparalleled in Australian exploration. Returning to find the camp abandoned by Brahe and his men only hours earlier, Wills and then Burke died of malnutrition on the banks of the Cooper – a spot which had initially excited the men as a veritable haven in the harsh desert landscape they were exploring. Today, Wills' grave lies on the end of Tilka Waterhole and Burke's on Yidniminckanie Waterhole, silent testimony to the harrowing ordeal suffered by these explorers (Figure 23). King was found between Minkie and Mulkombar Waterholes, and Howitt established a camp at Cullymurra Waterhole (Figure 23) in September 1861 to allow the emaciated man to convalesce.

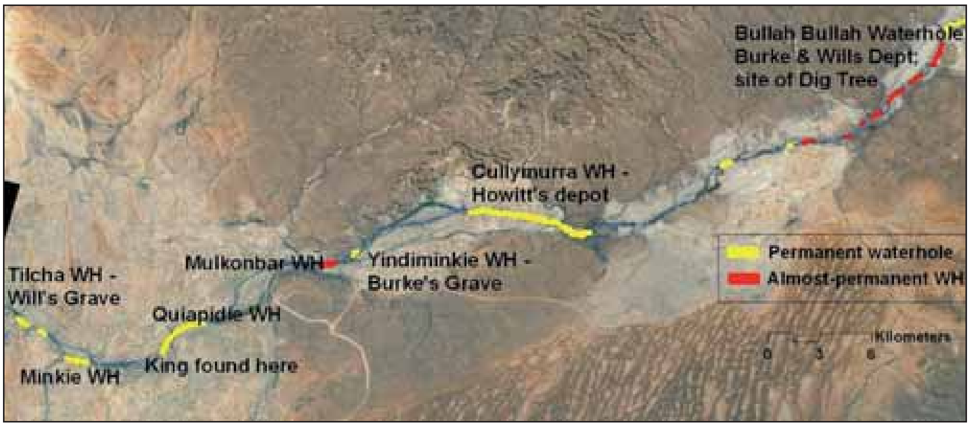

Figure 23: Geography of a Tragedy: Key Waterholes in the Burke and Wills Story

Howitt had a very different experience on the Cooper waterholes. His correspondence indicates that the journey verged on routine for him, with the party achieving their goals with apparent ease. At Cooper's Creek he explored towards Mount Hopeless, leaving the men to garden, fish and build a fort at the permanent

Cullymurra Waterhole. While King convalesced, the men entertained themselves shooting, fishing and relaxing (Tolcher 1986). Accounts of this 'peaceful and pleasant' camp make it sound more like a holiday retreat than a macabre expedition to recover the bodies of dead explorers! Howitt returned weeks later to a hearty meal of horse steak and fresh vegetables, a few kilometres from where Burke and Wills perished (Murgatroyd 2002).

4.5.3.6 'Discovery' and naming of water features

Explorers named many of the more prominent features they passed, especially creeks and rivers, reflecting the importance of these life-giving corridors to their expeditions in a harsh climate. Most watercourses were named after expedition members, respected peers, the explorers themselves, relatives, or politicians – the latter being men worth flattering in the pursuit of further exploration funds. Waterholes were generally only bestowed a name if they became a Depot, or were the backdrop to a portentous or noteworthy event.

Sturt's 1844-5 expedition was essentially a failure (by his own harsh judgement), but his party was the first to glimpse what would come to be seen as the most important natural assets of the region: the waterholes of the Cooper, Eyre and Strzelecki Creeks. In an oft-quoted passage, he wrote: *'Before we finally left the neighbourhood…where our hopes had so often been raised and depressed, I gave the name of Cooper's Creek to the fine watercourse we had so anxiously traced, as a proof of my great respect for Mr Cooper, the judge of South Australia. I would gladly have laid this creek down as a river, but as it had no current, I did not feel myself justified in so doing.'* Sturt also named Strezlecki Creek, which leaves the Cooper at Innamincka, after Polish Count who discovered Mt Kosciusko and Eyre Creek, in recognition of his friend and contemporary.

Mitchell, Surveyor General of NSW, 'discovered' the Barcoo River on his fourth journey of exploration into the tropical interior of Australia in 1845-6. He was hoping to find a large River flowing to the Gulf, which would open trade routes to the north and secure his reputation as one of the most important explorers in the nations' history. He first laid eyes on the river on September 15, near the present township of Tambo, and was very pleased with his discovery. He followed it north-west to near Blackall, becoming increasingly convinced that he was following a pathway to the Gulf. Despite this noble stream turning ominously to the south-west as he continued to trace its path, Mitchell confidently named this river the 'Victoria', and headed back to Sydney secure in the knowledge of his great discovery.

Meanwhile, as Edmund Kennedy soon discovered on his 1847 expedition to trace its course, the river continued to wind its way towards the centre of the continent. Kennedy's expedition, which somewhat portentously departed on April Fool's day 1847, followed Mitchell's "Victoria" to south of where it meets the Thomson, which he named after Mr Deas Thomson, then treasurer of NSW. As he got further south, past the present-day site of Windorah, he realised that Mitchell's grand hope – his ‘paradise on earth’ – was in reality part of Sturt’s ‘earthly hell’ (Bell & Iwanicki 2002). He renamed it the ‘Barcoo’, based on the Aboriginal name for the river, and headed dejectedly back to its source. It is thought to be a misinterpretation of the Aboriginal word *Baka Amoo*, meaning two rivers. During this period of discovery, there was a gap of about 150 miles between the two farthest points of discovery on the Cooper: Kennedy’s southern terminus and Sturt’s furthest north.

Burke and Wills named numerous tributaries of the Georgina-Mulligan system, including the Wills River and King Creek. (The Burke River was named posthumously). However, it was the four relief expeditions who followed them who were collectively responsible for inscribing the ‘ghastly blank’ of the interior with European names. Landsborough had already named the major upper tributaries of the Thomson (Aramac, Torrens, Landsborough and Tower Hill Creeks) on his 1860 foray. On his 1862 rescue expedition, he named the ‘Herbert’ River (which was later renamed the Georgina to avoid confusion with the coastal river of the same name), as well as two of the major waterholes of the upper catchment – Lakes Mary and Francis – after his nieces.

‘Big John’ McKinlay is known as the first white man to explore what would become known as the Diamantina River country. Heading north, he was forced to skirt the then-flooding river, passing through present-day Monkira, Davenport and Diamantina Lakes, and crossing the river near Old Cork. Impressed by this ‘magnificent stream, [here] at least 250 yards wide, and from 40 to 50 feet down the banks to the water, lined with noble gums, box, bean, and other trees…’ (p.52), he named it ‘Mueller’s Creek’, after his friend Ferdinand von Mueller. Towner (1955) lamented that ‘the white men of Winton’ preferred the name of an Italian Lady (the socialite wife of Governor Bowen) to a Danish scientist, resulting in a euphonious but meaningless name, which failed to commemorate the contributions of Mueller to Australian botany. McKinlay also named numerous lakes in the Coongie region (which he was fortunate to encounter in a good season) and tributaries of the Diamantina including the Hamilton River and Middleton Creek (Table 14).

The unflagging Hodgkinson was a member of the original Burke & Wills expedition, served on two of the search parties for this same expedition, then led a party to evaluate the land west of the Diamantina in 1876! He named the Mulligan River after James Venture Mulligan, discoverer of gold on the Palmer River, and camped on its large waterholes, including ‘Dickerrie’ and ‘Can-tan-tera’. Although the Mulligan was becoming ‘an hopeless arid funnel’, the constant oozing of springs provided the party with water. In doing so, he had established a connection between the furtherest points of Sturt and Landsborough.

By this stage, all major streams in the Cooper, Diamantina and Georgina catchments had been ‘discovered’ and named. (Although Winnecke named the ephemeral Hay River, on the far western edge of the study area, in 1883.) The journals and letters of early explorers largely paved the way for future settlement, and were devoured by potential pioneers as a source of information on the vegetation, soil, climate and, perhaps most fundamentally, the availability of permanent water. As such, the time lapse between formal exploration and pastoral settlement is extremely short, with the two 'phases' overlapping to some degree.

For example, Robert Christison was inspired by the Burke and Wills relief expeditions to explore the Queensland frontier. After departing Bowen in 1863, Christison was fortunate to meet Landsborough on the Suttor River, with the explorer advising him: '…you will find a creek which I named Towerhill Creek, with waterholes in it large enough to float the Great Britain' (Bennett 1927, p.49). Patsy Durack and John Costello were similarly inspired by Landsborough's exploits (Durack 1959). The first settler on the Cooper, John Conrick, was attracted to the area by the reports of permanent water by Burke and Wills and McKinlay (Tolcher 1986). By the time Hodgkinson's government-sponsored survey of the Diamantina in 1877, squatters had selected most of the country along the river (Simmons 2007). Table 14 summarises the watercourses and specific waterbodies named or mentioned by early explorers (those named are italicised). A current project looking at explorer records and observations in the Lake Eyre Basin will provide more detail on waterholes encountered and described by explorers (Toby Piddocke, pers.comm., May 2009).

Table 14: Watercourses and waterholes named or mentioned by explorers in LEB

Explorer/s	**Expedition Dates**	**Watercourses *named* or mentioned**	**Waterholes *named* or mentioned**
Eyre	1840	Lake Eyre/associated lakes	
Sturt	1844-6	*Strzelecki Creek, Cooper Creek, Eyre Creek*	*Depot Glen* WH (western NSW)
Mitchell	1845-6	*Douglas Ponds Creek, 'Victoria River'* (actually the Barcoo)	*Yuranigh Ponds*
Kennedy	1847	*Thomson River, Barcoo River*	
Gregory	1858	Diamantina River, Thomson River, Barcoo River, Cooper Creek	
Burke & Wills	1860-1	Browne's Creek, *Gray Creek, Wills Creek, King Creek,*	Cooper waterholes, Coongie Lakes, waterholes on Diamantina south of Birdsville, Boulia waterhole
Landsborough	1860 and 1862	*Aramac, Torrens, Landsborough and Tower Hill Creeks (1860);Herbert River* (renamed Georgina), *[also Gregory River]*	*Lakes Mary and Francis*
Howitt	1861	Cooper Creek	*Cullymurra Waterhole*, Quiapidrie Waterhole
Walker	1861		
McKinlay	1861-2	*'Mueller's Creek'* (Diamantina River), *Davenport Creek, Browne Creek, Browns Creek, Hamilton River, Middleton Creek, Warburton River, McKinlay Creek* (Gulf)	*Lake Hodgkinson, Lake Lady Blanche, Lake Sir Richard, Lake Massacre* (after the SA Governor MacDonnell and his wife)
Lewis	1874-5	*Goyder's Lagoon*	
Hodgkinson	1876	*Mulligan River, McLeod's Creek*	Dickerrie WH, Can-tan-era WH
Cornish	1879	Eyre Creek, Sylvester Creek	Womilia WH, Maria WH, Bindiacka WH

Winnecke	1883-4	Field River, *Hay River*	Nantowarpunna WH, Wyceculcuna WH, Dulcannia WH, Mungerannie WH, Chandlers WH, 'Top Hole' (Kallacoopah Ck, Cowarie), Bindiacka WH, 'Mataro' (Montara) WH, Coonamucka Swamp
Madigan	1939	Diamantina River, Mulligan River, Field River	Dickeree WH,

4.5.4 Early Settlement and Waterholes

From the outset, water was seen as being intimately and inescapably linked with the prospects of the burgeoning Queensland frontier (Powell 1991). As the era of exploration merged into the frontier period of settlement, waterholes continued to dictate the patterns of European settlement, just as they had governed the lives of Aboriginal people for millennia. By the 1860s, the waterholes of the Cooper and Diamantina systems were household knowledge throughout Australia, and inspired a pastoral rush (Bell & Iwanicki 2002). Rather than settlers advancing from the established settlement in eastern Queensland, they instead followed the routes along major watercourses and chains of waterholes established by the explorers (Allen 1968). As a result, most settlers arrived from the south along the Darling and Paroo or Warrego Rivers. The routes along the waterholes of Cooper and Strzelecki Creeks, established by Gregory, also provided reliable routes for entering these new 'Plains of Promise'.

Would-be pastoralists who failed to find water on their journeys in search of land suffered lonely fates in the desert. A farmer known as Coulthard set out in 1858 from Adelaide in search of new pastures to the north. His mummified body was found next to his empty water-bottle, into which he had scratched his last words: *'I never reached water…My Tung is stkig to my mouth and I see what I have wrote I know it is this is the last time I may have of expressing feeling alive & the feeling exu is lost for want of water My ey Dassels My tong burn. Ican see no More God Help'* (Muragtroyd 2002, pp.9-10).

Keen to avoid such agonising fates, explorers and settlers took particular care to map and record the reliability of all water sources they stumbled across. When 20-year-old John Conrick set out for the Cooper, his father's final words were: 'Do not stop until you get good and permanent water, and make no mistake about it' (Tolcher 1986, p.52). By the 1880s, the location of most major permanent waterholes were known by name and mapped. John Sand's 1886 map shows many waterholes along the Georgina and Diamantina systems (Nolan 2003, p.60), reflecting their importance to the new settlers. Table 15 provides a summary of some waterholes that were particularly significant to white settlement of the LEB.

Table 15: Waterholes of significance in early white settlement

Waterhole	River and Property	Notes
Andrewilla Waterhole	Diamantina River, Alton Downs	Site of Diamantina Native Police camp. These troopers patrolled much of the north-east of South Australia, and were implicated in numerous acts of violence against the local Indigenous population (Tolcher 1986).
Barracks Waterhole	Bourke River, Strathelbiss	Site of Native Police Barracks north of Boulia from 1875-1884; unsurprisingly, given the scarcity of permanent water in this area, it was also a significant site for Aboriginal people.
Cullymurra Waterhole	Cooper, Innamincka Regional Reserve	In mid-1860s, with unconscious irony, 650km^2, encompassing Cullymurra Waterhole, was set aside for the 'exclusive use' of Aborigines, in recognition of the services rendered to King. The intention was that a Mission should be established here to minister the needs of the Cooper people. However, the Morvian Mission relinquished any claim to this land in 1869, and it reverted to the Crown (Tolcher 1986).
Glengyle Station Waterhole	Eyre Creek, Glengyle	A coolibah tree near this waterhole is said to be the one under which Sidney Kidman camped when developing his holdings in western Queensland, and is now known as the 'Tree of Knowledge' (Nolan 2003)
Goonbabinna Waterhole	Cooper, Nappa Merrie	Site of John Conrick's (among the first permanent white residents on the Cooper) first camp in 1873. Conrick was alone at this waterhole for two months, during which time he was watched by Aboriginal people as he tended his vegetable garden, milked cows and rode among the cattle. Before dawn one morning, about 200 Wongkumara people surrounded his hut, determined to rid themselves of the white intruder. Fortunately for Conrick, his dog attacked an advancing warrior, and the others retreated (Tolcher 1986).
Koonchera Waterhole	Diamantina, Clifton Hills	Semi-permanent waterhole; important water resource on route of European explorers and drovers
Kyabra Waterhole	Kyabra, Kyabra Station	Site selected for John Costello's family homestead in late 1860s (Durack 1959).
Lake Mary	Georgina, Rocklands	Probably the first major waterhole on the Georgina River to feel the impact of sheep hoofs, in late 1860s – Sutherland (1913) describes the chaos of some 8000 sheep rushing 'through fires, blacks and all other impediments to quench their thirst'. The weary party made camp on the left bank of the river and called the station 'Rocklands', where the present homestead still stands.
Longreach Waterhole	Thomson River, Reserve	Site of town selected after surveyors had inspected Arrilalah as the site for railway terminus. After they left, they discovered the large waterhole and decided it was the most suitable site for a town, which was gazetted in 1887 (Moffat 1987)
Maapoo Waterhole	Cooper, Nappa Merrie	'Narran Jim', who brought the first cattle to graze on the Cooper in 1868, camped at this waterhole. Unfortunately, he had stolen the cattle from across southern Queensland, and Inspector Fitzgerald and his Native Police tracked him to this waterhole and arrested him. At the waterhole, they are said to have found branding iron with removable parts that could be used for many different brands, and threw it into the waterhole where it could do no more harm.
Mackhara WH	Diamantina, Monkira	Permanent waterhole on first run in area, in middle of Diamantina Channel, taken up by John Costello in 1875; possibly the site of 'Costello's camp' north-east of present-day homestead, which was the site of first white habitation in the area.
Milkara (Milkery) Lagoon/WH	Diamantina, Mooraberrie	During big droughts in the early days of settlement, household washing was taken to this waterhole, 24 miles south-west of the Mooraberrie homestead, leading Duncan-Kemp to exclaim 'Forty-eight miles to wash clothes! And these trips were made as a rule

		during summer with the blistering sandhills throwing the heat into our faces.' (1934, p.91). It was also used as a long-term base during large musters on Mooraberrie, sometimes serving as a camp for up to six weeks.
Moorabulla Waterhole	Mulligan River, Sandringham	Also site of Native Police barracks, at 'Bean Trees' (Nolan 2003)
Mudlacooncha Waterhole	Diamantina Roseberth	Native Police, whilst investing the death of a man from thirst in the stony desert in 1880, made their camp on this waterhole, and were stranded here for weeks due to a complete lack of water on their intended route back to Coongie (Tolcher 1986)
Narkool Waterhole	Towerhill Creek, Lammermoor	Site of first homestead on the upper Thomson tributaries; energetic pioneer Robert Christison, after exploring the waterless downs to the west in 1863, was so glad to see the hills and waterholes of Towerhill Creek that he named his new station 'Lammermoor' and settled on one of the wide waterholes (Bennett 1927).
Old Station Waterhole	Coorabulka, King Creek	A new mudbrick homestead was built at this waterhole after the 1902 drought, reliant on perhaps the only genuinely semi-permanent waterhole on the vast property (Nolan 2003)
Rio Waterhole	Thomson, Rio/Strathmore	Coxon family lived in a tent on the bank of Rio Waterhole for two years, before moving into their house in 1890 (Miss Alice Coxon, cited in Moffat 1987)
Thylungra Waterhole	Kyabra, Thylungra	Site selected for Patsy Durack's homestead in the late 1860s (Durack 1959)
Wantata Waterhole	Diamantina, Durrie	Search for Leichhardt's party focussed on this waterhole in 1871; it is now believed that they made it further west than this, perhaps to the Great Sandy Desert (Lewis 2007)
Whitula Waterhole	Whitula Creek, South Galway	A reserve for Aborigines was opened on the abandoned Whitula Station in 1902, adjacent to the 'fine lagoon'. This was an attempt by the Queensland Government to ease the suffering of Aboriginal people who, deprived of the physical and spiritual nourishment of their traditional lifestyle, were starving and dying of disease during the Big Drought. All the old and infirm Aborigines were to be 'collected' and brought to the mission. However, this intervention came rather too late, and the reserve was closed in 1904 (Tolcher 1936, p.137).

4.5.4.1 Waterholes and settlement patterns

Settlement proceeded in a rather haphazard fashion through the 1860s, with emphasis on securing access rights to waterholes and river frontages in close proximity to the most favourable sections of land (Allen 1968). As such, settlement of the Channel Country occurred in several distinct phases, with the 'cream of the country' selected first (Tolcher 1986). For a few pounds, squatters could purchase all permanent waterholes and river frontages, thereby tying up vast swathes of grazing land. There was active competition for runs with deep, permanent waterholes (Bell & Iwanicki 2002). Those unfortunate enough to select runs without permanent water were quickly rendered unviable in dry times, and were often forced to relinquish them. The value of waterholes is demonstrated by the contrasting settlement patterns of two neighbouring regions, the Cooper and Strzelecki. The Cooper, with its deep permanent waterholes was permanently occupied from the earliest days of settlement in the late 1860s. In stark contrast, the country along the Strzelecki, with few reliable waterholes, was taken up later and abandoned on numerous occasions during drought (Tolcher 1986).

On the eastern side of the Basin, Landsborough and Buchanan's 'Landsborough River Company' moved with haste to stock the runs and secure the best land and watercourses. The first stock were moved onto Bowen Downs in October 1862. Nat Buchanan surveyed the runs for waterholes and likely locations for outstations, and 'discovered' a series of waterholes further along Aramac Creek. Writes Moffat, 'Buchanan, ever mindful of the value of water, advised that this land be secured' (1987, p.26). Pioneer Robert Christison was impressed by the large waterholes of Towerhill Creek, but nevertheless continued to push west over 'shadeless, waterless, limitless downs' as far as the Diamantina River (Bennett 1927, p.51). After enduring the waterless trek back east, he was so grateful for the glimpse of the tableland which harboured these wide waterholes that he named his new station 'Lammermoor' after the ranges of his childhood home, and settled on one of the waterholes. Christison made a further foray into this waterless triangle in 1866; a journey dominated by paroxysms of thirst and desperation, punctuated only by idle dreams of rivers and waterholes (Bennett 1927).

Costello and Durack made their first foray into western Queensland in 1863, ultimately settling on Kyabra Creek in 1867. The Pastoral Leases Act of 1869 provided very favourable terms and conditions for pioneers. A man only had to run a few head of stock on land to 'claim' it – 'his tracks were on it and that was that (Durack 1959, p.110). Durack and Costello 'spread their tracks' liberally between 1868-75, until their combined territorial claims covered nearly all the land between Kyabra Creek and the Diamantina (Table 16). The mid-1870s saw the pushing back of the pastoral frontier, with land parcels sold easily or given away to friends and family. By 1875, most of the Diamantina Channels had been leased – unwatered 'back-block' country was only taken up after the more desirable watered runs had been occupied. Early property inspections by the Assessing Commissioner reported principally on permanent waterholes (Nolan 2003).

Table 16: Properties in the Costello and Durack 'Empires' (compiled from Durack 1959)

John Costello	Patsy Durack
Kyabra, Monkira, Davenport Downs, Mt Leonard, Daru, Mooraberrie, Morney Plains, Currawilla, Coongabulla, Connemarra, Keeroongooloo	Thylungra, Ray, Springfield, Bungiderry, Galway Downs, Wallyah, Warrabin, Bodalla, Copai, four large blocks along Cooper Creek + many others whose names no longer survive

European settlers generally built their new homesteads on large waterholes which appeared to be permanent or almost so. Not only did this provide a vital source of water, but it also provided a softer, more comforting vista for these pioneers in their new strange homeland. This wholly understandable preference can still be observed (and enjoyed) by residents and visitors to many stations across inland Queensland. A notable exception is Mooraberrie, which is situated on a usually-dry creekbed on a stony plain. Watson (1998) states that the Duncans heeded the wishes of local Aboriginal people when deciding where to situate their homestead.

Waterholes, being vital to the success of any inland pastoral enterprise, quickly inspired protectiveness among the new 'owners'. As the Durack and Costello party moved northwards through western New South Wales in 1863, men from the recently established cattle and sheep runs dropped in on the camps, ostensibly to greet the party, but mostly to ensure that they did not linger too long on station waters. Later, when the town site of Betoota was proposed in the late 1880s, the owners of Mt Leonard became fiercely protective of Teeta Waterhole, which was their main water supply. They were concerned about the destruction of 'timber and rushes', which the firm had gone to great lengths to protect, and had even planted more trees. Surveyor James Hood informed the Department of Lands of 'a number of very handsome bauhinia and other trees' growing around the waterhole and a timber reserve was subsequently proclaimed there (Nolan 2003). This is probably the first recorded incidence of official 'conservation' of a waterhole, and set a precedent of looking after these valuable waterholes which continues to this day.

4.5.4.2 Waterholes and travel

Permanency of waterholes dictated the movements of the early settlers from the time they first entered the Lake Eyre Basin. Sutherland was a member of the first white party to bring sheep to the upper Georgina. When Lake Mary dried up, the party shifted south to Lake Frances. Before long, however, '…the water vanished, and a shift of quarters was imperative' (1913, p.15). They remained at a new camp on Don Creek until Lake Frances half-filled again.

The distribution of waterholes continued to dictate travel for decades, when horse and cart provided the only means of moving throughout the area. Stock routes and roads, by necessity, followed the lines of major rivers where water could be found for horses and travelling stock. For example, the 'short-cut road' from Brighton Downs to the Hamilton, Burke and 'Herbert' (Georgina) Rivers was usable only soon after rain – otherwise there was an impassable 80 mile stretch with almost no water. For most of the year, it was necessary to travel down to the permanent water at Diamantina Lakes, up Spring Creek, and meet the 'short-cut road' 20 miles from the Hamilton Channels (Nolan 2003). In severe droughts, such as the 'Federation Drought', travel was well nigh impossible in affected regions until rains had replenished the vital stop-over waterholes.

Prior to the advent of bores, the Birdsville and Strzelecki tracks were often closed due to droughts, to avoid the catastrophic cattle losses that were experienced in the early years. At the onset of the fourth 'great drought' since white settlement, drovers taking cattle south for Kidman only just made Koonchere Waterhole. Trapped there with weakened stock and no other water within reach in any direction, they could merely watch as the water completely dried up, and 1200 cattle perished (Bell & Iwanicki 2002). Such stories are common in the early days of pastoralism, particularly along the unreliable Strzelecki Track, where stages of 130km between water had to be negotiated during dry times (Tolcher 1986). Many men also died lonely, agonising deaths on waterless stages of tracks (Moffatt 1987, Tolcher 1986).

A particularly unpleasant job for troopers stationed along the Cooper was to fashion shallow roadside graves for these unfortunate men. Some of these are still visible today, bearing silent testimony to the unforgiving aridity of the inland.

With the spread of settlement, towns began to spring up to service the needs of the pastoralists. Again, water was a primary consideration in selecting early town sites. Towns throughout the LEB tend to be situated near permanent, or semi-permanent, waterholes (although there are some exceptions). In many places, the width of the floodplain necessitated building a considerable distance back from the 'town waterhole'. However, towns such as Birdsville and Innamincka occur where the river narrows to one or two channels, providing both reliable water and a convenient crossing place (Historical Research Pty Ltd *et al.* 2002; Tolcher 1986).

Cobb & Co services operated between towns and properties, transporting goods and people. Change stations were situated on large waterholes, including Warracoota Waterhole on the Diamantina and Camoola Waterhole on the Thomson. Such was the importance of water to Cobb & Co carriers, and therefore movement of people and supplies around the inland, that many carriers were idle during drought times. In the 1902 drought, many roads were closed due to lack of water en route. Towns such as Longreach became completely isolated – the Longreach-Winton road was considered to be one of the worst tracks, with a stage of 100 waterless miles (Moffat 1987). Similarly, in prolonged droughts Innamincka and the surrounding Cooper country could be cut off for many months (Tolcher 1986). The motor car and tapping of artesian water, both of which began in earnest after the 1902 drought in the central-west, have rendered such considerations obsolete. Today, towns only become isolated during times of too *much* water.

4.5.4.3 Aboriginal assistance

Local Aboriginal people 'schooled' the early settlers in many aspects fundamental to survival of both pastoralists and stock: where to find water, the capacity and reliability of waterholes under certain conditions, and the likely extent of flooding (Duncan-Kemp 1934; Watson 1998). In this way, early pastoralists were intimately dependent upon Aboriginal knowledge, just as their white predecessors, the explorers, had been. Even during the drought of the late 1860s, with surface water across the district drying up, Christison remained secure in the knowledge that the oldest member of the Dalleburra tribe had never known the large waterholes of Towerhill Creek to fail (Bennett 1927). Upon arriving at a huge waterhole north-west of Quilpie, Patsy Durack questioned the hundreds of Boontamurra people who were camped there about the permanency of the water. The blacks made a 'babble of assent': 'You-eye! Thillung-gurra' ('Yes, good water. Not go dry.' The fumbling pronunciation from Durack's Irish tongue led to the waterhole being named 'Thylungra'. These Aborigines then drew him a mud map of Kyabra Creek and associated waterholes, including a big waterhole called 'Mommaminna' (Durack 1959).

When Longreach town was being surveyed, a group of Aboriginal people were still using the Longreach Waterhole, and were said to camp on 'Hospital Hill'. They provided surveyors with valuable information about the Thomson in flood, enabling them to select a safe location for the town (Moffat 1987). The historical record demonstrates that without Aboriginal people, white occupation of the Lake Eyre Basin would have been vastly more difficult than it proved to be (Tolcher 1986). One feels that, had the Indigenous people had any inkling of the white mans' intentions, they would not have been so hospitable or forthcoming with their knowledge.

4.5.4.4 Dark waters: waterholes on the frontier

Sadly, waterholes are fundamentally embroiled in one of the ugliest and most destructive phases of Australian history. The oft-cited 'rush for grass' can equally be viewed as a 'battle for the waterholes' (McGrath 1987, cited in Jackson *et al.* 2008, p.281), and much of the conflict that ensued between early settlers and the Aboriginal population stemmed from arguments about waterholes. While the European explorers had generally established cordial relations with Aboriginal people in the lands they travelled through, conflict became evident from the beginning of white settlement, once it became clear that the Europeans and their stock were going to stay. Resources, particularly water, are scarce for most of the time in the LEB, and the Aboriginal people quickly grew resentful of this new incursion on their waters.

Even the explorers incited understandable resentment if they lingered on waterholes. The arrival of white men and their snorting, cantankerous beasts must have been a bewildering event for the Aboriginal people, who had flourished in their environment for millennia. To the local people, the explorers must have seemed exceedingly rude, stomping determinedly towards their sacred waterholes and allowing their animals to splash carelessly around the banks. Landsborough found Aboriginal people of the upper Georgina to be 'anything but friendly', and deemed it dangerous to camp near the waterholes (Sutherland 1913). Wills noted that Aboriginal people often gesticulated wildly at the white men whenever they approached a waterhole (Murgatroyd 2002) – presumably they at least wanted to know how long the interlopers were going to stay.

It seems that a short stay was acceptable to the people who depended upon, and cared for, inland waterholes. However, when parties lingered, trouble often arose. Beckler, when searching for Burke and Wills, was forced to stay at Koorliatto Creek on the Bulloo River when two of his men were too sick to travel. Aboriginal people resented the party camping at one of their best waterholes, and maintained a threatening vigil around the camp for three tension-filled weeks (Murgatroyd 2002). Further on, at a large permanent waterhole on the Bulloo River (site of Becker's Grave), the frustrated Aboriginal tribes ambushed Wright's party. Despite being massively outnumbered, and most of his party being sick and/or dying, the white men's fire power proved too strong. 'Mr Shirt', an Aboriginal leader, was shot (presumably killed), as the rest of the warriors fled into the bushes (Murgatroyd

2002). This encounter set a precedent for the perhaps inevitable conflict that was to occur with the influx of white settlers (Lewis 2005).

Raids, battles and attacks feature prominently in the account of Sutherland (1913) from the upper Georgina in the 1860s. No deaths or even injuries are mentioned in the account. However, with sentences such as 'to protect ourselves and stock, necessity forced us to battle royal' and references to shots being fired at the 'ferocious and warlike' natives, it seems very unlikely that there were no casualties. Once again, waterholes – favoured camps of both the blacks and the white invaders – formed the backdrop for these conflicts.

Waterhole conflict is entirely understandable: the influx of thousands of cattle and sheep onto previously pristine waterholes, which were vital for the survival of Aboriginal people and often had immense cultural significance, had profound repercussions for Aboriginal life. Destruction of waterholes is evident from the accounts of the very first pioneers and explorers. After trudging over 'parched plains' and 'dusty mulga' west of the Paroo River in 1863, Patsy Durack and John Costello finally found some water in the Bulloo River. Mary Durack writes that: *'The frenzied cattle smelt water…and broke into a stampede. They plunged forward to the river, trampling fallen beasts to pulp under their frantic hoofs. Half were drowned in the milling turmoil, while the rest drank until they nuzzled the mud and then bogged, exhausted, too weak to pull themselves out.'* (1959, pp.69-70).

In a similar vein, Sutherland describes a scene of chaos as the first sheep hit Lake Mary on the upper Georgina in the 1860s. The Aboriginal people who were camped on the waterhole banks were *'roused out of their sleep at midnight by some 8000 sheep rushing madly and tumbling over them…[this] was something demonical to the simple natives, who never saw or heard of jumbucks before…*' (Sutherland 1913). One can only imagine the terror, bewilderment and anger of the local Aboriginal people as they watched the waterholes they had tended and conserved for millennia being desecrated in a matter of minutes. However, the impact of explorers and early pioneers on waterholes was relatively minor compared to the constant and intensive use of river frontage which followed.

Runs were initially relatively highly stocked and, in the absence of fences, stock were free to wander across the area, monopolising rivers and waterholes, and reducing both the quality and quantity of water available. Cattle destroyed fringing vegetation, scared off much of the wildlife and made hunting difficult by obliterating tracks of prey animals, as well as disturbing sacred sites (Roberts 2005; Jackson *et al.* 2008). The ecological impacts of this early stocking were severe: erosion, disturbance of game animals, reduction in and damage to fringing vegetation. When dry times hit in the 1880s, many runs were revealed to be severely overstocked. The stock losses during the drought years of the early 1880s are mind-boggling (see Section _), and the impacts on the remaining permanent waterholes, as dying stock concentrated, then died, around them, are self-evident.

Moreover, Aboriginal people were often chased away from their usual living areas near waterholes so the new white settlers and their stock might have exclusive access. While the wanderings of Aborigines was generally accepted as an ‘unavoidable evil’ by settlers, their presence near water needed for stock was undesirable. Even sympathetic pioneers such as Alfred Walker, manager of Innamincka Station, had no qualms in requesting police to move people on when they were camped at waterholes needed for cattle. Tolcher writes that ‘Everywhere, the Aborigine was driven away in dry seasons form the good waterholes to make room for the cattle, and if he returned he was harassed, sometimes shot at, and moved on again until the lesson was learnt’ (1986, p.133).

Reflecting the fear and mistrust of the frontier days, it was common practice not to allow Indigenous people near the homestead. As homesteads were usually built on the best waterholes in an area, there was always potential conflict, which could sometimes only be resolved by use of firearms (Bennett 1927). In Queensland, John Costello reported numerous instances of aggression towards the new white settlers. As with other early homesteads, Costello was forced to fortify his Kyabra homestead against these attacks. Conflict with local people on the Diamantina also saw the provision of small rifle holes in the walls of the original Monkira homestead (Kowald & Johnston 1992).

Townspeople were also less than enamoured by the presence of Aboriginal people at ‘their’ waterholes. An 1887 petition signed by Birdsville ratepayers requested the Divisional Board ‘remove and prevent Blacks and their animals from encamping on the Township Waterhole’ (Nolan 2003, p.176). At the time, the waterhole was low and up to 100 Aboriginal people and their dogs would bathe there, rendering the water ‘unfit for human consumption’. In the summer of 1934-5, Innamincka Waterhole became contaminated and resulted in a bout of gastro-enteritis. The mounted constable took prompt action, shooting surplus dogs in the Aboriginal camp, burning their wurleys and sending the inhabitants downstream, where they would have to dig for water in the dry riverbank (Tolcher 1986). Such competition over a very limited resource was a constant theme over these years, with conflict intensifying during dry years.

Aborigines were also forbidden from using traditional ‘poisoning’ methods to catch fish, with the usually sympathetic Duncan-Kemp writing that ‘…pituri drugging was considered a heinous offence, especially where stock watered. A crime punishable by a thorough good stock-whipping’ (1934, p.148). Put simply, the original inhabitants and introduced grazing stock were in competition for the same resource – and the possession of firearms (and willingness to use them) conferred a significant competitive advantage on the fledgling pastoralists. Before long, Aboriginal people, who had survived the vagaries of the inland climate for millennia, were starving to death in droughts.

Finding their land and water dwindling, Aboriginal people took to wholesale slaughtering of stock. Savage conflict was widespread across the Channel Country, upper Georgina and north-eastern South Australia in the period from the 1860s to at least the turn of the century (Tolcher 1986; Hercus 1990; Watson 1998; Bell & Iwanicki 2002; Roberts 2005). While there were myriad reasons for this (including abduction of gins and children for slavery and various other atrocities), the occupation and subsequent desecration of waterholes looms large in nearly all accounts of conflict across the area.

Some settlers argued that the country would only be safe when the last of the blacks had been killed – Durack writes that the Native Mounted Police 'rode to kill – to shatter the old tribes…to leave men, women and children dead and dying on the plains, in the gullies and river beds'. Constable Urquart's appalling frontier ballad told of the vengeance wrought upon the Kalkadoons following the murder of his friend Powell by 'ruthless blacks' (Durack 1959). He pledged that for every bone in Powell's body, a Kalkadoon would die:

> 'Soon the field is clear…
> Unless just dotted here and there
> A something on the ground,
> A something black with matted hair
> Lies without life or sound.'

Waterholes, being both precious resources and favoured camping spots, formed the backdrop to numerous massacres, including in the Channel Country (Table 17). There are numerous accounts of 'raids' on blacks camped at waterholes, often at dawn when people were asleep. Some massacres occurred when large numbers of Aboriginal people converged on waterholes for ceremonies. Many of the Wangkangurru people of the Simpson Desert were probably unaware of the presence of white men in their country. They found out quickly and violently when some of them travelled to Kalidawarry Waterhole near Muncoonie Lakes for a great *Warrthampa* ceremony. Nearly all who went were murdered by police in retribution for the death of a white man (Hercus 1990).

Station-managers like J.W. Wylie at Coongie and the notorious Johnnycake Miller fenced people out of their own lands and poisoned or shot anyone who returned. Wylie deemed the presence of Aborigines incompatible with good cattle management, and drove away or killed all but a few of the 500 he found on Coongie when he arrived in 1881 (Tolcher 1986). Waterholes provided the backdrops for much of this violence, including a particularly horrific massacre in the 1880s at Koonchera Waterhole, a great ritual centre, where the point of a sandhill forms a peninsula, jutting out into the waterhole. A large number of people from various groups had assembled at the waterhole for ceremonial purposes. The entire group (men, women and children) were cut off at the narrow point of the peninsula and shot, and the bodies burnt, to avenge the theft of one young bullock. Five men escaped – one by feigning death and four by diving into the waterhole (Hercus 1986). For obvious reasons, these events are generally poorly documented.

Table 17: Known or suspected sites of massacres at channel country waterholes

Waterhole	River/Creek	Notes
Koonchera WH	Diamantina	Site of viscous massacre in 1880s of large party who were camped on its shore for the Mindari ceremony; between 200-500 people were shot by Andrewilla police (Hercus 1986)
Kalidgiworra WH	Mulligan	Many people from surrounding areas travelled to this waterhole near Muncoonia Lakes for the great *Warrthampa* ceremony. Nearly all who went were murdered by police in retribution for the death of a white man (Hercus 1990).
Dangeri WH	Diamantina	Watson (1998); no further details provided
Cooningheera WH	Diamantina	A station cook was speared here, resulting in a spate of retaliation massacres of the Karangura people in the Pandie Pandie area; details of these events are sketchy (Bell & Iwanicki 2002; Hercus 1990)
Goyder Lagoon	Diamantina	Watson (1998); no further details provided
Thundapurty WH	Diamantina	Watson (1998); no further details provided
Waukaba/Jimburella Waterhole	Georgina	Massacre at 'Hangman's Bend' described in gruesome detail by Lamond (1953:19) and probably occurred in the 1870s: 'The pastoralists and stockmen decided to give the blacks a lesson…the water at the top end of Waukaba was red that day. The whites used their muskets on the black ducks in the water'.
Innamincka WH, near Will's Grave	Cooper	Details sketchy (Bell & Iwanicki 2002)
Oontoo WH, Nappa Merrie	Cooper	This massacre seems unlikely to have been connected to John Conrick, who had no record of violence; it is more likely to have been the work of the Queensland Native Mounted Police, acting without Conrick's knowledge (Tolcher 1986)
Wombinderry WH, Springfield	Kyabra	Young stockman who liked to 'playfully' shoot around the Aboriginal people killed one of their dogs. He then went to fish by the river and was killed in retaliation. His remains were found in the receding waterhole by the Inspector of the Native Police from Thargomindah. No questions were asked about the murder, and at dawn, a reprisal was undertaken at the camp, in which many men, women and children were murdered (Watson 1998)
Welford Waterhole?	Barcoo	Welford was murdered by an Aboriginal worker. Patsy Durack offered shelter to station blacks from the inevitable Native Police reprisal, but many fled into the surrounding bush. Mary Durack writes that 'Only a handful who had sought the refuge escaped the raid' (1959, p.140).

However, not all regions were marred by such violence. The exodus of the Wangkangurru people of north-eastern SA to missions and stations was largely a voluntary and non-violent one, as people gravitated towards these places in the last decade of the 19th century (Hercus 1990). On the Cooper, there were only isolated instances of confrontation as Aboriginal people were dispossessed of their land and waterholes. Pastoralists such as Alfred Walker on Innamincka and John Conrick on Nappa Merrie were genuinely concerned for the welfare of local Aborigines. In sharp contrast to other areas, there also seems to have been a reasonably good relationship between Aborigines and police on the Cooper, and no punitive expeditions are recorded (Tolcher 1986).

By about the 1890s, Pharmaleechie Channel on Mooraberrie, a wooded, well-watered stretch of country on the Diamantina, was used as a refuge for Aboriginal people from other areas who had been dispossessed by pastoral interests (Watson

1998). Aboriginal people also gathered in large numbers around Thylungra and Kyabra homesteads, receiving rations but maintaining traditional ceremonial life. Durack (1959) reports that, on special occasions, as many as 600 people would gather on the Thylungra Waterhole. The old and new cultures existed side by side for a couple of decades, until dependence and disease took their seemingly inevitable toll on the Aboriginal population.

Similarly, there is little evidence of bloody conflict on the Thomson River. There is comparatively little known about groups such as the Malintji, Kuungkari and Inningai and, while stock attacks and stealing are recorded, there are few accounts of widespread violence on either side. Lacy of Aramac Station and one of his employees were killed on Reedy Creek, by Aborigines angry at the intrusion of stock on their land and waterholes. European retaliation was 'swift and the group responsible…were dealt with in kind' (Moffat 1987, p.27). However, this seems to have been an isolated incident. There are, in fact, numerous accounts of Aboriginal groups leading semi-traditional lives whilst living and working at the new homesteads.

The story of Christison of Lammermoor provides a rare example of the original residents and new settlers living side by side in apparent harmony. The permanent waterholes along Towerhill Creek were well occupied when Christison arrived, including the Homestead (Narkool) Waterhole, which was a meeting place for various groups. In contrast to many pioneers, Christison did not try to interfere with their use of this waterhole. The traditional inhabitants were able to continue a semi-traditional lifestyle on Towerhill Creek during Christison's time, combining traditional ceremonies and lifestyle with new duties around the station. When he left, Christison pleaded with the new owners to allow the blacks to stay on Lammermoor. Before discussing the sale, Christison said: 'We will not discuss anything until their right to remain until their right to remain on the station as their home is settled…' (Bennett 1927, p.247). Sadly, even with such manifest goodwill, the clash of cultures had disastrous consequences for the original custodians.

Less than 40 years after white settlement, nearly all traditional owners had succumbed in the face of settlement, ravaged by violence, disease (mostly venereal), starvation and the spiritual malaise of apathy and despair (Watson 1998). By 1887, of the 300 Aborigines Alfred Walker found on Innamincka Station in the early 1870s, only 30-40 were left. On Nappa Merrie, equally small camps remained of the large populations the pioneers had found living around waterholes (Tolcher 1986). Duncan-Kemp claims that 3000 people living in the vicinity of Dangeri Waterhole were gradually decimated between 1864 and 1894. By the turn of the century, most waters in the Channel Country had become 'orphaned', and the waters were said to be crying out in pain (Duncan-Kemp; cited in Watson 1998). Apamurna Waterhole (*Ngapa-mana*) saw the last flicker of revival of Yawarawarrka traditions, with an initiation ceremony in the 1920s. The final initiation ceremony in South Australia was held at Innamincka in 1941. And so it was that the people who had depended upon, cared for and mythologised waterholes of the LEB for millennia all but disappeared from these now 'orphaned' waters.

4.5.4.5 Chinese gardeners

From the beginning of pastoral settlement, the population of many towns in the LEB had sizeable Asian populations. In Longreach, the Chinese population was reported to have outnumbered Europeans at one stage (Moffat 1987). Little is recorded about Chinese families across the region, however they are best remembered as suppliers of fresh fruit and vegetables. The usual pattern was for a gardener to establish a patch in the fertile alluvial soil beside a reliable waterhole and plant a market crop that could be watered by hand. Gardens often included potatoes, cabbages, watermelons and maize (Bell & Iwanicki 2002).

Throughout the late 19th century most towns, and some of the larger homesteads, had Chinese gardeners operating on the major waterholes. Many waterholes in the Thomson catchment supported Chinese gardeners, including Muttaburra, Strathmore, Longreach, Bogewong and Vergemont from about the late 1800s to the 1930s. At Lammermoor, the Chinese garden was situated on Newjenna Waterhole south of the homestead. By the early 1890s, it was '*taking on the semblance of a huge chessboard under Ah Tin's care. Among neat beds of vegetables rows of red cabbage were conspicuous by their ruby shadows and crisp cobalt lights, and watermelon plants by their rambling luxuriance; bananas rustled by the waterhole; paw-paw trees were growing apace; and oranges and citrons bent to the ground beneath a weight of fruit with blossoms showing here and there*' (Bennett 1927, p.206). Downstream, there were two Chinese gardens on the Muttaburra Broadwater, and Doug Langdon recalls riding his bike down to the gardens to feast on mulberries and other fresh produce.

On the Cooper at Innamincka there was half a hectare of market garden tended to by Chinese, who grew fine vegetables using water drawn from Cullymurra Waterhole by an impressive water wheel. Even as far west as Glenormiston on the Queensland border there are remnants of stone walls built for dams by Chinese gardeners. It is likely that these people were in the area from the late 1860s to early 1870s, when the Georgina was used as a route to the newly-discovered gold fields in the Northern Territory (Kowald & Johnston 1991). The garden established on the Birdsville town waterhole in the 1880s is still evident today, in a patch of ground cleared of stones (Bell & Iwanicki 2002). The Chinese overshots on the upper Diamantina at Kynuna Waterhole are perhaps the most visited relics. The Chinese gardeners were subject to the booms and busts of inland rivers just as much as the townspeople and pastoralists who bought their produce. Dan Kelly, the Chinese gardener at Innamincka, lost everything in the 1906 flood. With the flourishing garden buried under a metre of mud and silt and his fruit trees dead from inundation, he was faced with the choice to begin again or move on – he stayed on (Tolcher 1986).
There is no record of what became of the Chinese gardeners, and they seem to have gradually faded out as transport became faster and more reliable across the district.

It seems that the Birdsville garden may have operated until the 1950s (Bell & Iwanicki 2002). The many 'Garden Holes' across the LEB are a legacy of these Chinese gardeners, and the valuable dietary supplement their vegetables must have provided to the fledgling communities. It is yet another example of how waterholes have shaped human activities across the Lake Eyre Basin.

4.5.5 Waterholes and recreation

Waterholes have been foci for recreational activities over millennia. While Indigenous people fished primarily for utilitarian purposes, there seems to have been an element of frivolity involved. Duncan-Kemp (1934) writes of women and children enthusiastically rushing down to help the men sort out their large catches from netted waterholes. Children loved to amuse themselves by playing in waterholes. Duncan-Kemp describes such a scene: *'Shrieks of childish laughter floated up from the dome-shaped huts that formed the blacks' camp. Black heads bobbed up and down in the waters as two gins, playing Wirral-lee and Yamma-coona with four or five children, dived to the bottom of the creek and came up snorting with clawing fingers. Shrieks of delighted horror as five brown bodies scuttled out up the banks followed by an open-mouthed gin crawling on all fours'* (1934, p.185).

From the earliest days of settlement, waterholes were similarly enjoyed as meeting and recreation places. The first recorded waterhole 'picnic' in the LEB occurred in the 1860s. Robert Christison's first wife, the only white woman in the area during the early days of settlement in the 1860s, used to accompany her husband as he surveyed paddocks. She would rest during the day by a lily-covered waterhole where they would meet for lunch (Bennett 1927). On Kyabra Creek, the 'Thylungra Championship' was held at the waterhole on special occasions. *'All the fellows would line up and at the word 'go', they'd be off hell for leather, but the new blokes always got out in front somehow – through the tape and splash into the waterhole five foot down the bank.*' (1959, p.149). Even enforced stays on waterholes, by virtue of roads being cut or cars becoming bogged, were relished by the early settlers, as recounted by Alice Duncan-Kemp when the swollen Cooper halted their progress for five days: 'We passed the time pleasantly enough fishing and rowing and watching some pelicans' (1934, p.6).

Waterholes have provided shade, coolness and social outings for townsfolk since town were gazetted in the LEB, especially prior to the advent of televisions, public pools and air-conditioners. Boating, swimming and regular Sunday picnics were all popular at the Longreach Waterhole from the late 19th century (Moffat 1989). On the Cooper at Innamincka, fishing and picnics provided welcome diversions from the challenges and hardships of bush life, particularly during the trying dry years (Tolcher 1986). During the 1890s, boats were provided to numerous Channel Country properties, for use in flood time (Nolan 2003). Mr Moffat, from Camoola Park on the Thomson River, pioneered more adventurous boating on the Thomson in the 1940s/early 50s, when he transported a group of crutchers from Camoola Park to near Oakley during flood. Kate Deane recalls giving them lunch at Goodberry Hills before they launched back into the river. These boats were the forerunners of the current recreational use of boats on the major holes in the Thomson River.

Birdwatchers have long been drawn to permanent waterholes such as Diamantina Lakes (McGillivray 1929). Today, tourists are drawn to water in a dry land – a recent report (Schmiechen 2004) estimates that about 40 000 to 50 000 visitors per annum are attracted to the permanent Cullyamurra Waterhole near Innamincka. Inevitably, recreational hotspots such as waterholes will see some divergence in views as to what constitutes 'appropriate' activities. Many birdwatchers, kayakers and advocates of more sedate recreational activities view the use of motorboats, speedboats and jetskiis as a violation of the essential quality of inland rivers – their quietness and languor. The thrill-seekers aboard these vessels (or being towed behind them) are typically dismissive of such concerns. For them, waterholes are associated with fun, adventure and speed. Fortunately, waterhole adventurers like company and tend to congregate in large numbers in certain favoured reaches, leaving many waterholes for the more solitary souls to enjoy in peace.

4.5.6 Current knowledge

The detail and extent of knowledge of land managers, past and present, is impressive. Most long-term managers and owners have an intimate knowledge of all waterholes on their properties, which can sometimes number in the hundreds. Some graziers have become familiar with waterholes along large stretches of river, either through conversations over the years or piloting small planes and/or helicopters. Many are able to recount the hydrological history of particular waterholes since European settlement, including the exact dates of drying. There are strong parallels between this knowledge and the rich tapestry of knowledge held in traditional Aboriginal societies (Bayly 1999), reflecting the paramount importance of water in an arid land.

It seems likely that this 'observational knowledge' regarding the location and persistence of waterholes has diminished over the past couple of decades (Box *et al.* 2008). Managers generally spend less time traversing country on foot or horseback, and the tenure length of managers on one property has decreased. Most of the long-term land managers interviewed for this project were over 50, and it is common for younger managers to move around from property to property. There is also an increasing trend in some areas for properties to be amalgamated or have absentee land managers. Coupled with this is the fact that bores and dams have replaced natural waters as the primary sources of water for both humans and livestock, meaning that waterholes are often not monitored so closely.

A small number of people interviewed for this project were long-term residents in towns along the river systems. Such people had spent many years piecing together local histories, and were a wealth of information on waterholes. Keen fishermen were often fonts of knowledge about the permanence (and fishing potential) of waterholes along certain reaches.

4.6 Human impacts and management

From the beginning of settlement, humans have had some impact on waterholes. Aboriginal people netted the waterholes and hunted for game in their vicinity, sometimes harvesting large hauls from these areas. However, over thousands of years, these people had learnt to utilise these precious resources in a sustainable manner. The many accounts of Aboriginal management of and respect for waterholes bear testament to this. Today, waterholes are the focus of both animal and human activity in the LEB, and as such face numerous pressures. When wetlands in arid zones are degraded by human activities, the impacts can be irreversible (Box *et al.* 2008). The major potential threats to waterholes in the Cooper, Diamantina and Georgina catchments are discussed below.

4.6.1 Increased total grazing pressure

It was the influx of European grazing animals, both domestic and feral, that had the greatest and most obvious impact on waterholes. Introduced livestock and grazing management practices are among the most widespread agents of modification to riparian and wetland areas in Australia (Morton *et al.* 1995; Jansen & Robsertson 2001). Cattle, sheep, rabbits, horses, goats and pigs all contribute to total grazing pressure. Impacts include trampling and bank destabilisation, grazing of riparian vegetation, fouling and muddying of water, and directly depleting water supply through drinking (Duguid *et al.* 2005). The following sections outline historical and current grazing pressure and associated impacts on waterholes in the study area.

4.6.1.1 Historical overgrazing: domestic stock and feral animals

<u>Domestic stock</u>

Adverse impacts were evident from the very first stock to encounter inland waterholes. At the Depot in north-western New South Wales, where his party was forced to endure six tedious months waiting for rain to allow them to push further inland (see Section 4.5.3), Sturt wrote that: *'Our animals had laid the ground bare for miles around the camp, and never came towards it but to drink. The axe had made a broad gap in the line of gum trees which ornamented the creek, and had destroyed its appearance.'* (1849, p.208). However, such impacts were small and localised compared to the pastoral influx that was to follow.

Runs in the LEB were initially highly stocked, as optimism combined with favourable seasons and lease conditions to entice pioneers and large herds of cattle and sheep onto the unaccustomed land. When dry times hit in the 1880s, many runs were revealed to be severely overstocked. The stock losses during the droughts in the early years of European settlement are mind-boggling. The impact of the 1880s drought was felt even in the least arid and most well-vegetated part of the LEB – the tributaries that form the upper Thomson catchment: *'On the back blocks where there was grass there was no water; round the diminishing waterholes the ground was eaten bare, and cattle and sheep were in all stages of suffering –the dying among the dead; those that had any strength gnawed the bark from the trees'* (Bennett 1927, p.170). Further down the catchment, Mt Cornish lost more than 13 000 cattle in 3 months in 1884, while 60 000 sheep died on Strathdarr between 1883-5 (Moffat 1987).

Around the turn of the century, a disastrous drought (now known as the 'Federation Drought') struck the Channel Country. Carandotta, Oscar de Satges' property on the upper Georgina, lost 90 000 sheep and 10 000 cattle in this drought (Watson 1998). At the southern end of the LEB, on the lower Cooper, it was estimated that 70-90% of the region's cattle and 50% of sheep died during this drought (Tolcher 1986). As the drought worsened, weakened stock bogged in huge numbers around the edge of drying waterholes. By 1898, the waterholes of the lower Cooper were 'surrounded with the packed rotting carcases of beasts…' (Tolcher 1986, p.209). One large permanent waterhole was said to have more than 600 carcases to the kilometre on the bank! Similarly, the banks of the Longreach and Birdsville Waterholes were lined with dead and dying animals. Nuisance Inspectors and Common Rangers were given the unpleasant duty of preventing the precious water from being polluted by carcasses. However, this was an increasingly difficult task as more and more desperate animals came to the river in search of water (Moffat 1987; Nolan 2003). The effect on the few remaining waterholes (and the surrounding country) as stock battled for survival is self-evident.

Later droughts also brought heavy stock losses: Cordillo Downs lost about 26 500 sheep in 1915, while 30 000 and 10 000 cattle died on Innamincka/Coongie and Nappa Merrie respectively (Tolcher 1986). In the late 1920s, after another dry decade, the Government Inspector described waterholes along the Cooper as 'slimy travesties ringed with pockmarked mud and red carcases' (Tolcher 1986, p.213). Properties along the Georgina and Diamantina also suffered severe stock losses during the 1920s (Kowald & Johnson 1992). The 1940s and 1960s are also remembered as times of bad drought and associated stock losses (Sandy Kidd & John Ferguson, pers.comm., September 2008 & February 2009). In the days before reliable transportation allowed properties to be destocked, waterholes would have been subject to extremely heavy stock pressure, compounded by an influx of feral animals.

<u>Feral animals</u>

Today, rabbits are not an animal typically associated with the degradation of waterholes. However, the historical densities of rabbits in southern parts of the LEB suggest that their past impact on the landscape, including waterholes, was catastrophic. By 1884, rabbits were described as being in plague proportions in South Australia, and by the mid-1880s rabbits had been sighted on the Cooper in north-eastern SA. In 1888 work began on a rabbit-proof fence along the Queensland-South Australian border in a desperate bid to halt their rapid northwards migration. The effect of the rabbit plague on the fragile inland landscapes was severe. John C. Warren of Tinga Tingana on Strzelecki Creek recalled the impact of rabbits during the early 1890s: *'They came in like water through a funnel…ravaging all before them, rooting up the perennial grasses, destroying the edible bushes, and ringbarking all that they could not climb …When in December the great heat set in, they died by thousands round the waterholes, and tainted the air…'* (in Tolcher 1986, p.194).

The whole country resembled a 'sandy desert', and stations along the Strzelecki were abandoned. The mailman from Lake Hope and Coongie reported having come across a living carpet of rabbits, more than 6km wide and as thick as they could run together. The whole country was honeycombed with burrows (Tolcher 1986). Despite the frantic efforts of State Rabbit Boards, rabbits continued their inexorable march northwards. In addition, many brumbies were shot around waterholes on the Wilson and Cooper. In the 1930s, 4000 were shot by shooters on Innamincka alone, while between 1945-7, 8000 were shot along the Cooper in Queensland (Tolcher 1986).

The ecological impacts of this historical overgrazing on the few remaining permanent waterholes during droughts would have been severe, including bank erosion, destruction of riparian vegetation and deterioration of water quality. This conclusion is irrefutable. However, the long-term implications in terms of waterhole 'silting' are more contentious, as are the impacts of current grazing practices.

4.6.1.2 Current grazing management

Today, overgrazing is commonly cited as a threat to waterholes (e.g. Robertson & Rowling 2000; Jansen & Robertson 2001; Sheldon *et al.* 2003). Choy *et al.* (2002) found that riparian and channel condition in the LEB was adversely affected by stock access. These impacts were particularly noticeable during the dry season. Undoubtedly, grazing is concentrated around water sources and can have an affect on waterholes and the surrounding vegetation. This is most commonly manifested in a loss of groundcover, particularly perennial grasses, and bank instability and erosion. Grazing can also limit regeneration of riparian species and reduce the abundance of litter and woody debris (Robertson & Rowling 2000). These impacts are evident at many waterholes in the study area to varying degrees (Figure 24).

Jansen & Robertson (2001) found that riparian condition score was significantly negatively correlated with grazing pressure on the Murrumbidgee River, and that continuously grazed sites generally scored lower than paddocks which were regularly rested. Impacts on the riparian zone surrounding more permanent waterholes are likely to be particularly pronounced in dry times. In the Channel Country, stock are usually moved off properties during the dry season, which would allow waterholes and their surrounding vegetation a chance to recover. Stocking rates in many areas are also low enough to limit severity of grazing impacts at the majority of waterholes (Brock *et al.* 2006).

Figure 24: Impacts of overgrazing on waterholes in the study area

Feral herbivores that can potentially add to total grazing pressure around LEB waterholes are goats, pigs, rabbits, horses and goats. Today, rabbit numbers have declined by up to 80% in inland Australia due to the introduction of myxomatosis and, in the mid-1990s, rabbit calicivirus disease (Edwards *et al.* 2002). While their numbers remain high in some areas, the impact on waterholes is nowhere near as severe as it was prior to the introduction of such diseases. Goats have become a nuisance around waterholes in some areas, particularly where waterholes occur in close proximity to dense timber and/or range country in the south of the region (Freudenberger & Barber 1999; pers.obs.). Not only do they contribute to total grazing pressure, they have particular impacts on riparian trees and shrubs through browsing and destroying seedlings (Harrington 1979). Feral pigs can have localised impacts on bank stability and riparian vegetation through rooting around waterholes. The increase in kangaroo numbers since white settlement (Bennet 1927; Department of Lands 1993) also contributes to total grazing pressure around waterholes.

The combination of domestic stock, feral animals and, to a lesser extent, native herbivores, means that total grazing pressure around waterholes and across the surrounding landscape has been greatly elevated over the past 130-140 years. In general, waterholes seem to be quite resilient to increased grazing pressure, probably because flooding will always represent the overriding disturbance to the system. Where grazing pressure is high, however, impacts are manifested in loss of groundcover around waterholes, particularly perennial grasses, browsing of woody vegetation, bank erosion, lack of recruitment of woody riparian species, soil compaction, and higher nutrient levels in the water. These effects are obvious and quantifiable. However, it is the question of silting, and the contribution of grazing and broader pastoral land management to this process, that is more elusive.

4.6.2 The question of silting

4.6.2.1 Question 1: Is silting occurring?

The depletion of groundcover, not only from the immediate vicinity of waterholes but also from the surrounding landscape, has been implicated in the 'silting up' of waterholes throughout inland Australia. Many people interviewed for this project stated that there used to be more permanent waterholes, and that the permanent waterholes were deeper and more reliable. Numerous publications also refer to silting as a result of intensive stock grazing along the banks of waterholes and rivers (e.g. Kowald & Johnson 1992; Bell & Iwanicki 2002). Perhaps the first published reference to silting in the LEB was in a report from South Australia to *The Queenslander* in April 1886. During the 1880s drought, silting up of waterholes was reported to be worsening as increasing numbers of cattle drank from them (Nolan 2003). It makes intuitive sense that a reduction in groundcover would lead to increased soil loss, which would end up in the waterways. However, silting has not been uniform across the LEB, and there is debate as to how much silting has occurred.

Waterholes along the upper Thomson River and its tributaries were consistently identified by informants for this project as having been affected by silting. Anecdotal evidence points to substantial silting within living memory along some reaches of the Thomson River, Ernestina Creek, Prairie Creek, Torrens Creek, Towerhill Creek and Cornish Creek. Billy Rice has lived on Prairie Creek for most of his life. Many waterholes that his family used to regard as permanent or almost so, including the Rainsby Hole, now only last for 6-7 months, while even the last remaining semi-permanent waterhole on his property appears to be silting up. On nearby Towerhill Creek, many holes that were 6-8 feet deep and had not gone dry in the past 100 years have gradually silted up and went dry in the 2002 drought. For example, the waterhole near the Curragilla house used to be more or less permanent and supplied house water, but is now lucky to last four months (Loch Harrington, pers.comm., August 2008).

76-year-old Doug Langdon remembers fishing in many holes north of Muttaburra on the Landsborough Channel that were regarded as permanent. Many of these waterholes have silted up over time, and now generally only hold water for 4-5 months after rain (e.g. Horseshoe Bend on the Mount Cornish-Angora Park boundary). Some waterholes which were reliable enough to support Chinese gardens, as evidenced by stone walls as the base of waterholes, have now silted up, while occasional windmills now stand high and dry beside ex-waterholes (Doug Langdon, pers.comm., August 2008). In 2002, there was no water all the way up the tributaries north of Muttaburra, including Cornish Creek, Landsborough Channels and Slasher's Creek. South of Longreach, Lloyd Walker remembered a semi-permanent hole on Ernestina Creek near Arrilalah that no longer holds reliable water. He also spoke of having to 'de-silt' the Strathmore Garden Hole in 1990.

Lower down the Thomson River and along the Cooper, silting is not perceived to be such an issue, and where it is, there is a general belief that a big flood will 'clean out' the holes in due course. There is a similar perception along the Diamantina (John Ferguson, pers.comm., September 2008). Nevertheless, Toonka Waterhole on Monkira was never known to go dry prior to the 1960s; it is now regarded as only a semi-permanent hole and has been de-silted numerous times (Kowald & Johnson 1992; Anthony & Deb Desreaux pers.comm., October 2008). Conversely, there are a small number of waterholes, such as on Galway Downs on the lower Thomson and Andrewilla Waterhole on the lower Diamantina, where considerable de-silting has occurred during major flood events. The major waterholes of the upper Georgina, including Lakes Mary, Canellan and Francis, are perceived to be silting up (Ruby Saltmere, pers.comm., November 2008), as are waterholes on the Mayne River (Waddy & Chris Campbell, pers.comm., May 2009).

On balance, it appears that significant silting has occurred, and continues to occur, along many stretches of river in the LEB, particularly in the upper catchments. The vexed question is how much of this silting is attributable to natural processes and the inherent dynamism of rivers and landscapes, and how much is due to reduced groundcover and topsoil loss.

4.6.2.2 Question 2: Why is it occurring?

A. Natural dynamism

It has long been recognised that rivers, and the waterholes that they harbour, are dynamic. The geomorphology of arid-zone rivers tends to be more dynamic than in other areas, with the preponderance of unconsolidated sediment and sparse riparian vegetation promoting aeolian transport during drought, instability in the channel profile and channel re-routing during large floods (Costelloe *et al.* 2004). Over a longer timeframe, entire channel systems can shift. For example, Knighton & Nanson (1994) suggest that the preference for waterholes to develop towards the west below Windorah has possible implications for the westward migration of the channel system, accompanied by abandonment of eastern channels. In some waterholes on the eastern side of the channels, such as Narberry Waterhole, the rate of deposition exceeds the rate of excavation and infilling seems to be occurring. Combined with the extreme variability of climate and flows, this renders the rivers of the LEB inherently dynamic at a variety of spatial and temporal scales.

Anecdotal evidence points to some natural dynamism within human time spans. After the 1906 floods, residents of the Cooper country around Innamincka observed changes as a result of the big flood: *'…some deep waterholes had been silted up and new ones carved out, and the channel in some places was now twice the width where the banks had been washed away'* (Tolcher 1986, p.222). Anecdotal evidence across the LEB points to changes in flow paths following large floods, with resultant impacts on waterhole permanence. Up until about 20 years ago, the Toobrack Fish Hole on the Thomson River south of Longreach was regarded as close to permanent, and would only go dry if there was no run in either the Thomson or the Darr River for

15-16 months – a rare occurrence. However, a flood in the 1980s caused a re-routing of the channel, and this waterhole now lasts about 10 months, so is regularly dry by about October-November. On the lower Diamantina, a sill separating the Andrewilla flow path was scoured out by the 1974 floods, lowering the height at which this channel will run (David Brook, pers.comm., October 2008). New waterholes have also been formed in the past couple of decades, including one on Roseberth in the 1950s flood (Geoff Morton, pers.comm., September 2008).

The landscapes within which waterholes are positioned are also inherently dynamic. The North Australian Pastoral Company (NAPCO) history argues that 'silting has occurred in the watercourses – not from overstocking, but rather from droughts, dust storms and the moving of sandhills' (Kowald & Johnston 1992, p.133). Duncan-Kemp's (1934) account of a small waterhole being obliterated by a single sand storm shows that such infilling can occasionally happen with alarming rapidity. However, such events appear to be rare, despite the large quantities of small-sized particles moved by the wind in western Queensland's channel country (Knight *et al.* 1995; McTainsh *et al.* 1998).

B. An anthropogenic cause?

Some graziers and researchers believe that much silting occurred during early periods of heavy stocking. Undeniably, waterholes are foci for grazing activity, and some loss of groundcover is to be expected. The numerous reports of thousands of cattle dying during droughts (Section 4.6.1) suggests that impacts on the country and the waterholes, as starving stock struggled in for their last drinks, would have been enormous and scarcely imaginable in these days of easy transport and widespread artificial waters. The weight of evidence also suggests that there was a substantial and rapid loss of groundcover across the Lake Eyre Basin, particularly north-eastern South Australia, with the imposition of hard-hoofed stock and plagues of pest animals (e.g. Ratcliffe 1938; Noble 1997; Johnson *et al.* 2005).

However, even without elevated grazing pressure, there would have been many times, after big droughts, when flood waters tore over thousands of acres of exposed earth. As such, some degree of 'natural' silt transport into waterholes would have been occurring over millennia. It does seem reasonable to conclude that elevated grazing pressure has resulted in decreased groundcover and increased transport of sediment into rivers during periods of high flow (Robertson & Rowling 2000). During floods, some of this extra sediment will be deposited at the ends of waterholes, gradually resulting in a build-up of silt and reduced depth.

If silting is indeed a natural process, then the process is cyclical and a big flood, or series of floods, will de-silt many of the waterholes. If, however, historical and current loss of groundcover is implicated, the silting process is unidirectional and inexorable. Waterholes can then only be maintained by excavation or 'cleaning out', a process that has been undertaken at many waterholes over the past 50 years. There is no straightforward or unequivocal answer to the question of silting and the mechanisms behind it. Common sense would suggest that the story is unlikely to be uniform across the study area – in some areas grazing has probably contributed to silting of waterholes through increased run-off, in other areas silting probably reflects natural dynamism, while in others no appreciable silting has been observed over the past century. On balance, it appears that silting of existing waterholes is occurring faster than new areas of channel are being scoured out, which probably reflects greater volumes of silt in the waterways. In this way, elevated grazing pressure and depleted groundcover is probably accelerating a natural process.

4.6.3 Weeds

Duguid *et al.* (2005) suggested that the spread of non-native plant species may represent one of the biggest threats to the biota of central Australian wetlands. In the LEB, the number and abundance of riparian weed species tends to increase on a northerly gradient. The upper tributaries of the LEB are infested with numerous weed species, while reaches in the more arid parts of the catchment remain relatively weed free. In the study area, the three major 'waterhole weeds' are parkinsonia (*Parkinsonia aculeata*), rubbervine (*Cryptostegia grandiflora*) and noogoora burr (*Xanthium occidentale*). Coordinated weed control programs are already in place in the study area specifically targeting the two former species. Such strategies represent the best opportunity to improve waterhole condition on a regional and catchment scale (Section 4.7.5).

Parkinsonia, also known as Jerusalem thorn, is a slender, thorny shrub, easily recognisable by its rows of tiny leaflets, sharp spines along its smooth green branches and bright-yellow flowers. It can form impenetrable thickets around riparian vegetation and impact upon native species (Agriculture & Resource Management Council of Australia & New Zealand *et al.* 2000). Pods mature in late summer and are transported by flowing water. Seeds generally only germinate after substantial rainfall and/or flooding, but can remain viable for many years. Unfortunately, most of the semi-arid zone is apparently suitable for parkinsonia, meaning that it has the potential to continue spreading southward through the LEB.

Parkinsonia has spread throughout the Cooper catchment as far south as South Galway below Windorah, where it is currently in low densities. It occurs along the channels and waterholes of the Thomson and Barcoo Rivers and associated tributaries, as well as Kyabra Creek. It tends to grow as scattered plants along the riverbank but rarely becomes dominant, except over small areas. It is, however, extremely common in ephemeral lakes in the upper catchment such as Lake Mueller on Edgbaston. Along the Diamantina, parkinsonia has been recorded as far south as Diamantina Lakes. Brighton Downs represents its southerly limit on the main channel, and at Diamantina Lakes it seems to be encroaching via Spring Creek (Brett Carlsson, pers.comm., June 2009). It is also spreading south from upper tributaries in the Georgina catchment. On the main Georgina channel, it has spread as far south as Headingly, while plants on Marion Downs have come from the Burke River.

Rubber vine (*Cryptostegia grandiflora*) is regarded as one of northern Australia's worst weeds, covering large areas of the Gulf and Burdekin catchments which adjoin the LEB. It is a scrambling vine with bright green leaves and showy flowers, which forms thickets over riparian vegetation. It has become established along the tributaries of the upper Thomson, including Reedy, Thunderbolt, Pelican, Towerhill and Torrens Creeks. There is a thick infestation in the Muttaburra area, which is well-established but has not spread further south than the Muttaburra Broadwater south of town (Brett Carlsson, pers.comm., June 2009). Isolated plants have been detected and eradicated at the Longreach Waterhole, while an isolated population on Mayfield Waterhole south of Windorah was eradicated in the 1990s, but this apparently came from a local source (David Akers, pers.comm., June 2009).

Noogoora burr can become ubiquitous in favourable situations, especially along sandy stretches of river such as the Georgina River west of Boulia (Figure 25). It is also common along watercourses throughout much of the Thomson and Diamantina catchments. It is easily spread by people, animals and floodwaters and germinates on the edges of waterways following rainfall or rise and fall of water temperatures during warm weather (New South Wales Agriculture 2004). One seed in each burr will germinate in the first favourable conditions, while the second seed may remain dormant for 2-3 years or more. Plants grow rapidly during summer, flower in March and die off by late Autumn, but burrs hold onto dead plants until the next season.

Noogoora burr is extremely difficult to control, because there will always be bare ground along watercourses for plants to colonise. Hand-chipping is only economical over very small areas, while chemical spraying is effective when plants are young and actively growing but is also labour-intensive (NSW Agriculture 2004). Numerous biocontrols have been trialled, including rust and insets, but have failed to achieve widespread control. It is not currently listed as a Weed of National Significance, therefore little funding is directed towards it in the region (Brett Carlsson, pers.comm., June 2009). However, the two other major waterhole weeds are currently subject to control programs under Desert Channels Queensland funding, and this is discussed in Section 4.7.5.

Figure 25 : Noogoora burr along Georgina River, west of Boulia

Prickly acacia (*Acacia nilotica*) and mesquite (*Prosopis* species) may also occur as scattered plants along some waterholes. Prickly acacia is more commonly associated with Mitchell grass downs country, but can form quite dense stands around waterholes in the Flinders River catchment. However it does not appear to have taken off at any waterholes in the LEB, despite occurring as scattered plants along waterholes of the Thomson River and associated tributaries. Mesquite is often found around towns and properties (e.g. Georgina River near Urandangi) and localised plants and patches are usually easy to eradicate. Mother-of-millions (*Bryophyllum tubiflorum*) has spread along Ravensbourne Creek, a tributary of the Barcoo with numerous semi-permanent waterholes, and also occurs in the Tambo and Blackall districts within the Barcoo catchment. It does not appear to have become established elsewhere in the LEB.

Introduced couch grass (*Cynodon dactyloton*) and buffel grass (*Pennisetum ciliaris*) can dominate understories. Buffel grass tends to occur where sandy soils are adjacent to waterholes, particularly along the Barcoo River and sections of Wills and Burke Rivers in the Georgina catchment. Where dense swards of introduced grasses occur, they tend to displace native species and reduce local diversity (Fairfax & Fensham 2000). However, they can play an important role in providing groundcover and contributing to bank stabilisation.

The native aquatic perennial knotweed or smartweed (*Persicaria* species) is perceived to be ‘choking up’ waterholes in some areas, notably the permanent waterholes on the Wilson River (Figure 25). On the Thomson River, knotweed was rarely seen in the Jundah waterhole a couple of decades ago, and appears to be increasing in dominance (Doreen Pitman, pers.comm., May 2007). However, the scientific consensus seems to be that it would always have occurred on waterholes, and moreover plays an important role in bank stabilisation and provides habitat for birds and other animals (Stephens & Dowling 2002).

Figure 25: *Persicaria* is believed to be 'choking up' some waterholes, but also provides valuable habitat for aquatic species

4.6.4 Introduced aquatic fauna

Exotic fish, mostly plague minnow (*Gambusia holbrookii*) along with the occasional escapee goldfish, constitute only a minute fraction of the fish community in LEB rivers, despite apparently isolated temporary infestations being detected at a small number of waterholes (Costelloe *et al.* 2004; Adam Kerezsy, pers.comm., June 2009). It appears that when they do reach large numbers in a waterbody, small-bodied native fish may be detrimentally affected. At present, however, they are not in sufficient abundances to have a discernible ecological effect in LEB waterholes.

The introduced red-claw crayfish (*Cherax quadricarinatus*) is present in all three catchments in the study area. Red-claw are native to Cape York and Gulf Rivers, and have been translocated into the LEB as escapees from live fishing bait and stocked farm dams. They are common in main channel waterholes in the Georgina River, and anecdotal evidence suggests that they have increased in abundance over the past decade. They also appear to be becoming more numerous in the Thomson River, and have also been recorded in the Barcoo and Diamantina Rivers. Preliminary results suggest that red-claw may competitively interact with native blue-claw yabbies (*Cherax destructor*), especially where the former is well established in waterholes on the Georgina River (Adam Kerezsy, pers.comm., June 2009). It is also possible that red-claw have a detrimental impact on native crabs, fish, shrimps, prawns and mussels. However, little is known about such interactions.

LEB waterholes are warm and therefore suitable for most species of tropical fish. As such, potential threats include the exotic fish carp and tilapia. If either becomes established, the damage to the native species assemblage may be irreparable. Other translocated or escapee species could also pose a potential future threat. In general, however, the LEB waterholes are characterised by healthy native species assemblages, and future work should be targeted towards maintaining this situation (Section 4.7.5).

4.6.5 Tourism and recreation

Today, inland tourism focuses around water (Gibbs 2006). Visitation impacts tend to be concentrated at a small number of waterholes, rendering this a concentrated impact. Such waterholes tend to be accessible, close to major towns and deep enough to allow activities such as boating and waterskiing. A recent report (Schmiechen 2004) estimates that about 40 000 to 50 000 visitors per annum are attracted to the permanent Cullymurra Waterhole near Innamincka. Other waterholes that attract a relatively large numbers of visitors include the Muttaburra Broadwater, Longreach Waterhole (Thomson River), Oma Waterhole (Barcoo River), Currareva Waterhole (Cooper Creek), Basin Waterhole (Georgina River), Hunter's Gorge (Diamantina River) and Conn Hole (Wockingham Creek). Potentially impacts of recreational use include bank erosion, over-fishing, noise pollution, disturbance to native animals and plants, firewood collection (Figure 27) and pollution of water.

Figure 27: Legacy of chainsaw-wielding campers, Conn Hole, Diamantina River

One of the most insidious and pointless forms of waterhole degradation is the litter that often surrounds the more popular waterholes. A recent 500m traverse along the banks of the Thomson River near Longreach yielded no less than 32 beer bottles/cans, 8 non-alcoholic beverage bottles, countless cigarette butts, two plastic bags of rubbish (it is encouraging to think that people can at least go to the effort of packaging their rubbish up before dumping it), numerous wrappers/papers and two home-made bongs. Fortuitously, littering only plagues a small minority of waterholes in the LEB and does not permanently affect the structure or function of a waterhole. For these reasons, it is not included as an indicator in the condition assessment framework (Section 4.7).

4.6.6 Water extraction and flow modification

The importance of smaller, more frequent river flows in maintaining permanent refuges along the LEB river systems has been highlighted by Hamilton *et al.* (2005). This in turn has implications for water management. Flow regimes can be altered by upstream impoundments and/or water harvesting, while smaller alterations such as raised roads or crossings can have a local impact. If these flow modifications decrease the frequency of inundation of an important waterhole, the corresponding increase in frequency and/or extent of desiccation could result in reduction or local extirpation of the aquatic animals that depend upon it. It may also reduce water availability for riparian trees and floodplain wildlife (Kingsford 2000; Hamilton *et al.* 2005). Water extraction from individual waterholes during dry times will have similar effects, albeit on a more localised scale.

Numerous waterholes have small walls on them to dam water, including those for town (e.g. Longreach Waterhole, Oma Waterhole) and homestead (e.g. Lake Idamea, Glenormiston, which was made more permanent by repair of an old overshot dam in the early 1970s) supplies. Dams and weirs are especially common in the upper catchments, such as the creeks that feed into the Thomson and Barcoo Rivers and the upper Diamantina River itself. This increases the volume of water stored in the headwaters. Such impoundments are unlikely to affect flow during major flood events which provide the ‘booms’ characteristic of these systems. However, they may decrease the extent and frequency of smaller flows (Sheldon 2005). Over the long-term, this could impact upon the permanence and refugial value of waterholes by denying them of top-up flows between larger flow events. No such impacts have thus far been observed or demonstrated in the study area.

In general, flows in the LEB remain largely unregulated. The good condition of waterholes across the three catchments (Section 4.7.4) relative to aquatic ecosystems in the neighbouring Murray-Darling Basin (Maheshwari *et al.* 1995; Gehrke *et al.* 2003) is largely attributable to this lack of modifications and water extraction.

4.6.7 Climate change

Box *et al.* (2008) discuss the projected impacts of climate change upon central Australian waterbodies, however concede that any impacts can only be speculated upon. Current scenarios predict an increase in the influence of the El Nino Southern Oscillation (ENSO) cycle. This would result in heavier but less frequent precipitation events, which may lead to increased groundwater recharge and longer dry periods between flows (Box *et al.* 2008). This could result in the decreased permanence of waterholes, with flow-on effects for dependent biota. However, the changes to rivers and waterholes that might occur as a result of climate change are certain to be both less dramatic and controllable than the effects of river regulation. In fact, McMahon & Finlayson (2003) contend that indigenous biota of Australian rivers are adapted to low flow conditions, and that studies on the effect of climate change on stream ecology have little practical relevance for management of unregulated rivers. In effect, there is little that river managers can do to deal with climatically-driven changes to flow in the LEB, and we would be better served to focus on those determinants of waterhole condition which can be managed.

4.7 Condition assessment

4.7.1 Overview of literature and past studies

Recent years have seen considerable debate surrounding the definition and measurement of river condition or 'health' (e.g. Bunn *et al.* 1999; Norris & Thoms 1999; Jansen & Robertson 2001; Greenwood-Smith 2002; Sheldon 2005). 'Health' is perceived to be a useful way of expressing condition, because it is grounded in science but easily conveyed to the wider community. More than 100 river health indices have now been developed worldwide (Greenwood-Smith 2002). Indicators designed to measure river health or condition must focus on those components affected by human disturbance (Karr 1999). They should also be reliable, economical and easily repeatable over time. Ideally, there should be good knowledge of the indicator's natural variation over time in a particular river system (Boulton 1999).

Historically, dryland rivers have not been the focus of studies on river health, mostly owing to their spatial remoteness and relatively low levels of human disturbance. As such, most condition assessment methodologies are designed for perennial streams surrounded by relatively intensive land use, for which there is a significant amount of existing data (Sheldon 2005). However, over the past decade there have been numerous projects examining the condition of LEB rivers, including waterholes, and how this condition should be assessed and monitored. These are reviewed briefly below. Each of these studies was focused on 'river health', and although waterholes were usually considered, they have not been the focus of any specific project. Choy *et al.* (2002) assessed the ecological condition across 30 sites along the Georgina, Diamantina, Cooper-Thomson (and Bulloo) systems from 1997-1999, using several criteria: level of human influence, habitat condition, water chemistry and aquatic macroinvertebrate composition. They found that the most discernible and widespread impact was 'moderate' riparian and bank damage by stock.

Sheldon *et al.* (2003) assessed condition of the Georgina-Diamantina River systems by reach, 'using available information…combined with our professional judgement' (p.48). Where specific information was deemed insufficient, they used their experience of the ecology of arid rivers to predict the condition for the habitat or reach. All reaches were assessed as being in 'moderately good' condition, on the basis of extremely limited information and even less ground-truthing. They concluded that vegetation changes associated with grazing were the major impact across the catchment, but that it was very difficult to make objective judgements regarding the current condition of riparian vegetation due to a lack of baseline data describing condition prior to existing land uses.

The Lake Eyre Basin Rivers Assessment Methods Development Project (Sheldon *et al.* 2005) aimed to develop a scientifically-based methodology for assessing the condition of river ecosystems and catchments in the LEB, encompassing headwaters, river channels and waterholes, and terminating wetlands. They suggested a list of indicators, grouped under four themes: flood and flow, physical form, riparian and floodplain, and waterholes and wetlands. The two latter themes are especially relevant to condition assessment of waterholes. Riparian and floodplain indicators related to vegetation taxa and richness, condition (including recruitment, regeneration and exotic species) and waterbirds. Waterhole and wetland indicators encompassed measures pertaining to macroinvertebrate and fish assemblages, water quality and waterhole process and function (benthic metabolism, algal biomass and composition and stable isotope analysis). Some data was already available, but pilot studies would be required to ascertain the utility and feasibility of some indicators, including macroinvertebrate assemblage and waterhole function.

Jansen *et al.* (2005) presents a framework for rapid appraisal of riparian condition. Their overall condition index comprises five sub-indices (habitat continuity and extent, vegetation cover and structural complexity, dominance of natives versus exotics, standing dead trees, hollows and fallen logs, and indicative features), each of which encompass numerous indicators. Robertson & Rowling (2000) and Jansen & Robertson (2001) applied variants of this methodology to assess the impact of grazing on riparian condition along the Murrumbidgee River. While no work was conducted in Queensland or South Australia, the methods are broad enough to have some applicability to LEB waterholes.

4.7.2 Suggested framework for LEB waterholes

Given the number and diversity of waterholes across the Queensland and South Australian section of the LEB, a simple approach, based on a handful of key indicators, is put forward. These indicators are based on current ecological knowledge of waterholes and can be assessed objectively, repeatedly and relatively rapidly at low cost. The condition assessment framework is split into two components: riparian condition and aquatic vertebrate species assemblage. This method will allow collection of reliable data that can identify waterholes and reaches at risk and target management actions to alleviate decline in condition over time. A ranking system of A to D is used rather than a numerical scoring scale (see Jansen *et al.* 2005). The Queensland Department of Primary Industries & Fisheries 'Stocktake' methodology (Chilcott *et al.* 2003) uses these categories as a simple and flexible means of assessing land condition. This method will also translate well to landholders and managers as a 'report card' of waterhole condition. In essence, a waterhole in good condition supports healthy riparian and aquatic communities and is a functioning component of its wider catchment.

It is recognised that more complex approaches to river health assessment have been used across the Basin, including macroinvertebrate and nutrient sampling. In particular, the Australian River Assessment Scheme (AusRivAS) is a national bioassessment program that uses aquatic macroinvertebrates to assess river health (Smith *et al.* 1999). Sheldon *et al.* (2005) recommend that macroinvertebrate taxa richness and SIGNAL and AusRivAS scores be used for waterhole condition assessment, however concede that pilot studies will be required before such data can be interpreted with confidence. Most macroinvertebrate assemblages in the LEB are opportunistic and tolerant of a wide range of conditions, and their life histories are linked to flow conditions (Choy *et al.* 2002). As such, they vary considerably between sites with the same level of anthropogenic disturbance but markedly different hydrological connection histories (Sheldon 2005), reducing their utility for assessing waterhole condition. Based on our current level of knowledge, macroinvertebrate sampling is not perceived to be a reliable indicator of waterhole condition (with the exception of the translocated redclaw crayfish, as discussed below).

Sheldon *et al.* (2005) also use water quality measures as components of condition assessment, including conductivity (salinity), pH, turbidity, dissolved oxygen, water temperature and dissolved nutrients (nitrogen and phosphorous). Such parameters are easy to record and measure, and should be noted at waterholes assessed as they can affect fish assemblages. However, such parameters are not reliable indicators of waterhole condition due to their natural variability within Lake Eyre Basin catchments, and their tendency to change with time since flow. As an example, in certain waterholes of the Georgina catchment fed by saline aquifers, electrical conductivity can approach levels recorded in marine environments, whereas the majority of Lake Eyre Basin waterholes are non-saline.

Vegetation species richness surrounding waterholes (Robertson & Rowling 2000; Sheldon *et al.* 2005) is not used as an indicator, as it tends to reflect the diversity of surrounding habitat (see Section 4.4.2) and time since flow or rainfall. The Anderson method, used to assess river health in Queensland, incorporates the quality of scenic and recreational value (Greenwood-Smith 2002). This measure, while relevant given the uses and values of LEB waterholes (Schmiechen 2004), was not incorporated in the assessment framework due to its subjective and largely intangible nature.

4.7.2.1 Riparian condition assessment indicators

Jansen *et al.* (2005) define 'riparian condition' as the degree to which human-altered ecosystems diverge from local semi-natural ecosystems in their ability to support a community of organisms and perform ecological functions. In the LEB, grazing pressure is the prime determinant of riparian condition around waterholes, with some localised recreational impacts. While upstream water harvesting and hydrological modifications will affect waterholes, such impacts are more effectively measured at the wider catchment scale (Sheldon *et al.* 2005) and are not considered in this framework. The indicators below are modified from Jansen *et al.* (2005) and Sheldon *et al.* (2005), based on experience and observations of LEB waterholes. They can be assessed visually and will primarily reflect total grazing pressure and presence of introduced species. As such, they will be responsive to changes in grazing management and weed control over time.

A one kilometre section of waterhole/riparian zone on one side of the river should be assessed at each site, as per Jansen & Robertson (2001). Riparian condition assessment generally takes about 30 minutes per site. Where a waterhole spans >3km, numerous sites along different portions of the waterhole should be sampled and the results averaged to give overall riparian condition for that waterhole. As a general rule, there should be one site per every 3-4km length of waterhole. Given the typical spatial variation in condition indicators along any given stretch of waterhole, a general assessment of an entire 1km site is preferred over a transect or quadrat-based methodology. Indicators are discussed below, and the ranking system outlined in Table 18.

<u>(i) Bank Stability</u>

Bank stability relates to the amount of accelerated erosion occurring at a waterhole due to removal of protective vegetation and direct trampling of banks (Figure 28). Jansen & Robertson (2001) assigned a bank stability score ranging from 0 (extreme erosion with little vegetation) to 4 (stable banks and good vegetation cover) on the Murrumbidgee River. Given the flat nature of many waterholes in the LEB, bank stability is likely to be better in the study area, as considerably more grazing pressure will be required to trigger substantial erosion.

Figure 28: Unstable bank due to heavy cattle grazing; note lack of groundcover and deeply-incised cattle pad

<u>(ii) Groundcover</u>

Groundcover is perhaps the best visual indicator of waterhole condition, as it has flow-on effects for water quality, bank erosion and sedimentation. Studies on the Murrumbidgee River show that groundcover biomass decreases with grazing pressure (Robertson & Rowling 2000; Jansen & Robertson 2001). However, a couple of key points need to be kept in mind. Regardless of grazing pressure, there will always be a bare zone adjacent to the water (the ‘shear zone’), which may be vegetated with scattered annual forbs such as cudweed (*Pseudognaphalium* spp.). There will also be naturally bare areas during dry times, such as deeply cracking clays or small channels back from the waterhole.

In general, however, waterholes in good condition tend to have good coverage of perennial grasses back from the 'shear zone' (Figure 29a), usually comprised of Warrego grass (*Paspalidium jubiflorum*) and/or rat's tail couch (*Sporobolus mitchellii*). The Mulligan River waterholes are a notable exception, as samphires and forbs tend to dominate around these waterholes. In heavily-grazed waterholes, bare ground continues for some distance back from the waterhole (Figure 29b), with perhaps only scattered unpalatable species surviving (commonly *Sclerolaena muricata*).

Figure 29a: Bare 'shear zone' and start of vegetated area, Jundah Waterhole, Thomson River

Figure 29b: High grazing pressure – groundcover does not increase even back from shear zone

<u>(iii) Overstorey and midstorey vegetation condition</u>

This parameter also relates to total grazing pressure (primarily domestic stock and feral goats), and assesses grazing impacts on existing individuals, as well as abundance and health of recruitment of riparian species. For mature individuals, this indicator considers whether trees and shrubs around the waterhole have been grazed, and to what extent. Where grazing pressure is very heavy, plants such as coolibah (*Eucalyptus coolabah)*, creek wilga (*Eremophila bignoniflora*) and belalie (*Acacia stenophylla*) will often display a noticeable 'browseline', with branches within reach of animals grazed. Larger trees may also be denuded of bark where animals have rubbed against the plant. The grazing of palatable sub-shrubs such as Queensland bluebush (*Chenopodium auricomum*) is also a good indicator of total grazing pressure around a waterhole.

Regeneration of woody species will be precluded or reduced under heavy grazing, due to destruction of seedlings by trampling and grazing. Robertson & Rowling (2000) found that seedlings and saplings of the dominant *Eucalyptus* tree species were up to three orders of magnitude greater in areas with no stock access compared to grazed riparian zones. This parameter, although vital to long-term riparian functioning and waterhole habitat value, requires some caution due to the irregular and patchy nature of regeneration of arid-zone riparian species, both in space and time (Brock *et al.* 2006). For example, the presence of regeneration of river red gum at any one point in time may not be critical, as the species does not regenerate regularly (Jansen & Robsertson 2001). In particular, population structures of riparian species will often reflect the history of flood events (Brock *et al.* 2006). However, the shorter-lived species such as *Acacia stenophylla* and *Eremophila bignoniflora*, both of which are ubiquitous in LEB waterholes, germinate at more frequent intervals. Therefore, some saplings or seedlings should be present at most sampling times.

<u>(iv) Terrestrial woody debris and leaf litter</u>
This indicator reflects both grazing pressure and human use. The presence of dead timber (both standing hollow trees and ‘fallen woodies’) is important for habitat condition (Eyre *et al.* 2006), while leaf litter provides important soil protection. Woody debris and litter are consistently more abundant in ungrazed riparian areas (Robertson & Rowling 2000), often disappearing entirely in very heavily stocked areas. Waterholes subject to high visitation are often denuded of dead timber due to firewood harvesting (Figure 27), while standing dead trees may have been stripped or pushed over.

<u>(v) Introduced species</u>
Even where grazing pressure is very light, introduced species are still present at most waterholes, lowering the overall condition. This indicator considers presence and abundance of introduced species only, as outlined in Table 10, primarily noogoora burr, parkinsonia and, less commonly, rubber vine and prickly acacia. As this framework is designed to assess ecological condition, introduced pasture plants such as buffel grass and couch grass are included in this category. Buffel grass is considered a valuable pasture plant and contributes substantially to groundcover and bank stability at some waterholes. However, it has negative impacts on native plant diversity (Fairfax & Fensham 2000). Thus while a waterhole surrounded by buffel grass will score highly for groundcover and bank stability, the waterhole would receive a lower score for this indicator, depending on the dominance/abundance of the introduced species.

4.7.2.2 Aquatic condition indicators

Fish are useful in the assessment of waterholes as they are long-lived, span a range of trophic levels and are relatively easy to sample and identify in the field. Previous work in the LEB has demonstrated that the majority of fish species can generally be sampled using a combination of passive fyke nets and active seine netting (Costelloe *et al.* 2004; Arthington *et al.* 2005). Ideally, passive sampling equipment appears to produce best results if set overnight (Arthington *et al.* 2005; Adam Kerezsy, pers.comm., June 2009). Large macroinvertebrates such as crayfish and crabs are sampled concomitantly using the same equipment.

<u>(i) Native species assemblage</u>

Sheldon *et al.* (2005) suggest that given the high tolerance, low diversity and generalist nature of the LEB fish assemblage, a few specific measures may provide a better assessment of health than more complicated indices of biotic integrity. Essentially, a 'healthy' waterhole should be home to strong populations of native fish species with very few exotic species. Native indicator species common to all major catchments include yellowbelly (*Macquaria* sp.), bony bream (*Nematolosa erebi*), Hyrtl's tandan (*Neosiluris hyrtlii*) and silver tandan (*Porochilus argenteus*). Healthy, permanent, in-channel waterholes would be expected to have at least three of these species present ± desert rainbowfish (*Melanotaenia splendida tatei*), spangled perch (*Leiopotherapon unicolour*), glassfish (*Ambassis* sp.) and grunters (*Scortum barcoo* and *Bidyanus welchii*). Less permanent waterholes, or those in upper catchments, should not be expected to have as complete a species assemblage.

<u>(ii) Exotic species</u>

Currently, populations of alien fish species such as gambusia (*Gambusia holbrooki*) and goldfish (*Carassius auratus*) are known to occur in the Lake Eyre Basin (Arthington *et al.* 2005; Fairfax *et al.* 2007). Translocated fish species known to occur in the Thomson River (part of the Cooper Creek catchment) also include Murray cod (*Macchullochella peeli*) and sleepy cod (*Oxyeleotris lineolatus*) (Adam Kerezsy, pers.comm., June 2009). The translocated crayfish redclaw (*Cherax quadricarinatus*) is expanding in range throughout the LEB, based on surveys conducted between 2006 and 2009. This may have detrimental effects on native species assemblages, in particular the native blueclaw crayfish, as discussed in Section 4.6.4. The presence of any alien or translocated aquatic species (including others that may not currently be detected) will reduce the aquatic condition score of any surveyed waterhole.

4.7.2.3 Overall framework

Table 18 presents the overall condition assessment framework for LEB waterholes, encompassing five riparian condition parameters and two aquatic condition indicators. Appendix 6 is the proposed Template for Waterhole Condition Assessment in the LEB.

Table 18: Suggested parameters for waterhole condition assessment

Parameter	Score = A	Score = B	Score = C	Score =D
A. RIPARIAN CONDITION				
(i) Bank stability	Stable banks with good vegetation cover and no accelerated erosion or stock pads	Isolated patches of erosion or disturbance, generally restricted to pads	Moderate bank erosion with many pads and trampling	Extreme erosion and bank instability;deeply-incised pads + much trampling
(ii) Groundcover	Perennial grasses dominate bank above 'shear zone' (Figure 29) and area adjacent to waterhole (except Mulligan River)	Perennial grasses and forbs common, providing good coverage of bank despite some grazing pressure	Groundcover obviously denuded around waterhole, but perennial grasses still present	No perennial grasses present in vicinity of waterhole; overall groundcover very low
(iii) Woody species health (existing species + regeneration)	Minimal grazing of trees and shrubs + abundant and healthy regeneration of both canopy and mid-storey species	Some grazing of trees/shrubs; regeneration present, but young plants showing signs of stress	Most individual trees and shrubs grazed; limited regeneration evident OR seedlings heavily grazed	Ring-barking of trees ± palatable trees and shrubs heavily grazed; no regeneration of dominant riparian species
(iv) Terrestrial woody debris and litter	Fallen timber, dead logs and litter abundant under standing trees; dead branches remain on trees; hollow-bearing trees present	Fallen timber, dead logs and litter present; some standing dead trees	Little fallen timber, dead logs or leaf litter; often obvious signs of firewood harvesting	No fallen timber in area; few old dead branches; signs of firewood collection often obvious
(v) Introduced species	No introduced species present at site	Some introduced plants present amongst riparian vegetation, but scattered	Introduced species common OR dominant in understorey but with healthy native overstorey	Introduced species dominate both understorey AND overstorey, with few natives persisting
OVERALL RIPARIAN CONDITION (average of above five scores)				
AQUATIC CONDITION				
Aquatic Fauna Assemblage	3 out of 4 native indicator species present if permanent in-channel WH	3 out of 4 native indicator species present if permanent in-channel WH	Few native species	No or few native species
Exotic species	No exotics detected	Presence of exotics detected but <10% of catch	Abundant exotics (>10% of individuals caught)	Exotics dominant (>50% of catch)
OVERALL AQUATIC CONDITION (average of above two scores)				
OVERALL WATERHOLE CONDITION (average of riparian and aquatic scores)				

It is important to know the desired 'state' to which a waterhole should conform (Costelloe *et al.* 2004). As such, condition rankings need to be benchmarked against relatively pristine sites in order to provide a measure of variation from natural situations (Boulton 1999; Jansen & Robertson 2001). All waterholes in the LEB have been modified in some way from their presumed 'natural' condition over the past 150 years. However, sites where grazing has been excluded or very low for varying lengths of time may provide useful reference sites. Potential reference waterholes in the LEB include waterholes on National Parks (Forest Den, Lochern and Welford in the Cooper, Diamantina Lakes in the Diamantina), as well as waterholes on private property which have been subject to historically light grazing pressure. Such waterholes exist for a variety of reasons (e.g. conservation interests of landholder or company, inaccessibility of waterhole, provision of artificial water nearby), and should be relatively easy to find through discussions with land managers.

A valuable component of the condition assessment of waterholes is to obtain accurate stocking rate information from managers for the preceding months, as well as general stock management over time. Such information is kept by all managers, and can be easily obtained through informal interviews. This would allow waterhole condition to be related to stocking, and identify stocking rates and regimes (e.g. continuous versus non-continuous grazing) that are consistent with maintenance of waterhole condition. In addition to such information, Jansen & Robertson (2001) used dung counts to assess grazing pressure at particular sites. This is a quick and useful measure of cattle activity at a waterhole in the months leading up to the assessment (providing the assessment is not undertaken following flooding). At each site, cowpats occurring within 1m of the line along two 100m-long transects running along the river bank should be counted.

4.7.3 Implementation of condition assessment framework

4.7.3.1 Practical considerations

Two people are required to undertake assessments, ideally one with fish skills and one with an ecological/botanical background. Between them, assessors must have a general understanding of waterholes and riparian processes in the LEB, a good knowledge of major waterhole plant species and sound fish identification skills. Equipment required is minimal, consisting of a 4WD vehicle, fishing nets and permit, hand-held GPS, digital camera, and the relevant water quality meters. Using the proposed methodology, a maximum of three waterholes can be assessed per day, not including driving time between waterhole clusters. Thus assessing the proposed sites (see below) would take one week for each of the Georgina and Diamantina, and two weeks for the Cooper catchment, equating to one month sampling time.

4.7.3.2 Site selection

As only a tiny proportion of all waterholes in the LEB can be assessed, site selection is critical. Waterholes selected must represent the range of types, permanence and condition encountered in the LEB. Firstly, a good spatial spread of sites across all catchments and reaches, from headwaters to lower reaches, is required. A variety of waterhole types, ranging from semi-permanent to permanent, must also be included, although this means that aquatic sampling is not possible at semi-permanent waterholes when they are dry. To avoid such problems occurring frequently, most waterholes selected have water in for >90% of the time overall.

Sites must also encompass range of tenures across LEB, including private grazing properties, National Parks/Conservation Reserves, Stock Routes and Town Commons. Preference is given to sites of particular importance or with existing data/monitoring (Sheldon *et al.* 2005). The Birdsville-Durrie Waterhole aggregation and Diamantina Lakes wetlands are listed as wetlands of international importance, so should be incorporated into any condition assessment project. Pre-existing research sites include those used by ARIDFLO and Dryland Refugia Project, as well as sites that have already been intensively sampled for fish as part of work by Griffith University.

The waterhole permanence map produced for this project provides a solid basis for site selection. Selecting clusters of waterholes within relatively small areas will achieve maximum sampling efficiency, with three waterholes able to be sampled per day. The riparian condition methodology is less time-consuming than aquatic assessment, so more waterholes could be assessed opportunistically using this methodology only. Table 19 provides a list of proposed assessment sites by catchment and river system.

Table 19: Suggested waterholes for assessment program

Reach	Group Name	Waterholes	Total
GEORGINA CATCHMENT			**16**
Mid_1	Roxborough Downs area	Mungala Yards, Walkabee, Lake Katherine	3
Mid_2	Glenormiston area	Lake Idamea, Basin, Paravituri	3
Lower_1	Glengyle area	5 Mile, Glengyle Station, Tomydonka	3
Lower_2	Mulligan River	Yarrandilla, Pulchera, Kalidewarry	3
Tribtary_1	Burke/Wills River	Wondolbie, Manuka, Barracks	3
Tributary_2	Hamilton River	Bulla Bulla	1
	OPTIONAL	*Camooweal Lakes; Toko Gorge; Mt. Guide*	
DIAMANTINA CATCHMENT			**15**
Upper	Upper Diamantina	Conn Hole, Tulmur, Old Cork	3
Mid_1	Diamantina Lakes	Wangeri, Warracoota WH, Lake Constance	3
Mid_3	Durrie/Roseberth cluster	Cooninghera, Nerathella, Cuppa	3
Lower	Clifton Hills	Andrewilla, Koonchera, Yammakira	3
Tributary_1	Farrars/Morney Creek waterhole complex	Woomera, Big Moorathulla, Alleogera	3
	OPTIONAL	*Brackenburgh; Monkira; Mooraberrie; Cowarie/Kalamurina*	
COOPER CATCHMENT			**27**
Upper	Upper Thomson tributaries	Rainsby WH (Torrens Creek), Buckleseas WH (Cornish Creek), 4 Mile (Reedy Creek)	3
Mid_1	Longreach district	Longreach, Darr Hole, 8 Mile Reserve WH	3
Mid_2	Vergemont area	Waterloo Hole (Thomson R), Big Hole & Native Hole (Vergemont Ck)	3
	OPTIONAL	*Towerhill/Prairie Creeks; Jundah Area*	
Upper	Avington/Coolagh	Avington, Coolagh, Honan Hole	3
Lower	Welford	Trafalga, Shed, Boomerang	3
	OPTIONAL	Powell Creek	
Mid	Keeroongooloo/Tanbar	Eulbertie, Wombunderry, Curraonga WH	3
Lower	Nappa Merrie/ Innamincka	Nappapathera, Cullymurra, Queerbidie WH	3
Tributary_1	Kyabra	Bodella, Nomminah, Springfield WH	3
Tributary_2	Wilson	Noccundra WH, Nockatunga WH, Cobar	3
		TOTAL	**58**

4.7.3.3 Temporal considerations

Sampling should be conducted during the warmer months, as existing studies suggest that fish activity – and therefore catchability – is reduced during winter (Costelloe *et al.* 2004; Arthington *et al.* 2005). September/October or March/April would be the optimal sampling times, as this is during the dry season when rain or wet conditions are less likely to interfere with sampling. Condition assessment should ideally be conducted annually for three years to provide baseline data across the catchments. After this, once every 3-5 years is likely to be sufficient given the time frames that the suggested indicators will change on. Fundamentally, a long-term perspective and commitment to repeated sampling are required (Boulton 1999; Reid & Odgen 2006).

One of the biggest challenges in interpreting condition assessment data is to understand and account for the large spatial and temporal variations in natural 'condition' that are evident across LEB waterholes, reflecting the overriding influence of flow and rainfall (Sheldon 2005). Detecting the impacts of human disturbance beyond this natural variability may be difficult. A decline in condition with time since last flood or rainfall is expected, even in waterholes in excellent condition. However, sites in poor condition fail to respond or appear healthy even immediately following flooding or substantial rainfall (Sheldon *et al.* 2005). In this regard, it is imperative that seasonal and flooding conditions preceding sampling are recorded based on local knowledge and discussions with landholders.

4.7.4 Preliminary results

Preliminary results from the LEB waterholes visited indicate that most waterholes across the three catchments are in B or C riparian condition. Grazing is certainly the most widespread impact on waterholes, primarily from domestic stock. As with Jansen *et al.* (2005) for other river systems in Australia, a strong negative relationship is generally observed between grazing intensity and riparian condition. However, at most waterholes (with some notable exceptions), grazing pressure is generally low enough for waterholes to still be scored as B, or even A, condition for grazing-related indicators. A small number of waterholes were assessed as being in D condition due to intense grazing pressure. Such waterholes are easy to identify, however active management to rectify this situation is likely to be more challenging. Visitor impacts are evident at the more accessible waterholes, but represent localised and isolated impacts. Introduced species, particularly parkinsonian and noogoora burr, are present in some abundance at nearly all waterholes, and are the main relegating factor at lightly to moderately grazed waterholes.

In general, existing studies demonstrate that the majority of Lake Eyre Basin waterholes contain an intact native fauna (Costelloe *et al.* 2004; Arthington *et al.* 2005). However, anomalies exist, such as infestations of gambusia at Edgbaston (Fairfax *et al.* 2007) and Noccundra (Adam Kerezsy, pers.comm., June 2009). The present situation (i.e. a strong native fauna), though suggestive of relatively healthy ecosystems Basin-wide, is also ideal for detecting aberrations at smaller scales and disruptions caused by invasive species. As discussed above, the general health of LEB waterholes stands in stark contrast to the neighbouring Murray-Darling Basin, where flow modifications and water extraction have had catastrophic consequences for riparian vegetation, water quality and aquatic biota (Maheshwari *et al.* 1995; Thoms & Sheldon 2000; Gehrke *et al.* 2003).

Riparian condition does not always correlate with aquatic condition, suggesting that while riparian habitat may be severely modified, aquatic habitat and processes continue to function unimpeded. This is consistent with the observation of Norris & Thoms (1999) that it is possible to have degraded channels supporting quite healthy biota. In saying this, many aspects of riparian condition, including groundcover and health of woody species, do have flow-on effects to a waterhole and river system. For example, reduced organic matter from riparian vegetation is a significant contributor to waterhole food chains, while riparian vegetation also reduces sedimentation into a waterhole (Robertson & Rowling 2000). However there is little knowledge about the links between riparian and aquatic condition over time.

4.7.5 Future work

The condition assessment framework discussed above provides a broad framework with which to assess anthropogenic impacts on, and resultant condition of, LEB waterholes. Where problems, anomalies or particular areas of interest are detected, more intensive surveying and/or on-ground works (e.g. weed control, lowering of stock pressure) can be undertaken in that reach. Results of this condition assessment work, both good and bad, need to be communicated to land managers, along with possible management strategies (Karr 1999). It is suggested that any waterhole condition assessments should be framed in the context of the river system and catchment, rather than treating waterbodies as isolated entities.

Lack of effective grazing management is likely to result in continued decline of waterhole condition, regardless of efforts to retain natural flow regimes (Robertson & Rowling 2000). Today, numerous waterholes are fenced and grazing excluded or at least controlled, often with partial financial assistance from Government grants. Where this has occurred, benefits tend to include increased groundcover, more woody debris and improved regeneration of riparian species. In other places, domestic stock grazing pressure at waterholes is so light as to render such expense unnecessary.

However, there are a number of waterholes that are heavily grazed as they are the only source of water across a large area. In such cases, the waterhole is a key pastoral resource, and fencing is not a desired option. Fencing in riparian environments can be difficult due to periodic flooding, while the sheer length of waterholes on many properties precludes fencing as a solution to the impact of livestock on riparian condition. As Jansen & Robertson (2001) point out, the exclusion of grazing from riparian zones is not practical. Instead, they suggest that lowered stocking rates, better-managed grazing including resting of paddocks and waterhole areas, and off-channel watering points could all be used to improve riparian condition.

In this way, protection of waterholes rests largely with land managers. It has always been in the interests of pastoralists to protect their valuable waterholes. As early as the 1880s, such 'conservation' interests were evident, albeit personally motivated (e.g. Teeta Waterhole near Betoota, Nolan 2003). Graziers should be assisted in this goal as much as possible. The best approach is likely to combine education and practical assistance, such as currently occurs through regional body funding with Desert Channels Queensland or the Queensland Department of Environment & Resource Management 'Nature Assist' program. Some very heavily grazed waterholes are situated on Town Commons, where it is up to the relevant Shire Council to stipulate controls on grazing management. Results from the Murrumbidgee River indicate that while improvements in riparian structure and function may occur within five years of lowered grazing pressure, full recovery from the impact of livestock may take decades (Robertson & Rowling 2000). As such, a long-term commitment to waterhole protection and monitoring is paramount.

Weed control needs to occur in conjunction with livestock management. As the seeds of major riparian weed species in the LEB are mostly spread by water, all programs require a whole-of-catchment focus. Existing projects facilitated by Desert Channels Queensland should be continued and expanded, particularly in regard to species such as parkinsonia and rubber vine which can be controlled via chemical means. Experience in other regions shows that both species can be controlled on a regional level, provided there is long-term commitment to ongoing follow-up (Agriculture & Resource Management Council of Australia & New Zealand *et al.* 2001). Current work in the LEB is directed to maintaining 'buffer zones', preventing further spread of parkinsonia south of its present limits (Section 4.6.3). When infestations are detected in these areas, all plants are chemically treated by contractors with assistance from DCQ (Brett Carlsson, pers.comm., June 2009). Southern populations in all catchments have been treated, and this work is ongoing, combining aerial surveys and responsive control measures.

Prevention of spread of rubbervine is also difficult, as seed is easily dispersed by wind, water and animals. Large new infestations can arise rapidly and once established are very difficult to control, so the focus must be on early detection and control (Agriculture & Resource Management Council of Australia & New Zealand 2000). Fortuitously, it has so far only spread as far south as Muttaburra in the LEB. This infestation is currently being chemically controlled by a contractor in a partnership between Muttaburra Shire Council and DCQ. Large projects have previously been undertaken in the upper Thomson tributaries, and aerial surveys were recently completed to map its distribution in the Thomson system (Brett Carlsson, pers.comm., June 2009). Focus should remain on continued regular surveys and early treatment where infestations are detected.

Education and public awareness programs can play a major role in protecting LEB waterholes from existing and potential threats. In particular, education must focus on distinguishing between native and exotic species and preventing escape or liberation events. In particular, stocking of waterholes with farm-bred yellowbelly fingerlings should be discouraged. All populations of native fish appear to be doing well, so there is no need to risk disease or genetic corruption through stocking (Adam Kerezsy, pers.comm., June 2009). An education program highlighting the ecological cost of using red-claw crayfish as bait should also be aimed at recreational fishers. A long-term monitoring project would be beneficial to gauge the existence and potential spread of exotic species, as well as the dynamics of native populations in relation to season and flow. Research should also focus on cryptic species such as the golden goby (*Glossogobius aureus*) and Cooper catfish (*Neosiluroides cooperensis*). These species have a limited range and very little is currently known of their biology or ecology.

Fundamentally, the current good health of LEB waterholes in comparison with other areas in Australia and internationally needs to be highlighted to the community. This is not to downplay the existing and potential threats discussed above. With ongoing vigilance and commitment, however, the Cooper, Diamantina and Georgina catchments represent a vast area where threats can be dealt with before they escalate and begin to have real impacts on waterholes, thereby maintaining these vital oases in healthy and functional condition.

5 LAKES

5.1 Background

The casual peruser of a topographic mapsheet will notice that there are many 'lakes' dotted across the Lake Eyre Basin. The very term 'lake' tends to conjure images of shining expanses of blue water providing a haven for waterbirds. Such a perception could not be more misplaced for most 'lakes' in the LEB for most of the time. The great majority are ephemeral and bear little resemblance to the traditional conception of a 'lake'. Although technical words such as the Spanish-derived 'playa' or 'salina' are often used by geomorphologists to describe these features, the English language has no name for the flat expanses that, once or twice a decade fill with water (Donovan & Wall (eds) 2004). When full, they abound with life, including spectacular influxes of migratory birds (Kingsford & Porter 1994).

However, for most of the time they are shimmering, white and desolate expanses, where only mirages provide fleeting promises of water (Figure 30). Even comparatively deep so-called lakes such as Lake Hope, which can last for up to 18 months after filling, are dry more often than they have water in them. At such times, they are more likely to inspire horror than reverence. Gregory (1906) described Lake Eyre as 'repulsive in its forlorn barrenness', while Lewis, after his 1874-5 explorations, bemoaned that '..the very sight of it creates thirst in man and beast' (in Williams 1990, p.85). Madigan (1946) was perhaps even more appalled, writing 'The vast plain that is the lake is no longer a lake. It is the ghost of a lake, a horrible, white, and salt-crusted travesty'.

Figure 30: '…salt-crusted travesty' – typical dry 'lake' in the Lake Eyre Basin

Numerous waterholes along the Georgina and Diamantina Rivers are referred to as 'Lakes' (e.g. Lakes Mary, Katherine, Idamea on the Georgina and Lakes Constance and Teeta on the Diamantina). In this study, they are treated as waterholes, as their width to length ratio is much more similar to waterholes than true lakes (Costelloe *et al.* 2004). Lakes are much wider than waterholes, and as such have greater surface area to volume ratios. These wide, flat features are subject to extremely high rates of evaporation. As such, the only lakes with any degree of permanence in the LEB occur in the Desert Uplands on the north-eastern margin of the study area, and the Coongie Lakes in north-eastern South Australia. Due to their limited distribution, semi-permanent lakes have not figured as prominently in human history of the areas as channelised waterholes (see Section 4.5). Nevertheless, in the areas where they do occur, they are highly significant features, both ecologically and culturally.

5.2 Desert Uplands Lakes

Like the rest of the LEB, the Desert Uplands area in the north-east of the basin has experienced much wetter climates in the distant past. Extensive areas of claypans were once the bed of a large freshwater lake. Lakes Buchanan, Galilee and Dunn represent a portion of the original lake remaining (EPA 2006). Under present climatic conditions, however, only three Desert Uplands lakes have any degree of permanence: freshwater Lakes Dunn (Figure 31) and Huffer, and a small portion of the otherwise salty Lake Galilee (Table 20; Figure 32).

Figure 31: Lake Dunn, one of two semi-permanent freshwater lakes in the north-east portion of the LEB

Table 20: Summary of semi-permanent lakes of Desert Uplands

Name	Permanence	Hydrology/geomorphology
Lake Dunn	Semi-permanent – goes dry during extended dry spells, about 10 times in past 50 years (Bernie Dickson, pers.comm., August 2008). Usually only dry for 1-2 months then filled again, but in 2003 dry for three years.	Average depth of 1.5m; rocky bar at outlet acts like a subsurface ‘dam wall’, preventing subsurface drainage and maintaining a high water table. Floodwaters flush lake of salt almost every wet season (EPA 2006).
Lake Huffer	Semi-permanent – can be dry for extended periods in drought, but holds on in good seasons (e.g. dry throughout 2001-2003, but has held water from 2004-2009, Tina Hoch, pers.comm, January 2009)	About 1.5m deep on average. Filled from local run-off from country to east, then overflows into Thunderbolt Creek (tributary of Cornish Creek) when full.
Lake Galilee (freshwater arm)	Almost permanent – ‘freshwater arm’ has only been effectively dry once in past 40 years – birds were dying and cattle could not drink the water (Bob Marshall, pers.comm., January 2009)	Most of Lake Galilee dries up and/or becomes extremely saline, but this section is at freshwater inlet and remains fresh.

The other major lake in the system, Lake Buchanan is the most northerly salt lake in eastern Australia. It is a temporary wetland and is usually dry by mid-year after filling during the wet season. However, Caukingburra Swamp (Figure 32) occupies a natural depression at the northern end of the Lake and harbours a semi-permanent freshwater waterhole, which may last all year in good seasons (Mal Lorimer, pers.comm., January 2009).

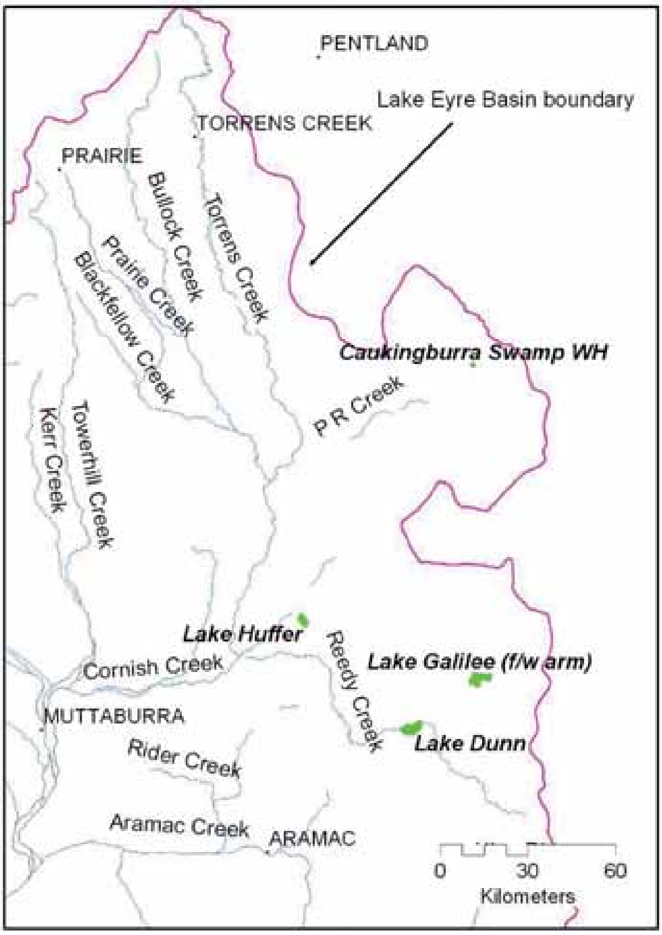

Figure 32: Semi-permanent lakes in the Desert Uplands, showing creeks and towns

5.3 Coongie Lakes

5.3.1 Geomorphology and hydrology

Despite being the largest of the LEB watercourses, the Cooper has reached Lake Eyre only 11 times since 1880 (representing about once every 10 years, and just 16% of the total flow to Lake Eyre over this time) (McMahon *et al.* 2008b). This is due in part to one of the most significant ecological sites in the Basin: Coongie Lakes. Flow reaches Innamincka practically every year, at least as a channel flood. However, about 25km west of Innamincka, the Cooper branches: most water travels along the north-west branch, and it is only in large floods that water begins to travel down the 'main channel' towards Lake Eyre (Reid & Puckridge 1990). The north-west branch feeds numerous semi-permanent to permanent waterholes, before spreading out through myriad small braided channels at Tirrawarra Swamp. It then reforms into the well-defined Kudriemitchie Channel, which empties directly into Coongie Lake (Reid & Puckridge 1990). These lakes represent the terminus for small to medium flows in the Cooper; it takes a very large flood to fill all the lakes and continue on the Lake Eyre.

The geomorphology of the Coongie Lakes area is largely a product of the interaction between the creek and dunefields of the Strzelecki Desert. The north-west branch has been 'captured' by the dunes, and lakes appear to have formed where dune swales have widened. There are six main lakes, which have similar saucer-shaped forms and depths between 2-2.5m at the cease-to-flow stage. They range in size from 12km^2 (Coongie) to about 50km^2 (Goolangirie) (Costelloe *et al.* 2004).

Coongie Lakes has received flow from Cooper Creek every year since 1973. The lakes fill sequentially through connecting channels, so the frequency of flooding, and therefore permanence of the lakes, decreases downstream. Conversely, salinity increases towards the terminal lakes, with Lakes Sir Richard, Lady Blanche and Apanburra all having elevated salinities, except immediately following flooding (Figure 33). The most permanent of the Coongie Lakes system is the freshwater Coongie Lake, the first in the system (Figure 33). It has been completely dry twice in the past 16 years, including when it effectively dried prior to the arrival of flow in February 2003 (Graham Morton, pers.comm., December 2008). When full, it holds water for a couple of years and is a haven for bird and animal life.

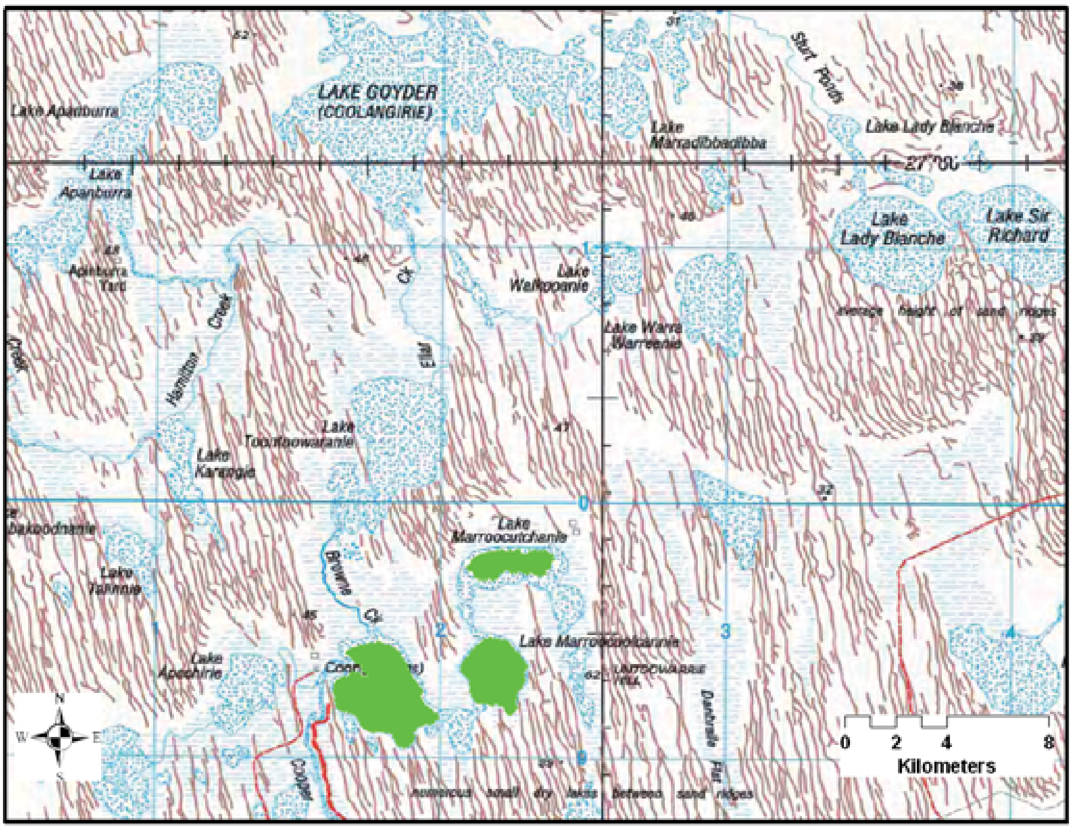

Figure 33: Coongie Lakes area, with semi-permanent (>70%) lakes highlighted in green: Coongie, Marroochoolcannie and Marroocutchanie

Once Coongie Lake is filled, the lakes directly to the west begin to receive water. Lakes Marroocoolcannie and Marroocutchanie (Figure 33) are less permanent, but usually have some water in them and are classed as semi-permanent. After these lakes have filled to a depth of about 1.5 metres, a sill at the start of Brown Creek is breached and water proceeds north to Lake Toontoowaranie, then sequentially to Lakes Goyder and Marradibbadibba (Reid & Puckridge 1990). Although these lakes can hold water for 18 months when full, the Cooper floodwaters only get past the Coongie group every 2-3 years, so they are often dry. Heading west, Cooper becomes still less defined, morphing into shallow lakes and floodplains, before reforming into a single channel closer to Lake Eyre.

5.3.2 Human significance and descriptions

The importance of such a seasonally-productive system to Indigenous people in an arid region is self-evident. During 'boom' seasons, it provided a concentration of resources that would have been unimaginable elsewhere in north-eastern South Australia. The lakes area is significant to many Aboriginal groups, but principally to the Yawarrawarrka people, who know the area as Kayityirru (Murgatroyd 2002). It is from the explorer and early settler records that most insight is gained into the indigenous society in the region.

Burke, Wills, Gray and King were uncannily lucky in the path they travelled to the Gulf of Carpentaria, finding reliable sources of water for most of the way – an unlikely feat in the vast desert country. Their first stroke of good fortune was to travel through the Coongie Lakes area. Wills was delighted by what they saw: *' [The lagoon] is of great extent, and contains a large quantity of water, which swarms with wildfowl of every description. It is shallow, but is surrounded by the most pleasing woodland scenery, and everything in the vicinity looks fresh and green'* (cited in Murgatroyd 2002, pp.186-7). Moreover, the party of 40-50 Aboriginal people camped at the lake were remarkably welcoming, bringing the white men a gratefully-received present of fresh fish.

McKinlay provided the first detailed descriptions of the South Australian lakes, as he spent three months in the vicinity searching for Burke and Wills, and exploring the surrounding countryside. McKinlay obviously travelled through this area in a good season. Despite the oppressive heat (he was in the area over the summer of 1860-61), his journal is littered with descriptions of 'splendid lakes', 'abundance of feed', thousands of waterbirds, including 'tens of thousands of flock pigeons' (p.19), and frequent encounters with large parties of 'natives'. From November 1860 to January 1861, his diary is dominated by descriptions of lakes, their character and likely permanence.

He established a Depot at Lake Cudye-cudyena and described and named numerous other lakes. Fortunately for McKinlay, these lakes mostly had water or lush green growth on them, and he enthused about their great depth and good water. His descriptions of Lakes Lady Blanche and Sir Richard, which he named after the then-SA Governor, are typical: *'…two beautiful lakes [with]…tens of thousands of pelicans on it, one solitary swan, with innumerable other birds…and plenty of fish'* (p.34). At the height of summer, he found it *'quite a treat to sit on the banks of this fine sheet of water and look at the innumerable waterfowl on its surface chasing their prey'* (p.35).

Over 150 Aboriginal people were camped at these lakes. In fact, McKinlay's party met with Aboriginal groups at nearly every lake, and on Browne Creek, which flows north from Coongie Lakes, they 'met with not less than 200 to 300 natives' along this 'continuous sheet of water' (p.33). He puzzled over why Sturt had reported only to have seen few natives: 'How the large body of people that is scattered all over this part could have escaped him, I cannot account for…' (p.33). The contrasting worlds experienced by McKinlay and Sturt, as the latter trudged through an 'earthly hell', highlight the extreme variability of this system of lakes. In good seasons, humans and animals exploit these ephemeral sources of water, before retreating back to more permanent water such as Coongie Lake and the Cooper waterholes (where Sturt did see many people) in dry times. McKinlay was soon to receive ominous hints as to the unreliability of his splendid lakes. Upon returning to Lake Hodgkinson, he was 'astonished to find it so much dried up in only 12 days…and the water now quite bitter' (p.37).

Later, Coongie Lake was to provide a Christmas camp for Surveyor W.H. Cornish on his 1879-80 expedition to survey the 'Herbert' (Georgina) River. Coongie Station was taken up in 1875 by Hector and Norman Wilson of Victoria (Tolcher 1986). The run was originally known as Promised Land or Land of Promise, owing no doubt to the series of lakes that dominate the property. However, reality soon struck and after heavy stock losses and a run of dry years, Coongie was merged with Innamincka Station in 1908 (Tolcher 1986).

5.4 Another 70% lake?

There is another Lake in South Australia that may just make the 70% cut-off. Known locally as 'Freshwater Lake' (marked on topographic maps as Lake Uloowaranie), it is situated amongst the sandhills north of Clifton Hills outstation. It gets filled about once every 3-4 years from the Diamantina River, with water draining back into the lake for about 6 months after the flood. The water then lasts for a couple of years (David Morton, pers.comm., November 2008). This regime means that, although it goes dry regularly and sometimes for considerable periods, it has water in more often than it is dry.

6 ROCKHOLES

Perhaps there is no harsher environment for life in inland Australia than the stark, low ranges that rise like barren fortresses from the sweeping plains (Figure 34). Tenacious plants seem to grow out of sheer rock and the unrelenting sun reflects off the bare, stony ground. However, even amongst the remote and rugged ranges of western Queensland, far from large rivers and waterholes, lie hidden sources of water. Small depressions, often carved in sheer rock, harvest local run-off when it rains and, depending on the time of year and the depth and size of rockhole, may retain water for many months. This section provides an overview of these features, including their distribution, ecology and human significance.

Figure 34: Typical ranges of western Queensland: Lark Quarry district (left) and Grey Range east of Noccundra (right)

6.1 Overview, distribution and permanence

Rockholes capable of holding water are dotted throughout the granite and sandstone ranges of inland Australia, particularly in sheltered gorges and gullies. Range systems occur across the Lake Eyre Basin in Queensland and South Australia, from the rugged sandstone country of the Great Dividing Range to the low, barren stony hills that intersect north-eastern South Australia. Most of these systems harbour only ephemeral rockholes, which hold water for weeks to a couple of months after rainfall. Truly semi-permanent rockholes are relatively rare, and tend to be concentrated in certain areas. The major concentrations of rockholes in the LEB form loose rockhole regions or 'provinces' (Figure 35), as summarised in Table 21.

Table 21: Major rockhole regions or 'provinces' of the Lake Eyre Basin

Region	Description	Rockhole Overview
Northern Grey Range	Tertiary sandstone ranges associated with the northern Grey Range and Gowan Range west of Blackall, on Bulloo-Barcoo watershed	Semi-permanent, and occasionally permanent, rockholes occur throughout this area, mostly in rocky gully heads
Vergemont Residuals	Includes Tertiary plateau east of Vergemont Creek and dissected residuals west of Vergemont Creek, on the western edge of the Cooper catchment	Series of semi-permanent to permanent rockholes along creeklines and in rocky gully heads

Goneaway Tablelands	Stony tablelands and sandstone ranges in upper catchments of Mayne River and Farrars Creek, on eastern edge of Diamantina Catchment	Numerous semi-permanent and occasional almost-permanent rockholes along creeklines and in rocky gully heads
Winton Plateau	Sandstone ranges and dissected plateaux south-west of Winton	Series of permanent and semi-permanent rockholes, concentrated on Bladensburg National Park
Kynuna Plateau	Sandstone ranges of the upper Diamantina River and tributaries	Numerous permanent and semi-permanent rockholes, mostly in rocky gully heads
North West Highlands	Rocky ranges south of Mt Isa and Cloncurry, associated with outcrops of igneous and folded metamorphosed rocks; on watershed between LEB and Gulf Rivers	Small number of semi-permanent to permanent rockholes in generally rough, inaccessible ranges

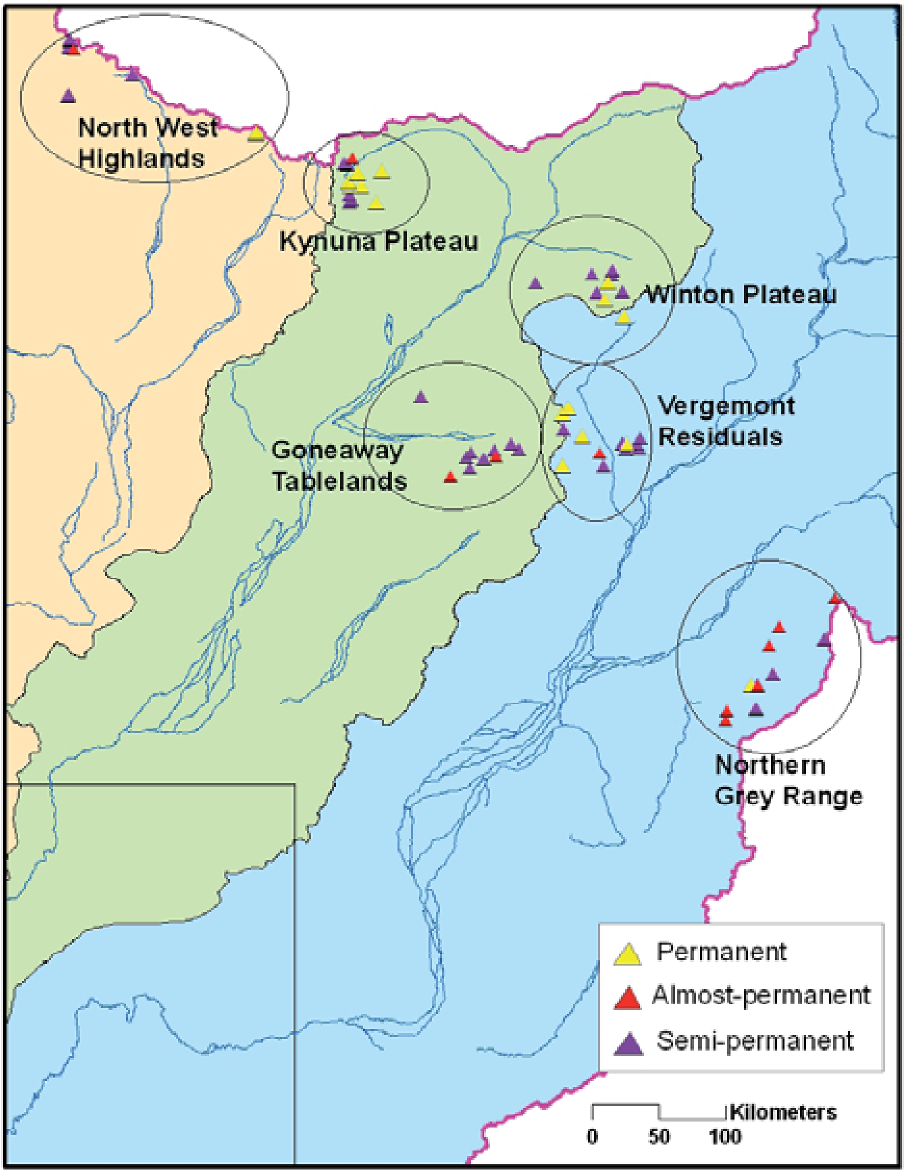

Figure 35: Rockholes and rockhole 'provinces' of the Lake Eyre Basin

These ‘rockhole provinces’ are centred on the watersheds of the LEB, mostly in the northern and eastern higher-rainfall areas. There are numerous rockholes along the Great Dividing Range which marks the eastern margin of the LEB, but these are mostly spring-fed (GAB recharge springs) and are discussed in Section 7. In other range areas, interviews with landholders revealed that rockholes do exist, but generally go dry within 1-3 months. In particular, lasting rockholes virtually disappear from the southern and western parts of the study area. This is probably related to lower rainfall, which means that rockholes are topped up less frequently, but can perhaps be partly attributed to the underlying geology. The ranges in the northern half of the Queensland LEB are generally characterised by steeper, more precipitous formations, which provide places for large rockholes to form and harbour water. In contrast, ranges in the south, including the southern section of the Grey Range in Queensland and the stony tablelands east of the Cooper, are more rounded and are not characterised by the caves, cliffs and deep rockholes of ranges further north.

Overall, 72 individual rockholes were documented during this project: 26 in the Cooper Catchment, 35 in the Diamantina and 11 in the Georgina. 15 of these were visited by the author. More than half of all recorded rockholes in the Vergemont Residuals, Winton Plateau and Goneaway Tablelands were visited, but no rockholes were visited in the North West Highlands or Kynuna Plateau, reflecting the generally inaccessible nature of rockholes in these areas. Most (60%) of rockholes in western Queensland are semi-permanent, and go dry regularly, often towards the end of each dry season. Almost-permanent waterholes are those that go dry less than once a decade, while permanent rockholes have not gone dry to the best available knowledge. An inventory of these rockholes is provided in Appendix 7, while Table 22 summarises their distribution by region. The Spatial Data CD which accompanies this report contains the full Excel spreadsheet and shapefile for rockholes.

Table 22: Permanence of rockholes by province

Region (Catchment)	**Permanent**	**Almost-permanent**	**Semi-permanent**	**TOTAL**	**% Permanent**
Northern Grey Range (Cooper)	1	6	6	**13**	8%
Vergemont Residuals (Cooper/ Diamantina)	6	2	9	**17**	35%
Winton Plateau (Cooper/Diamantina)	2	0	7	**9**	22%
Goneaway Tablelands (Diamantina)	0	2	8	**10**	0%
Kynuna Plateau (Diamantina)	6	1	5	**12**	50%
North West Highlands (Georgina)	2	1	8	**11**	18%
TOTAL	**17**	**12**	**43**	**72**	**26%**

The permanence of rockholes is determined primarily by their size and depth, while shade from rock overhangs and fringing vegetation may also protect the water from evaporation in some rockholes. In contrast to waterholes, rockholes need only be about two metres deep to be close to permanent, as they are filled from even small local rainfall events on the 'tin roof' country that surrounds them. Hence rockholes owe their permanence not to their immense water-holding capacity but to landscape position. Some of the most permanent rockholes, such as Man Hole on Bladensburg National Park, are almost completely sheltered by a cave or overhang, minimising both animal access and evaporation.

The permanence of a rockhole in any given season will depend upon timing and amount of rainfall, particularly 'lucky' storms during the dry, which will top up rockholes between wet seasons. The relative preponderance of rockholes in the central and eastern sections of the study area reflects the higher, more reliable rainfall of these areas. Although the North West Highlands receives comparable annual rainfall, it is strongly seasonal, with nearly all rain falling in the summer months. As such, there is greatly reduced chance of winter rainfall topping up rockholes. Thus even 6-7 month rockholes, which may be almost-permanent further south by virtue of receiving winter top-ups, will be dry by August-September and are not replenished until monsoonal summer rains.

6.2 Formation and geology

Rockholes in sandstone ranges result from geomorphologic fracturing followed by scouring out as water runs into them. There is some overlap between rockholes and small waterholes in the upper catchment of rivers and creeks. Rockholes are often associated with small gullies and drainage lines, blurring the distinction between 'waterholes' and 'rockholes'. In general, rockholes are defined as those holes *not* located on a major (named) drainage line, and therefore mostly reliant on local rainfall and gullies for their water (Duguid *et al.* 2002). Rockholes often occur in gully heads, while some are dotted along rocky creekbeds (Figure 36).

Figure 36: Common landscape positions (i) along rocky creekline (Spring Creek, Goneaway National Park) and (ii) rocky gully head (Ju Ju Rockhole, Tonkoro)

Queensland's rockholes occur primarily on sandstone, and so differ from the 'gnammas' of central Australian ranges, which are formed through chemical weathering of granite (Bayly 1999). Sandstone ranges were formed in the Tertiary and comprise plateaux, mesas and buttes (Hughes 1980). They are characterised by shallow and skeletal soils, and typically support open lancewood (*Acacia shirleyi*) woodlands and/or various hardy *Eucalyptus* and *Eremophila* species. The North West Highlands rockhole province, which occurs on the Mt Isa Inlier formation, is a notable exception. This outcrop of igneous and folded metamorphosed rocks of the Cloncurry complex is characterised by shallow and skeletal soils supporting sparse snappy gum (*E. leucophloia*), box and bloodwood, typically with a spinifex (*Triodia* spp.) understorey (Perry 1964). These Pre-Cambrian rocks are much older than those that comprise the Tertiary sandstone ranges further south.

Stony ranges have been neglected in terms of detailed study, and much remains to be understood about the hydrogeology of these features. In some cases, such as the Puritjarra Rockhole in central Australia, rockholes are sustained by a regional aquifer (Bandler 1995). There are a couple of rockholes in the LEB with soakages in the bottom, meaning that water is present even during very dry times, although it may dry back to a damp patch of sand (Peter Magoffin, pers.comm., February 2008). In general, however, there appears to be minimal interaction between groundwater aquifers and rockholes, and most rockholes rely totally on local rainfall. There are some cases where Tertiary springs (see Section 7.2) feed substantial rockholes.

A feature of rockholes is their clandestine, if not downright incongruous, nature (Figure 37). They usually occur in the most hostile and seemingly lifeless landscapes, where one would not expect to find any free water. The explorer Austin (1856) was led by local Aborigines to a hidden rockhole in the Murchison region of Western Australia, 'in a region where we would never have thought of searching for one' (Bayly 1999, p.18).

Figure 37: Concealed…there are few indications that there is a small semi-permanent rockhole hidden in this stony tableland on Spring Plains west of Longreach

6.3 Rockhole ecology: water, flora and fauna

Whilst rockholes may be unwittingly stumbled upon by those who wander in the arid ranges, numerous signs can provide clues as to their location. Their presence is often revealed by the stately trunk of a river red gum (*Eucalyptus camaldulensis*) twisting above the rocky tableland and stunted wattles (Figure 38a). River red gums like 'wet feet' and require seasonal inundation for their survival, so are good indicators of where water lies for a considerable time, or is very close to the surface. They produce seed freely, and dense thickets of saplings can appear around rockholes. Another eucalypt, the much-loved ghost gum (*Corymbia blakei* or *C. aparrerinja*; Figure 38b), may also be present around rockholes. Whilst enhancing the aesthetics of the rockhole with their smooth, striking white gnarled trunks, they also survive in waterless tableland (albeit in a more stunted form), so are not reliable indicators of surface water.

In more sheltered areas, the luminous green leaves of a fig tree (*Ficus* species) may contrast with the muted greys and browns of the surrounding landscape (Figure 38d). While fig trees are relatively common throughout more mesic areas of northern and eastern Australia, further inland they are mostly restricted to permanent or semi-permanent rockholes and springs in the ranges. Other plants with rainforest affinities, such as red ash (*Alphitonia excelsa*) and lolly bush (*Clerodendrum floribundum*) may also signal the presence of reliable surface water. Soap bush (*Acacia holosericea*) is also a distinctive component of many rockholes (Figure 38c), with its broad, longitudinally-veined silver-grey phyllodes. Rockholes are probably providing refuges for these species, which would have been more widely distributed during less arid palaeo-climates (Morton *et al.* 1995; Box *et al.* 2008). Water-loving sedges (*Cyperus* species) and forbs such as water primrose (*Ludwigia peploides*) are common components of the ground flora fringing the more permanent rockholes.

The whistles and warbles of birdlife may also reveal a hidden rockhole. Margarey (1889, cited in Macinness 2007), in his review of Aboriginal use of desert waters, wrote that 'as thoroughly reliable guides to water in very dry regions the birds have no rivals'. In particular, grain-eating birds, which gain little moisture from their food so must drink regularly, are unsurpassed as 'water diviners'. The presence of zebra finches, painted finches, diamond doves, various pigeon species, as well as melodious red-browed pardalotes and western gerygones, can indicate a hidden water source. Such birds were much lauded by early explorers, and their absence viewed as an ominous sign of lack of surface water. At his Depot in the Barrier Range of north-western New South Wales, which was to become the party's 'drought prison' for many months, Charles Sturt mused *'Was it instinct that warned the feathered races to shun a region in which the ordinary course of nature had been arrested, and over which the wrath of the Omnipotent appeared to hang?'* Not only does the birdsong of finches, pigeons and parrots brighten the rugged ranges, it also assures the traveller that water may be near. Nevertheless, birds can utilise sources of water that are invisible or unusable to humans, and are therefore far from infallible indicators of the presence of permanent water (Box *et al.* 2008).

Figure 38a-d: Common rockhole species, clockwise from top left (a) river red gum (*Eucalyptus camaldulensis*), (b) ghost gum (*Corymbia blakei*), (c) soap bush (*Acacia holosericea*) and (d) fig trees (*Ficus cerasicarpa*)

Rockholes are also home to numerous less conspicuous forms of life. Those sitting by a rockhole may be enchanted (or deafened) by the humming of cicadas, while butterflies and dragonflies flit across the surface of the water. Bayly (2001) found nine species of invertebrates in one small ephemeral rockhole in central Australia, mostly comprised of Crustaceans. Larger rockholes, typically those connected to drainage lines, often provide a haven for fish. Spangled perch (*Leiopotherapon unicolour*) and rainbow fish (*Melanotaenia splendida tatei*) may be abundant in rockholes, along with yabbies and crayfish. As the rockhole recedes and water becomes increasingly oxygen-deficient, these doomed aquatic inhabitants are stranded in their isolated habitat. Frogs, however, may burrow under the moist sand and survive until the rockhole fills again. The large but non-venomous olive python also relishes the shady recesses around rockholes.

By night, numerous species of bat flit around rockholes, dipping to drink, while spotted night jars and owls emerge from their rocky diurnal shelters. A single rockhole on Bladensburg National Park is home to at least 4-5 species of bats (Alicia Whittington, pers.comm., May 2009). Rockholes are also utilised by grazing animals, and so have an impact on the surrounding landscape that far surpasses their tiny surface area. Rockholes in the Northern Territory and South Australia are known to be used by rock wallabies, and it is likely that these agile mammals also make use of rockholes in areas where they still occur in Queensland, including on Idalia National Park. The hardy wallaroo and numerous feral animals also utilise rockholes (see below), becoming increasingly dependent upon the more permanent ones during dry times.

Nonetheless, the parched wanderer of the rocky promontories, entertaining notions of a crystal clear oasis of verdure and birdsong, will usually be disappointed. The quality of water varies depending on time since rain, and becomes increasingly rank and stagnant without replenishment, ultimately deteriorating to the point where 'in civilisation [it] would be thought only fit to be used as manure for the garden' (Carnegie 1898). In reality, civilisation is a distant notion in these remote ranges, and humans and animals have long viewed rockholes as a vital source of life-giving water.

6.4 Human significance

Rockholes have always inspired reverence in the people who encounter them. Perhaps this harks back to our deepest evolutionary psychology: rockholes represent the perfect hunter-gatherer habitat, providing reliable water, game, and a clandestine vantage point from which to observe the world and watch for potential threats (Appleton 1975). The presence of intricate rock art and substantial stone arrangements in many range systems points to the sacredness of these landscapes over millennia. Ludwig Beckler, travelling through western NSW in search of missing members of the original Burke and Wills party, was enchanted by the Mootwingee rockholes, writing that 'Nothing could disturb us from the sensual ecstasy of this day…' (Murgatroyd 2002, p.177). The wanderer in arid ranges today feels a similar reverence for these hidden, incongruous, life-giving pools.

6.4.1 Aboriginal

Despite their cryptic and often ephemeral nature, rockholes were of key importance to Aborigines dwelling in many areas of arid Australia. Bayly (1999) writes that Aboriginal tracks in many regions were largely governed by the occurrence and distribution of rockholes. Penetration of the arid zone has long been regarded as the most crucial test of successful adaptation to all major ecological zones within the Australian continent (Thorley 1998). The arid ranges must be regarded as the supreme test of such adaptation, and but for the presence of rockholes, they would not have been habitable at all, even for brief periods.

The context of Aboriginal use of rockholes must be considered in light of fluctuating climatic conditions over the past 40 000 years. Results from central Australian ranges suggest that initial use of rockhole sites occurred around 30 000 years ago, during a cooler and wetter time than present (Thorley 1998). Sites which show a clear continuity of occupation tend to be those with reliable and widespread permanent water, such as Lawn Hill Gorge. Ranges with less permanent water, including the 'rockhole regions' of the LEB (Table 21) seem unlikely to have provided reliable habitation sites during the last glacial maximum (25 000 to 12 000 years BP).

During this period, conditions were much more arid than today, meaning greater distances between rockholes and reduced permanence of these isolated features. In central Australia, the glacial maximum period shows a very slow accumulation of artefacts around rockholes, suggesting that sites were abandoned or not used regularly until less arid conditions returned about 12 000 years ago (Thorley 1998).

Rockholes are not isolated entities in the 'cultural landscape' (Armstrong 2001; Holdaway *et al.* 2000), and the proximity to other reliable water supplies would have been the principal factor in determining patterns of use of certain rockholes and districts. Even under current climatic conditions, nearly all rockholes go dry, or dwindle to putrid puddles, during dry times. In the absence of a good wet season and storm rains to top them up, the arid ranges become essentially waterless, as was the case across much of western Queensland in 2002. Therefore, rockholes in arid ranges would have been linked to wider networks of permanent water along major river systems. Even in good seasons, the small, widely-spaced rockholes would not have supported large numbers of people on a permanent basis. In dry periods, the ranges would have been unoccupied until rains replenished the vital oases.

Nevertheless, background artefact scatters occur across many seemingly inhospitable range environments in the Lake Eyre Basin, indicating that these areas were utilised over millennia, albeit on a rather ephemeral and opportunistic basis. The density of artefacts tends to increase with proximity to ephemeral drainage lines (Simmons 2007). Stone arrangements nestled among many range systems testify to their importance for ceremonial purposes, while there are also concentrations of rock art in the vicinity of some larger rockholes. There are many signs of Aboriginal occupation of the rough country west of Blackall, including caves, stone arrangements and artefact scatters. The Grey Range further south is similarly dotted with cave paintings, stone arrangements, occupation sites and native wells (Jenkins 2001). Quarries and stone arrangements, apparently consisting of rings and possible associated pathways, are present in the ranges around Stonehenge (Knuckey & Kippen 1992).

There are also stone arrangements on Goneaway National Park and Mt Windsor, midway between the Diamantina and Thomson Rivers (Simmons 2007). This places them on the return leg of the Maiwali trade and exchange route from Winton. Rockholes, along with Tertiary springs and 'native wells' in some areas, would have been the primary source of water for people making forays, both material and spiritual, into these ranges.

It seems likely that the rugged ranges were visited only during good seasons, for ceremonial and meeting purposes, with little permanent occupation. For example, the gorges and rockholes at Mutawintji in western NSW provide the only permanent water for many kilometres, and as such have been a place of ceremony and celebration for thousands of years. The narrow gullies shelter permanent pools, which are surrounded by some of the most sacred rock art in south-east Australia (Murgatroyd 2002). It provided an 'emergency larder' of sorts, to which people retreated back to in times of drought. It was not permanently occupied, and when the good times returned, people dispersed onto the surrounding plains, secure in the knowledge that supplies of water and food would remain at their 'drought refuge'. Some rockholes are so remote, and separated from other water sources by vast expanses of inhospitable, rocky, prickly and dry terrain that it seems unlikely that they were regularly visited (Bob McDonald, pers.comm., June 2009).

Unsurprisingly, these small but precious sources of water were protected, and even enhanced, over thousands of years. Bandler (1995) reports that rockholes were sometimes extended by pounding the sides and bottom to increase their capacity, while they could also be made more permanent by creating guiding grooves to direct the natural run-off into holding pools. In central Australia, rockholes were a crucial source of water for the Anangu people, and regular cleaning allowed them to properly hold water (Wilson *et al.* 2004). When dark clouds were gathering over the horizon, men would clean the rockholes out so they would fill with clean water. They sometimes covered smaller openings of rockholes with stone slabs and vegetation to minimise evaporation and exclude wild animals, which often fell in and drowned. As such, Carnegie (1898) noted that a 'patient search over the whole surface of the rock' was necessary to locate such rockholes.

6.4.2 Explorers and settlers

Explorers often navigated from range to range in search of rockholes and springs, particularly in regions without reliable riverine waterholes. In the Northern Territory, Anna's Reservoir north of Alice Springs was 'discovered' and described by John McDouall Stuart in April 1860. Being the only reliable water across a vast area, this 'splendid reservoir…in a ledge of rocks' proved indispensable for Stuart on each of his three attempts to cross the continent. Later, linesmen on the Overland Telegraph Line and early pastoralist Alfred Giles relied upon this rockhole. It then formed the homestead site for the Barrow Creek Pastoral Company, until attacks from the understandably possessive Anmatjere Aboriginal people forced withdrawal from the area (NT Parks & Wildlife Commission 2002).

Giles, Carnegie and Warburton also relied upon hidden rockholes, often pointed out by local Aboriginal people. Charles Sturt followed the Grey Range north for much of his expedition in western New South Wales, moving between water sources before establishing a Depot in north-western NSW. Rockholes do not feature in Queensland's exploration history to the same degree that they do in the Northern Territory and Western Australian deserts, probably because of the comparative abundance of reliable waterholes along the major rivers. The waterholes that characterise the Georgina, Diamantina and Cooper systems, which provided vital supplies for the explorers (see Section 4), are virtually absent from the sandy rivers of the centre, necessitating a reliance of explorers on other sources of water.

In reality, the ranges of inland Queensland have horrified and repelled Europeans since they first ventured inland. The Selwyn and Standish Ranges south of Cloncurry (Figure 39) left Burke and his party exhausted, and the camels sweating with trepidation. The full extent of the party's ordeal has to be imagined, since even the conscientious Wills was too exhausted and disheartened to keep a journal during this stage of the journey. Over a century later, two experienced bushmen set out to recreate the Burke and Wills journey. Tom Bergin described the land around the Selwyn Ranges as 'the cruellest ground I have ever dragged an animal over' (Murgatroyd 2002, p.202).

Figure 39: '…the cruellest ground…' Selwyn Ranges near Cloncurry

Due to their often inaccessible nature, rockholes did not figure prominently in early settlement patterns in western Queensland. Nevertheless, it seems that the ranges south and west of Winton saw their share of frontier violence, including a supposed massacre at Skull Hole on Bladensburg National Park and a fierce battle at the aptly-named Battle Mountain in 1889, during which Sub-Inspector Ughardt of the Native Mounted Police destroyed much of Kalkadoon society (Armstrong 1981).

A small number of large, almost-permanent rockholes such as Mountain Hole in the low stony tablelands west of Longreach, were used as 'stop-overs' on droving runs, due to the reliable supply of water in otherwise waterless areas (Steve Hawe, pers.comm., January 2009). Some of the more permanent rockholes have remnants of old yards and fencing around them, indicating that they were used to trap stock, presumably during dry times when animals would be concentrated around remaining water sources. Many rockholes have been 'discovered' by chance, by landholders, mustering contractors or helicopter pilots (e.g. Neil Marks, pers.comm., December 2008; Bob McDonald, pers.comm., January 2009; Johnny Avery, pers.comm., February 2009), or more recently by naturalists and Queensland Parks & Wildlife staff exploring the ranges.

Despite (or perhaps because of) being seldom visited, the remote, rugged inland ranges that harbour rockholes also harbour the sort of intriguing histories that would not be out of place in the pages of a gothic western novel. From long-lost travellers whose lonely spirits haunt the rocky recesses to covert drug-growing operations and anarchic opal fields, the harsh and powerful nature of these areas seems to give rise to a rich repository of local folklore.

6.5 Present-day status

Today, very few people ever venture into the arid inland ranges of western Queensland, and the landscape is most often seen from the comfort of a helicopter or small plane. Only a few rough bush tracks have managed to penetrate the country, rendering motorbike, horseback or foot the only viable modes of transport. As such, human impacts on rockholes are generally small – only those who have cause to venture into this rough country will be aware they exist, and even then they can be difficult to find! A small number of rockholes on private property are favoured spots for camping and swimming, but impacts from these activities would be minimal. Furthermore, such inhospitable country is rarely grazed by cattle or sheep, and the more rugged areas are considered virtually unsuitable for grazing (Perry 1964).

Feral goats are the major scourge of inland ranges across western Queensland, while elevated wallaroo numbers and camels may also have some impact. The fact that rockholes can often be located by following animal pads, and the concentration of goat droppings around many of them, indicates that they are foci for animal life. During dry times, when few other sources of permanent water remain in the arid ranges, rockholes and their surrounding landscape will be subject to high total grazing pressure and its associated impacts, including depletion and fouling of water through animal use, loss of groundcover and silting up.

The numerous accounts of Aboriginal people ‘husbanding’ natural rockholes raise the possibility that water was more widespread and permanent in the ranges prior to European settlement. In central Australia, it is now realised that maintaining these sources of water in an otherwise dry environment has major impacts on biodiversity, and is an effective management technique for increasing wildlife numbers. As a result, there is a program underway where traditional owners are ‘caring’ for the rockholes using traditional methods (Wilson *et al.* 2004). Durack (1959) writes that ‘gnamma holes’ in the Grey Range, which had always contained water, went dry in the drought of the early 1870s. When filled again by rainfall, they quickly evaporated because, since the coming of white man, Aboriginal people had neglected the careful ritual covering of them.

Unsurprisingly, the level of knowledge surrounding rockholes in the Lake Eyre Basin is much less than for the other types of waterbodies. They are not mentioned in any land resource assessments or vegetation mapping of western Queensland (e.g. Perry 1964; Western Arid Region Land Use Studies), and this project was the first to formally document their existence. In some areas, long-term landholders have detailed knowledge of the location and permanence of rockholes (e.g. Duncan Lawton, pers.comm., February 2009; Angus Logan, pers.comm., February 2009; Bob McDonald, pers.comm., June 2009). More commonly, however, the location of certain rockholes is only known roughly, and there is very little information available on their likely permanence.

Ongoing observations of rockholes in different seasons will shed further light on their permanence, as well as dependent biota. The surrounding habitat represents a potentially rich repository of fascinating and rare species inhabiting a chronically understudied environment. In particular, the distribution and habitat preferences of numerous rare fauna species, including the notoriously elusive night parrot (*Pezoporus occidentalis*), suggests that surveys concentrated around these rockholes may be potentially fruitful. Ultimately, however, the mapping, permanency assessments and our understanding of the ecological and cultural significance of many of these remote waterbodies is likely to remain somewhat obscure.

7 SPRINGS

Where groundwater comes to the surface in the Lake Eyre Basin, its permanence stands in stark contrast to the variability of most waterholes and rockholes and the overriding aridity of the surrounding landscape. Springs occur where underground water is forced to the surface, and may emanate either from the Great Artesian Basin (GAB) or local aquifers. Artesian springs occur on the margins of the Great Artesian Basin in western Queensland, northern New South Wales and north-eastern South Australia. Non-GAB springs are widely but infrequently distributed across western Queensland. They often emanate from local aquifers in rocky ranges, although they may be present in other landscapes. Soaks and seepages occur where groundwater is present on the surface, but there is not the same force or volume of water associated with these features.

7.1 GAB springs in the LEB

7.1.1 Overview and distribution

The Great Artesian Basin (GAB) underlies much of the Lake Eyre Basin. It is the largest groundwater basin in the world, with an area of 1.7 million square kilometres, underlying one-fifth of the continent (White 1994). This huge sandstone basin was formed 250 million years ago, and stores 8700 million megalitres of water, which sits between just a few metres and three kilometres underground. Most of the GAB lies under the 70% of Australia that is classified as arid or semi-arid (Noble *et al.* 1998).

Spring wetlands fed by perennial groundwater are distinctive in semi-arid and arid regions, where they represent one of the few sources of truly permanent water. Fensham & Fairfax (2003) provide an overview of the hydrology of the GAB springs. Prior to European settlement, there were about 3000 flowing springs in the Great Artesian Basin, and these represented the only permanent water source in many parts of inland Australia (Ponder 2002). The drilling of the Basin (discussed further in Section 8) has led to the extinction of about one-third of these springs, and flow reductions in the remainder (Ponder 2002). The extant springs are clustered in 13 major groups, mostly in South Australia and Queensland (Figure 40).

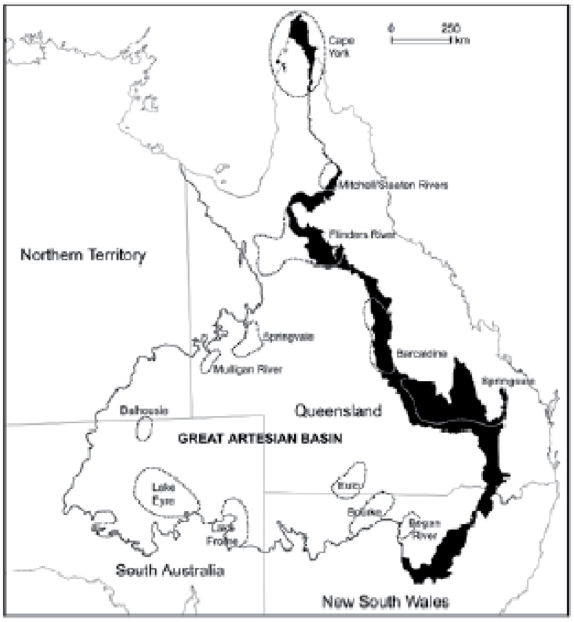

Figure 40: Great Artesian Basin, showing recharge area (black) and spring groups (from Ponder 2002)

The only GAB springs in the Georgina, Diamantina and Cooper catchments occur in Queensland – Dalhousie and other South Australian springs occur in other catchments to the south and east of Lake Eyre and are not considered in this report. There are 370 documented GAB springs in the study area. Of these 230 are still active, while 140 are considered inactive. They can be grouped into three 'super-groups': Mulligan River on the western edge of the GAB, Springvale straddling the Diamantina-Georgina watershed east of Boulia, and a cluster along the eastern margin of the Basin (Figure 41). The eastern springs are typically recharge springs, and water therefore has relatively short residence times. In contrast, the Springvale and Mulligan River supergroups are comprised of discharge springs, and are remote from recharge areas. This results in much longer groundwater residence times, manifested in alkalinity with high levels of dissolved solids (Fensham *et al.* 2004).

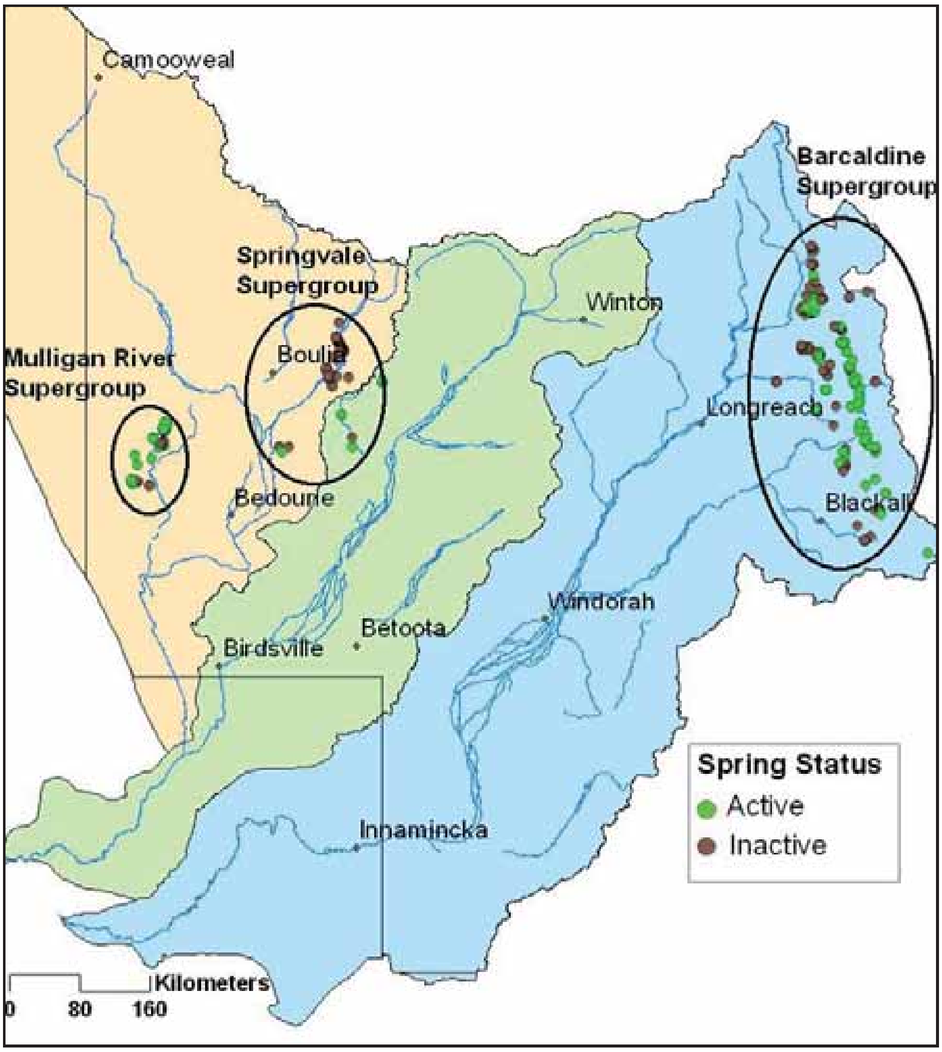

Figure 41: GAB Springs of Cooper, Diamantina and Georgina Catchments

7.1.2 Ecology

In many of areas, particularly on the harsh western edge of the GAB, springs provide permanent freshwater in an otherwise harsh desert environment. The refugial nature of springs in arid environments has been widely discussed. Each group has a distinct assemblage of flora and fauna, which often includes highly specialised and endemic species (Figure 42). Recent studies have revealed them to be evolutionary hotspots, providing habitat for a mind-boggling array of endemic plants, fish, snails and other invertebrates (Boyd 1990; Ponder 2002; Fensham & Fairfax 2003; Ponder 2003; Fensham & Price 2004; Fensham *et al.* 2004; Fairfax *et al.* 2007). Both discharge and recharge springs support populations of non-endemic native plant species isolated by over 500km from other populations (Fensham *et al.* 2004). These authors found that discharge springs of the GAB were floristically distinct from the recharge springs and non-GAB springs.

Figure 42: 'Type Locality' Spring, Edgbaston, central Queensland

In terms of the distribution of water, the discharge springs on the western edge of the study area, incorporating the Mulligan River and Springvale supergroups, are especially significant. They occur in relatively arid areas, providing the only permanent water across vast swathes of country. The extinction of many springs in the Springvale group therefore has a significant effect on the distribution of permanent water in this area (Section 8.2.2).

7.1.3 Human significance

The cultural significance of GAB springs is well-recognised for the arc of mound springs that occur around the southern and western edges of Lake Eyre. These springs are associated with one of Australia's most richly-patterned trade and communication routes, spanning both Aboriginal and European history. In contrast, very little is documented surrounding the cultural history of the GAB springs in Queensland.

7.1.3.1 Aboriginal

In South Australia, springs such as Dalhousie were important Aboriginal camp sites, feature prominently in Aboriginal stories from the LEB and were vital nodes in continent-wide trade and communication routes (Boyd 1990; Harris 2004). Dalhousie Springs were collectively known as *Irrwanyere*, or 'the healing spring', and provided much more than a source of water in a harsh environment. Today, it remains 'a travel path…a source of healing when we are sick, and it provides us with many spiritual and cultural interests' (Ah Chee 2002). Archaeological remains associated with one camp site at Dalhousie Springs extend for almost three kilometres (Bayly 1999).

The Aboriginal history of Queensland's springs is not as well documented. Hodgkinson encountered a group of 30-40 people west of the Diamantina River near a set of permanent springs (Hodgkinson 1877). This would have been springs within the Springvale group, possibly Elizabeth Springs (Simmons 2007). The country was showing signs of recent drought, suggesting that people congregated around more permanent waters, including springs, in dry times. In the 1880s, government surveyor Twisden Bedford recounted a story from the Mulligan River region suggesting that a large spring, possibly Ethabuka Spring, was the resting place of an 'oracle', whom the local people consulted by diving deep into this bubbling pool. The diary entries of Charles Winnecke (1883; Table 22) confirm that the Mulligan River springs were intimately known to, and used by, the local Aboriginal population.

Intriguingly, the concentration of springs along the eastern edge of the GAB, including Edgbaston and Myross complex, show little sign of Aboriginal occupation, despite the presence of occupation sites in the escarpment immediately to the east. Local stories suggest that these springs were regarded as sacred and therefore not used as drinking water. This is despite being a major source of permanent water between the highly productive Desert Uplands Lakes and reliable waterholes of Aramac Creek and the Thomson River. There are numerous habitation, burial and rock art sites in the Sandstone Belt on the far eastern side of the LEB (Godwin 2001), and the GAB springs throughout these ranges (Figure 41) would have provided vital water for these people. Black's Palace, south-west of Alpha, is one of the largest art sites ever recorded in Australia, and points to the ceremonial significance of this area to Aboriginal people (Godwin 2001).

7.1.3.2 Role in exploration and early European settlement

The springs on the western and southern sides of Lake Eyre played a vital role in 'opening up' the country (Harris 2004). Babbage, and then Warburton, 'discovered' and named a number of springs in 1858. John McDouall Stuart was the first to describe the extent and importance of the springs in 1859. He perceived them as important 'stepping stones' to the interior, and accordingly used them for his numerous inland forays, which finally culminated in his transcontinental crossing in 1861-62 (Bailey 2007). This triumphant crossing was only successful because of these springs (Harris 2004). The reliable water supply provided by the mound springs, coupled with favourable reports of grazing land, soon enticed pastoralists into the region. By 1859-60, the first pastoral stations were established in the southern portion of the LEB. Later, two significant infrastructure developments, the Overland Telegraph Line (completed 1872) and Central Australian Railway (commenced in 1878, but not extended past Oodnadatta until 1929), followed the arc of mound springs from the south to north-west of Lake Eyre (Gibbs 2006). Mound springs provided vital permanent water for repeater stations along the line.

In the Cooper, Diamantina and Georgina catchments, where waterholes are much more numerous and widespread than springs, there is no close association between springs and settlement history. Charles Winnecke provided the first European descriptions of the far-western Queensland springs on Sandringham and Ethabuka in 1883. These springs were the only source of permanent water amongst the 'hideous spinifex desert' west of the Mulligan, and as such were vital 'stepping stones' on Winnecke's push west into the Northern Territory. His observations of the springs he encountered are summarised in Table 23.

Table 23: Winnecke's observations of Mulligan River Springs, 1883

Spring or Group	Winnecke Observations
Biparee Springs	'These springs are situated at the north end of a small claypan, which is surrounded by high spinifex sandridges. A few natives were encamped here…; the springs, three in number, are close together and similar to a great many mound springs on the overland telegraph line; they are slightly above the level of the claypan on little mounds; the water, although somewhat charged with soda, is drinkable. One of these springs has been fenced in and cleaned out, which has caused a small stream of water to flow into the claypan. I found it to run about 2,000 gallons a day; a far larger quantity of water could be obtained by further improving the spring' (p.6)
Boolcoorra	'…another small claypan, containing several springs similar to those at Biparee; they are at present useless, being choked up with rubbish. It would require but a little labor (sic) to render these springs capable of watering a large quantity of stock. We camped at these springs, which the natives call Boolcoorra' (p.6)
Tintagurra	'Another small claypan, containing several springs similar to Boolcoorra, and situated about half a mile to the N.W., amongst the sandhills, is called Tintagurra…We passed Tintagurra Springs and another small spring at about one and a half miles; this last spring seems to be a favourite camping place for the natives; probably the water is slightly better than that in the other springs' (p.6)
Montherida	'At four and a quarter miles we passed Montherida Spring' (p.6)
Alnagatar	'I now turned south, and at three quarters of a mile pulled up at a small spring which the natives call Alnagatar. We filled our kegs here in case this should be our last water' (p.6)
Cunja	'On ascending a high sandridge, to the east of Alnagatar Spring, I saw another small spring which the natives call Cunja. All these springs are similar, and are situated in small claypans amongst high red sandhills; they could be made to water a large number of stock if properly developed' (p.6).
'Etabucka'	'...a small spring of very pure water, amongst a clump of timber situated between two high sandridges. The blackboy declared this spring to have no bottom; the surface water is about ten feet long, six feet wide, and one foot deep…I found four axes and a tomahawk buried at this spring' (p.12).

Although not as numerous or widespread as waterholes, where springs do occur they were considered a vital pastoral resource, especially during drought. One correspondent described a 'fine spring' in the vicinity of the Hamilton River: 'one of many on the run that would ensure that in a drought stock would be watered' (Nolan 2003, p.45). Patsy Durack and John Costello were able to penetrate into western Queensland during the drought year of 1863 by establishing a depot at springs in north-western NSW. Later, when taking stock from the Channel Country to the Gulf, droving parties used 'Parker springs' as a vital stopover between the Diamantina and Georgina Rivers (Nolan 2003).

7.1.4 Current status

The impact of stock upon springs was evident from the first herds to set foot on springs in the LEB. Governor MacDonell followed in the footsteps of Stuart, and was looking forward to a bath and a scientific examination of the springs. However, cattle being herded across the plains had rushed at the springs, and had instantly trampled down the vents and churned them into a peaty quagmire. MacDonell was dismayed as he looked at this ruination – the clear pools Stuart had described were now a 'morass of mud' (Bailey 2007, p.107). Bailey writes poignantly of this destruction: *'So it was that unique plants, invertebrates and fish which had adapted to the mineralised waters of Hergott Springs over thousands of years were annihilated in one afternoon in a cattle stampede. The Kuyani and Thirrari peoples, who regarded the springs as an unending source of drinking water and sacred to their beliefs, saw their most valuable possession destroyed.'*

Since this first ominous encounter, springs of the GAB have attained the dubious distinction of being the most damaged and modified of all waterbody types in the LEB. Fairfax & Fensham (2002) provide an overview of this 'cataclysmic history', while Fensham & Fairfax (2003) summarise the major threats facing GAB springs and their dependent species in Queensland today. Many have ceased flowing due to loss of pressure in the GAB, resulting in loss of unique biotic assemblages. In addition, numerous springs have been excavated in an attempt to make their water supply larger and more accessible to stock, irrevocably damaging their habitat and biodiversity values.

Over the past two decades, however, the ecological and heritage values of springs have become increasingly recognised. Three spring complexes are now protected under various programs: Elizabeth Springs Conservation Park, the Mulligan River Nature Refuge on NAPCO properties Glenormiston and Marion Downs, and the recent purchase of Edgbaston by Bush Heritage Trust. The Great Artesian Basin Sustainability Initiative (GABSI) has achieved a return of water pressure through bore capping, and anticipated recovery of springs will be monitored over the coming years. The unique flora and fauna of the springs has been the subject of numerous studies over the past decade, which continue to inform management decisions.

7.2 Non-GAB springs

7.2.1 Geology, distribution and permanence

While the GAB underlies much of the Lake Eyre Basin, shallower local aquifers may have flow paths restricted to a few hundred metres, but can provide highly significant sources of semi-permanent and permanent water. Most non-GAB springs in western Queensland form via discharge from fractured rock aquifers, and commonly occur in rocky ranges. Such aquifers are recharged after rain events by a combination of creek flow and direct infiltration into the ground (Box *et al.* 2008). They often occur at the base of cliffs or escarpments in sandstone country, where they are fed by water tables from higher terrain within the ranges under gravitational pressure.

Groundwater residence times vary considerably across the LEB, and some of these springs can dwindle to seepages or disappear completely in dry times. After a succession of wet summers, water will seep out pores in sandstone ranges for some months, but then the same areas may be dry for years (Peter Magoffin, pers.comm., February 2009). The focus of this section is those areas where water is present for more than 70% of the time. Some non-GAB springs feed sizeable waterholes, while others form small, shallow pools. The springs feeding large waterholes of the Georgina are not considered here, as they are discussed in detail in Section 4.

Non-GAB springs have not received the same level of study as GAB springs. Fensham *et al.* (2004) considered the floristics, classification and conservation values of numerous non-GAB springs in the Lake Eyre Basin as part of their wider study on spring wetlands across inland Queensland. They found that non-GAB springs were, in general, not floristically distinct from GAB recharge springs. In contrast to GAB discharge springs, both types are fed by water with relatively short residence times. Some non-GAB spring wetlands have high conservation values comparable to GAB wetlands (Fensham *et al.* 2004). No springs visited during this project contained any endemic flora species. Their ecological significance lies primarily in providing small sources of water in areas that otherwise have little permanent water.

35 non-GAB springs were documented across the study area (Table 24). The majority of these (64%) were permanent, while the almost-permanent Durack Spring on Galway Downs spring had gone dry for the first time since white settlement in the 2004 drought. Four springs of unknown permanence are known to exist from interviews with long-term land managers or are marked on topographic maps. However, there is not enough information available to provide an assessment of their permanence. Some springs which apparently used to be permanent or semi-permanent now no longer flow are classified as ‘ex-permanent’ or ‘ex-semi-permanent’, as discussed below.

Table 24: Non-GAB springs by catchment

Catchment	Permanent	Almost Permanent	Semi-Permanent	Unknown	Ex-Permanent	Ex-Semi-Permanent	TOTAL
Cooper	20	2	1	3	1	1	**29**
Diamantina	1	1	1	1	1	2	**7**
Georgina	1	0	0	0	0	0	**1**
TOTAL	**23**	**3**	**2**	**4**	**2**	**3**	**35**

The majority of springs occur in the Cooper catchment, and are clustered in the northern Grey Range and Gowan Range, on the watershed separating the Bulloo-Barcoo catchment (Figure 43). These springs are mostly permanent, and many occur on Idalia National Park and surrounding properties – an area that also harbours many semi-permanent rockholes (Section 6). Three permanent springs occur in the vicinity of Vergemont Creek, including the Noonbah Spring (Figure 44). These springs also occur in sandstone ranges, albeit in areas with less topographic relief than the Idalia district springs. The Noonbah Spring lies along a sandy creekline on a small plain between low stony hills, while the Spring Plains ‘ex-spring’ sits in a drainage line near the base of an escarpment. The Diamantina catchment springs also tend to occur in creeklines in range country, often in incised gullies. A full inventory of non-GAB springs in the study area is provided in Appendix 8. More detailed information on human significance and condition of these springs is contained in the Spatial Data CD that accompanies this report.

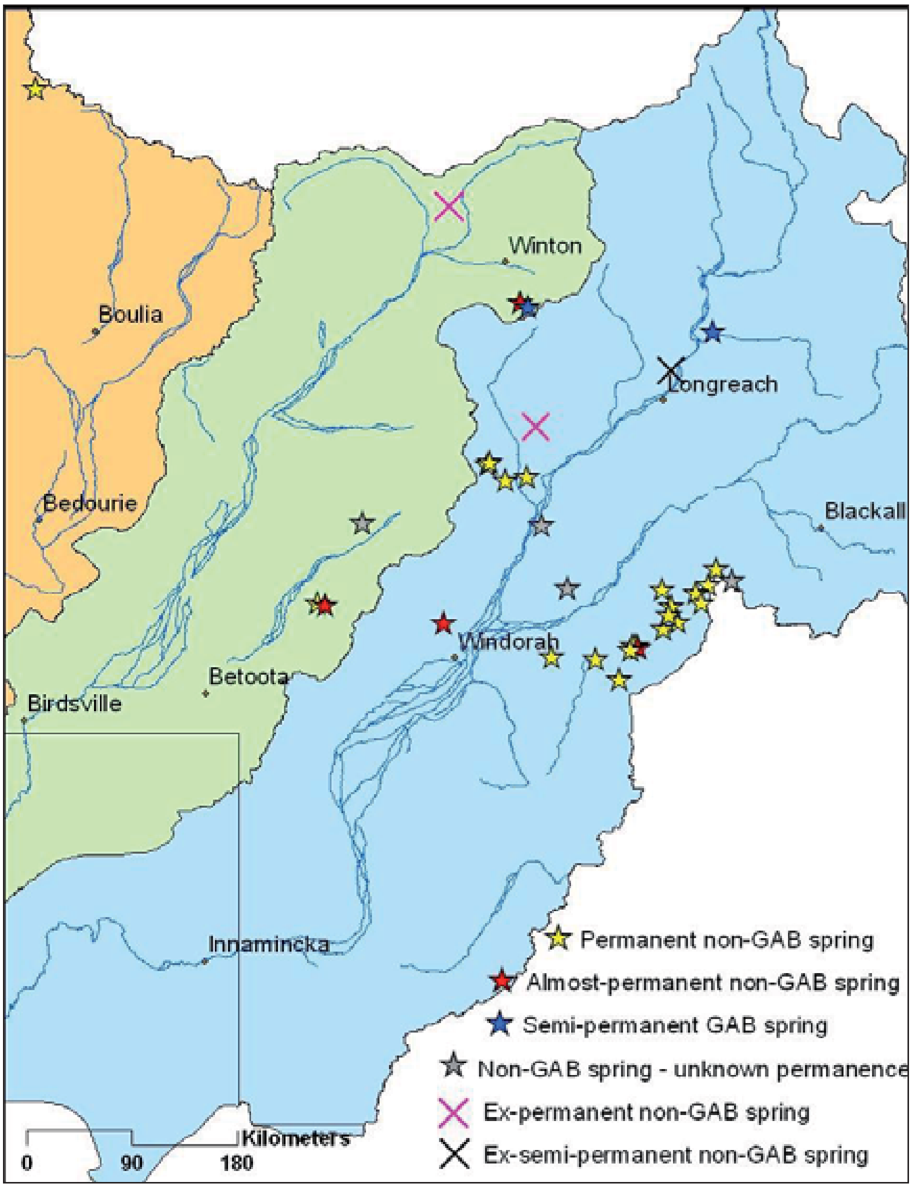

Figure 43: Non-GAB Springs in the Cooper, Diamantina and Georgina Catchments

Figure 44: Noonbah Spring, south-west of Longreach

7.2.2 Cultural significance

The concentration of artefacts in the vicinity of many springs, combined with their typically large distance from other reliable sources of water, hints at the significance of these isolated waters. At least one spring in the LEB has a substantial stone arrangement within 400m of it, which appears to be arrows pointing towards the spring (pers.obs.). Along the Thomson River, there is a rock painting site north-east of Longreach (Moffat 1987), in the low rocky hills that rise from the floodplain. Springs in this area used to be more permanent than they are today (Paul Smith, pers.comm., October 2008), and it seems likely that, in conjunction with the permanent and semi-permanent waterholes of the Thomson River, they formed an important site in the cultural landscape.

The presence of springs is often revealed by property names, for example Springvale, Spring Plains, Spring Hill. There are also numerous Spring Creeks scattered across the study area – however it seems that most of these were 'discovered' and erroneously named in good seasons when the quantity and quality of water present suggested a spring-fed origin (Bob McDonald, pers.comm., June 2009). The fact that properties were named after these features suggests their value and interest to early settlers. On properties without river frontage, such as Noonbah, the original homesite was established next to such springs as a source of reliable water (Angus Emmott, pers.comm., November 2008). Springs were also used as sites to muster stock during the dry season, as evidenced by the remnants of fencing around some springs and ex-springs.

7.2.3 Current status

Like GAB springs, these sandstone springs are less numerous and permanent than in the past, although for different reasons. A small number of springs have been excavated and even dynamited in an attempt to enhance the amount of available water. Sadly, this has usually achieved the opposite effect, and most springs that have been subject to this treatment no longer flow any water at all (Figure 45).

Figure 45: 'Ex-spring', Spring Plains, February 2009 (water present after recent rainfall)

The outlying spring towards the northern edge of the Diamantina catchment (Figure 42) is 'Fig Tree Hole'. It may be another example of the unwitting destruction of a non-GAB spring. Local sources suggest that this rockhole in the Ayrshire Hills used to be more permanent, and overflow almost to the road – a distance of over one kilometre down a small creekline. Due to its permanence in an otherwise waterless area, it was used as a stock camping and water reserve in the early days of pastoral settlement. Aboriginal engravings in the rock have been vandalised, however point to former ceremonial significance. It seems that its permanence was due to a spring at the base of the escarpment. Some locals believe that this spring was dynamited many years ago, while others suggest that gravel has fallen into it over the years, blocking off the spring. Regardless, it now only holds water for 1-3 months after rain, during which time it is an impressive oasis, with water dripping slowly into a clear blue pool from the cliffs above. For most of the year, however, it is a dry, sandy hole with only the fig trees (*Ficus cerasicarpa*) hinting at a past permanence (Figure 46). Although the history surrounding this rockhole is ambiguous, it has been included in this study as it would have been the only reliable water for a distance of 350km x 150km of Mitchell grass downs, stretching from Torrens Creek to the Georgina watershed, and north almost to Julia Creek.

Figure 46: Fig Tree Hole in Ayrshire Hills, north-west of Winton, May 2009

Some non-GAB springs, such as springs in the ranges along the Thomson River, have become less permanent under apparently ‘natural’ circumstances. These springs are recharged from rainfall, and seep out of the sandstone following rain. Such springs and soaks that used to be regarded as reliable sources of water now only last for a couple of months at best (Paul Smith, pers.comm., October 2008). It remains to be seen whether the return of good seasons and prolonged, drenching rainfall will restore these springs to something like their former permanency. Other springs have been excavated, piped or had wells sunk in them, meaning that they still flow but the former spring wetland has been destroyed or modified. As with rockholes, trampling and grazing by goats and domestic stock has impacted some springs.

The exact location of some springs is not known, even by long-term residents of an area. Some are known to exist through local knowledge passed down through the generations (e.g. Connemara Spring; Bruce Rayment, pers.comm., November 2008). The location of others is assumed due to the disappearance of stock for long periods of time, suggesting that they were using an alternative water source in the ranges (e.g. ‘Wagon Spring’, Idalia NP; Johnny Avery, pers.comm., February 2009). It is very difficult to locate such springs, due to the rugged and inaccessible country and often clandestine nature of the springs themselves. It is clear that much remains to be learnt and discovered about the hydrology, permanence and ecology of non-GAB springs in the Cooper and Diamantina catchments.

7.3 Soaks

Soakages or soaks are simply locations where the water table comes to the surface without the force associated with springs (Box *et al.* 2008). In a river bed, the water table may add to river flow and even when the channel is ostensibly dry, small soakage puddles may remain, often just below the surface. Mistake Creek soak on Bladensburg National Park has very little surface water for most of the time, but water can reliably be found by digging, except during extended droughts (Sue Cupitt, pers.comm., January 2009). Less commonly, soaks can also be found in sandhill country, where water collects in small subterranean basins below the sand. Soaks also occur on old alluvial plains, on the margins of salt lakes and claypans, and in limestone country. Limestone is soluble and groundwater etches out waterways and caverns (Bayly 1999).

Soak sites are usually not obvious. Unlike their showy cousins, they seldom reveal their presence in the form of large mounds or pools of water. However, landform and vegetation can provide clues to soak sites to the shrewd observer. Tea-trees (*Melaleuca* species) are often an indicator of groundwater burbling close to the surface, particularly in limestone environments. Soaks have received comparatively little attention as sources of permanent water in the arid zone, probably because they don't tend to support the rich endemnicity of springs. However, they were of utmost importance to Aboriginal people in arid areas, as indicated by the tracks radiating out from major soaks such as Ooldea Soak in South Australia (Bayly 1999). They are not considered in detail here, as they generally do not provide a substantial amount of free surface water without digging.

8 A BASIN TRANSFORMED: CHANGES TO DISTRIBUTION OF WATER SINCE 1870

The preceding sections have explored the distribution of natural permanent and semi-permanent waters in the Cooper, Diamantina and Georgina catchments. Since European settlement, the distribution and permanence of water has changed dramatically. Some water sources have declined in abundance and/or permanence through a variety of mechanisms. However, far surpassing this has been a massive increase in the distribution and abundance of permanent water. In just 150 years, the arrival of pastoralism in western Queensland has transformed the landscape from one of generally occasional water (in most areas) to a situation where permanent water is ubiquitous across much of the landscape.

The current situation with regard to water in the arid zone forms the basis of the final section of this report. Numerous recent studies have suggested that the rapid proliferation of 'artificial waters' may have profound implications for the ecology of the inland, including changes in species abundance and decline of vulnerable 'decreaser species' (Landsberg *et al.* 1997; Noble *et al.* 1998; James *et al.* 1999; Fensham & Fairfax 2008). It seems that we have acquired the knowledge necessary to manage point impacts *on* individual waterbodies and riparian environments (although such guidelines are not always practiced; see Section 5.7). However, we are still grappling with how to understand and manage the far-reaching effects *of* permanent water across the vast expanses of the inland. Water, long the panacea of desert animals, residents and travellers, has paradoxically become perhaps the major conservation challenge for arid Australia.

8.1 Summary of natural permanent waters pre-1880

Sources of natural water in the Lake Eyre Basin are widely spaced and unreliable. This is underscored by the fact that there are only about 500 sources of truly permanent water spread over the 661 000km^2 of the Cooper, Diamantina and Georgina catchments of Queensland and South Australia. This translates to one permanent water source for every 1300km^2. However, apart from underscoring the general paucity of permanent water, such broad analyses are meaningless. In some areas, considerable amounts of water would always have been available along the major rivers even in dry times, including Vergemont Creek, the Cooper below Windorah and limited sections of the Diamantina and Georgina Rivers. At the opposite extreme, vast areas, particularly in the Georgina and Diamantina catchment, would have been essentially waterless for three to four months (or more) of each year.

In general, areas away from major rivers and the more precipitous ranges, with the exception of discrete and comparatively small clusters of GAB springs, would have been completely devoid of water during dry periods. In prolonged dry times, even the major watercourses would have been mostly reduced to widely-spaced, dwindling waterholes. Table 25 provides a summary of the major naturally 'water remote' areas of the Cooper, Diamantina and Georgina catchments (Figure 47).

Table 25: Major 'water remote' areas in study area

Name	Approx. area (km^2)	Perm. & SP waters *	Broad landscape and vegetation description
Strzelecki dunefields	100 000	0 (0)	Dunefields and stony desert; extends from Grey Range west of Bulloo Downs in east to Lake Eyre, south of Cooper Creek
Northern Mitchell Grass Downs	70 000	0 (10)	Extensive open downs dominated by *Astrebla* species; drained by Rupert, Alick and Eastern Creeks (Flinders River catchment) and Wockingham Creek/Diamantina River
North-west LEB**	65 000	0 (15)	Open downs of Barkly Tableland in west and rocky range systems of Mt Isa Inlier in east
Mulligan/Eyre Creek system, far western Qld/ northern SA†	40 000	0 (6)	Extensive dunefields of Simpson Desert; smaller areas of flood-outs and shallow lakes; all waterholes are broad holes that can be dry for years at a time (Figure 48d)
Clifton Hills to Kalamurina	40 000	0 (11)	Dunefields and dry lakes, stony desert and low barren hills (Figure 48b-c)
Burke/Hamilton River catchments	40 000	5 (10)	Mix of land types associated with Burke and Hamilton Rivers, including alluvial plains and woodlands, sandplains and low range systems
Farrars Catchment (upper and mid)	25 000	1 (17)	System of low ranges intersected by Farrars Creek and associated tributaries; some alluvial plains and sandplains
Cordillo area, north-east SA	20 000	0 (2)	Sand dunes and dry lakes (northern Coongie system) and stony desert
Coorabulka plains	18 000	1†† (14)	Mostly vast, open stony and ashy plains;flood-outs associated with Georgina River/King & Eyre Creeks
Range country east of Cooper Creek	13 000	1 (3)	Low, rocky ranges (Coleman, Macgregor & Grey Ranges) interspersed with some open downs
Central Mitchell Grass Downs	10 000	0 (0)	Open and wooded downs with coolibah-lined channels and patches of gidgee woodland; south of Aramac Creek to Barcoo River

* Permanent waters shown first, total permanent + semi-permanent in brackets; springs are counted as clusters (if separated by <1km) rather than individual waters

** Only includes Queensland section; area devoid of permanent water extends into NT for considerable distance across Barkly Tableland (Duguid *et al.* 2002)

†Waterless dunefields extend to west into NT and SA; only area inside Qld/SA study area included

†† Small, inactive spring on Coorabulka; most waterholes in area are 70% along King Creek, and go dry annually

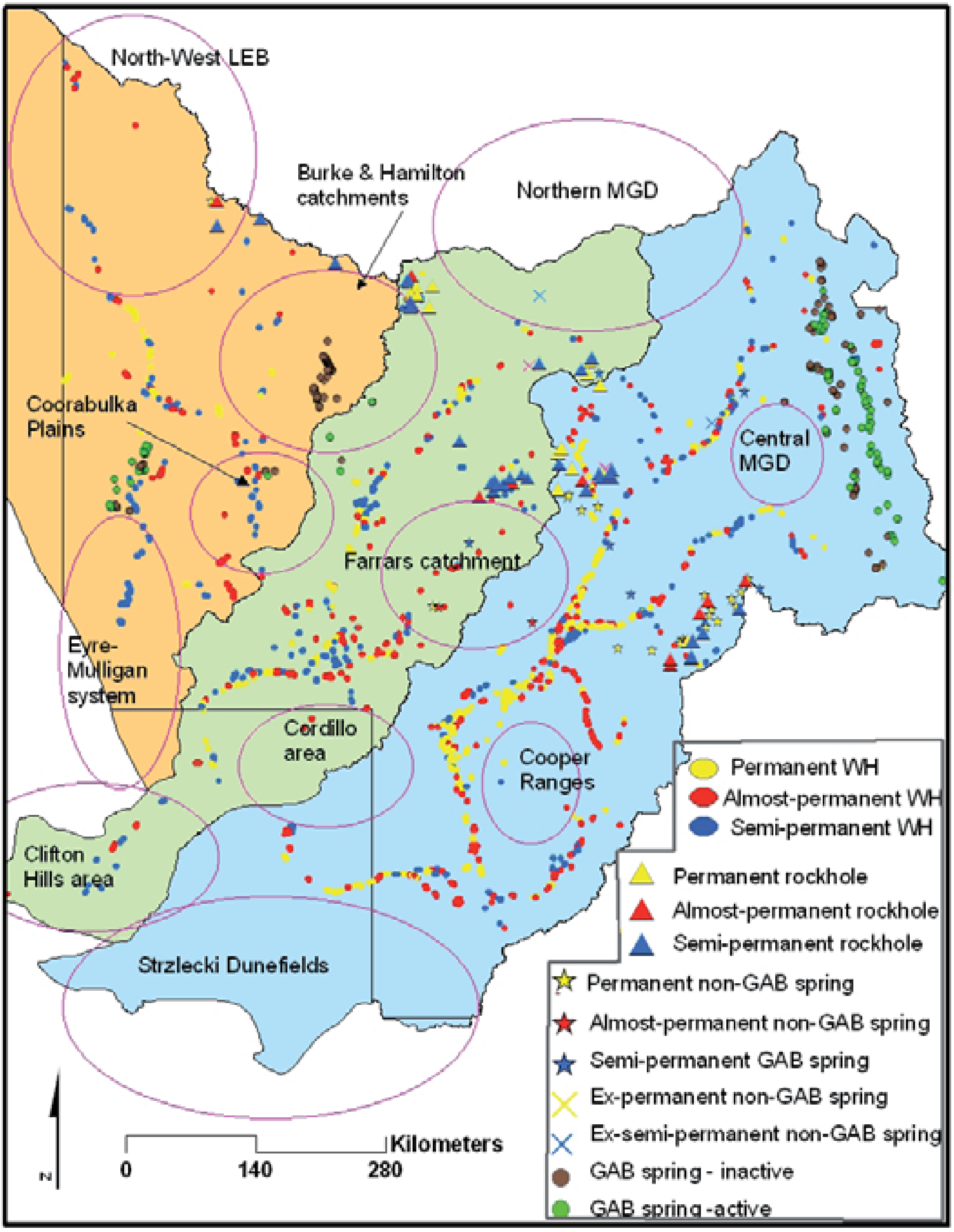

Figure 47: Major water remote areas in study area

The true aridity of these areas, particularly the larger ones such as the Northern Mitchell Grass Downs, Coorabulka plains, Mulligan-Eyre system and most of north-eastern South Australia, is highlighted by the observations of early explorers and travellers in these areas. Protector of Western Queensland Aborigines Harold Meston reported 'absolute desolation' at the end of 1901 when he returned from a trip to Innamincka and the Cooper. Not only had 70-90% of cattle and 50% of sheep died, but so had the wildlife: in about 1600 kilometres of travelling, he saw only one emu, five kangaroos and seven bustards (Tolcher 1986, p.211). In a similar vein, a shearing contractor travelling between Murnpeowie and Cordillo in the late 1920s drought commented: *'I travelled 200 miles and never saw anything alive, not even a bird, until I got to the Cooper'* (Tolcher 1986, p.93). Francis Ratcliffe described inland South Australia as a 'waterless land', writing that *'I spent month after month travelling through this region, and never once did I see permanent natural water'* (1938, pp. 205-206). Prior to artificial waters, the entire north-eastern portion of South Australia contained just 12 sources of truly permanent natural water, all clustered along Cooper Creek in the far east of the region (n=8) and the Diamantina in the far north (n=4). Only a further 20 semi-permanent waters were mapped across the entire area, and all bar seven of these either go dry or salty by the end of each year.

The situation is similar throughout much of Queensland's channel country. By the end of most years, the vast open plains centred on Coorabulka would have been devoid of water (Figure 48a). After a run of dry seasons, all water west of the Diamantina River would have dried up, except for Tomydonka Waterhole on Eyre Creek and the Mulligan River springs. When moving cattle into the Channel Country during a very dry time in 1876, stages of 500-600 miles between watering places were reported (Nolan 2003). This country was described by an early correspondent as 'splendidly grassed high downs, but with little water' (Nolan 2003, p.44). The aridity was gruesomely highlighted by the deaths of three experienced bushmen travelling west from Davenport Downs in the late 1870s. They died of thirst just 12 miles from the Georgina River, after going 12-14 days without water (Nolan 2003). Mt Prout stands in the midst of this arid land on Breadalbane, testimony to one of the men and their horrendous struggle across a waterless land.

Figure 48: Waterless terrain (clockwise from top left): (a) Channel Country plains, Astrebla Downs; (b) north-eastern SA dunefields, Cowarie; (c) Stony Desert, Clifton Hills and (d) Simpson dunefields, Carlo

The country west from Towerhill Creek to the upper Diamantina and north to the Flinders River also forms a great 'waterless triangle'. This area straddles the watershed divide between the Gulf and LEB, with the northern area drained by Rupert, Alick and Eastern Creeks, which flow into the Flinders River, and the southern half drained by Wockingham Creek and the upper Diamantina River. There are no permanent waterholes on any of these tributaries, although Minamere (Rupert Creek) and 30 Mile Hut (Eastern Creek) Waterholes south of Julia Creek are close to permanent (Duncan Fysh & Shirley Eckford, pers.comm., May 2009). Heading north from the last permanent water west of Winton, Conn Hole on Wockingham Creek, the first truly permanent waterhole is more than 260km distant, on the Flinders River on Millungera (Evan Acton, pers.comm., April 2009). Pioneer Robert Christison, spurred on by exploration fervour in the 1860s, travelled west from Towerhill Creek to the Diamantina, across these 'shadeless, waterless, limitless' downs (Bennett 1927, p.51; Figure 49). He was grateful to stumble upon a muddy, dwindling waterhole on the upper Diamantina, and even more relieved to return to the well-watered Torrens Creek.

Figure 49: 'Shadeless, waterless, limitless…': open downs country between Richmond and Winton

Today, these downs remain impressive in scale, are more shaded in places by virtue of the invasive prickly acacia (*Acacia nilotica*), and are extremely well watered, enabling utilisation of the rich Mitchell grass pastures. Permanent water also exists throughout most other areas identified as naturally water remote, to varying degrees. These changes and potential implications are explored in Section 8.3.

8.2 'Lost waters': loss and decreased permanence of some sources of water

Since white settlement, some sources of previously permanent water have either become less permanent or dried up completely via a number of mechanisms. These are explored in the preceding sections, so only a brief summary is provided here. Figure x shows the main concentrations of such 'lost waters' in the study area.

8.2.1 Silting of waterholes

Silting of waterholes is discussed in Section 4.6.1. It is concluded that some reaches, particularly the upper Thomson and its tributaries, upper Georgina and some reaches of the Diamantina (Figure 50) have experienced substantial silting over the past 140 years. While there is some contention about the underlying causes, it is generally accepted that silting has resulted in decreased depth, and therefore permanence, of waterholes (except where they have been 'de-silted'). In some areas, there are now fewer semi-permanent waterholes, as affected holes now only last for less than six months. Figure 50 shows the areas where silting is apparently occurring, based on anecdotal evidence. Only those reaches where there was a general consensus that silting has or is occurring are shown.

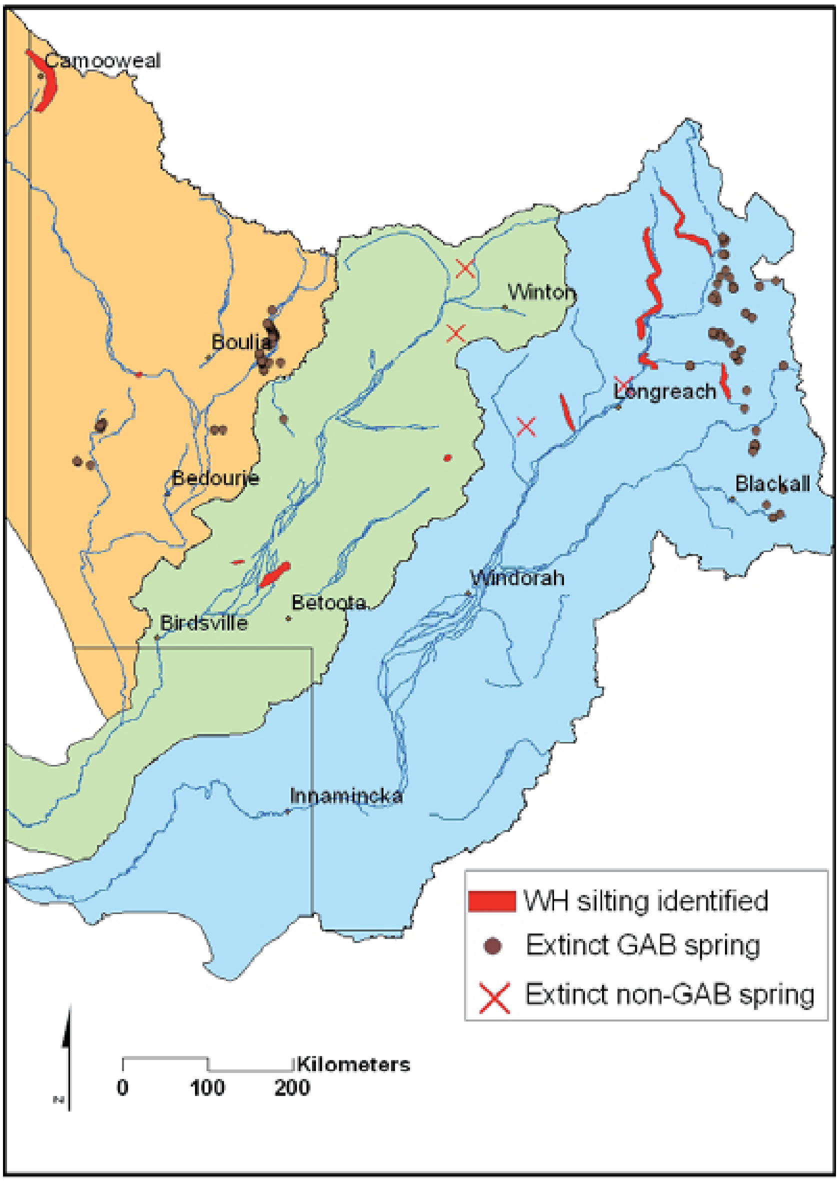

Figure 50: Waterbodies that have decreased in permanence since 1870

8.2.2 Loss of springs

The discharge of artesian water from uncontrolled bores into open drains has lowered water pressure in the Great Artesian Basin. As a result, many GAB springs have ceased flowing (Noble *et al.* 1998; Fairfax & Fensham 2002). Springs are dynamic entities on century timescales, and individual springs have been forming and going extinct since well before European settlement (Fensham & Fairfax 2003). However, the drawdown of the GAB has greatly accelerated the loss of springs.

In the LEB, this has been most pronounced in the Springvale supergroup, while numerous Mulligan River and Barcaldine Springs have also ceased running (Figure 50; see Section 7.1.4). Although individual springs in both the Mulligan River and Barcaldine Supergoups have become extinct, at least some springs in most clusters have remained active, resulting in little overall effect on the distribution of permanent water. A cluster of springs on Aberfoyle, representing the most northerly springs along the eastern margin of the LEB, have become inactive. A distance of 30km now separates the closest active spring from the inactive Aberfoyle springs, while they are less than 20km from two permanent waterholes on Torrens Creek.

In contrast, the loss of the majority of springs in the Springvale supergroup has had a major effect on the distribution of natural permanent water in that area. Prior to drawdown of the GAB, a line of springs spanned about 70km along the Hamilton River east of Boulia, extending from Pathungra to Warra and comprising 51 individual springs. There was little other permanent water in this area, with the exception of Bulla Bulla Waterhole. Two permanent waterholes on the Burke River near Boulia are some 50km distant, while Paravituri on the Georgina and Warracoota Waterhole on Spring Creek (Diamantina catchment) are both more than 100km away. Today, all springs except two, both on Warra at the southern end of the Supergroup, are inactive. As a result, this area now forms part of a large naturally water remote triangle extending east to the Diamantina River and north and west to the LEB watershed, encompassing most of the Burke and Hamilton catchments (Figure 50).

A small number of non-GAB springs have also become extinct or much-decreased in permanence (Section 7.2). The loss of such a small number of tiny water sources does not have an appreciable impact on the distribution of water in the LEB. Nevertheless, one ‘ex-spring’ (Fig Tree Hole) lies within the vast ‘water remote’ triangle of the Northern Mitchell Grass Downs, so would have been extremely locally significant (see Section 7.2.3).

8.2.3 Possible decline in permanence of rockholes

Silting of rockholes was widely reported across the study area. In some more accessible areas of inland range country, silting may have increased since European settlement due to elevated grazing pressure. In particular, goats occur in moderate to high densities in some areas, particularly the southern Grey Range and Ayrshire Hills (Pople *et al.* 1998; pers.obs.). However, this does not account for the silting reported in extremely inaccessible areas such as the Goneaway Tablelands, where total grazing pressure has always been low. Moreover, soil run-off into rocky gullies and rockholes would have been happening ‘naturally’, as inland range country is characterised by much bare ground regardless of grazing pressure. There is a possibility that Aboriginal people may have ‘husbanded’ some rockholes, primarily by cleaning them out, as documented in the Northern Territory (Wilson *et al.* 2004). This would have meant that they were deeper and more permanent prior to 1900. However, knowledge of these features in western Queensland is so limited to render any such hypotheses purely speculative.

8.3 Proliferation of artificial sources of water

This loss of water from relatively localised areas and environments (i.e. springs, certain reaches of rivers/creeks and possibly ranges) has been far surpassed by the proliferation of artificial sources of water. These sources of water not only far outweigh the number of ‘lost waters’, they also affect a much greater total area and type of environments.

8.3.1 Augmentation of existing sources of water

Numerous existing waterholes have been ‘de-silted’ or excavated to increase their permanence, particularly smaller waterholes in the upper catchments. This has increased some previously ephemeral waterholes to semi-permanent or permanent, and enhanced the reliability of naturally semi-permanent waterholes. Such excavations have been occurring since European settlement. In recent years, improved technologies have allowed de-silting to occur more regularly, and greater amounts of soil to be removed.

Weirs have been constructed at the end of some waterholes, usually to guarantee reliable water for townships and households. In some cases, this has had little or no effect on permanence of waterholes: holes such as the Longreach Waterhole, Goodberry Broadwater and Oma Waterhole would have been naturally permanent prior to weir construction. However damming has increased the permanence of some naturally semi-permanent or ephemeral waterholes. Waterholes of the upper Diamantina, with Chinese overshot wells, provide a good example: these would not have lasted more than 6 months without these overshots, but now some such as Combo Waterhole are certainly semi-permanent.

Only modified waterholes that would have been semi-permanent (i.e. 70%) prior to excavation or impoundment were mapped for this project. Augmentation of existing sources of water has not had a pronounced effect on distribution of water across the study area, mainly because these works have been carried out on major drainage lines in close proximity to other natural sources of water.

8.3.2 Dams and earth tanks

Dams and earth tanks have been placed both on and off drainage lines, typically in areas that would naturally collect water but would not hold it for any length of time. This includes small drainage lines and low-lying points in the landscape. Dams were popular early in pastoral history as they became increasingly easy to dig as technology improved, while bore-drilling technology remained expensive. In the late 1870s, Christison excavated a major reservoir on the shallow Landsborough Creek, forming Lake Cameron, a 33 yard x 1.5 miles x 24 feet deep reservoir, deemed 'the finest artificial water in the west' (Bennett 1927, p.188). Today, dams are common across the landscape but nearly all will go dry at some time, meaning that they are best regarded as semi-permanent features. Geoscience Australia mapping reveals that tanks and dams are ubiquitous across the LEB, with over 8000 mapped in the study area (Table 26; Figure 51).

8.3.3 Groundwater exploitation

By far the biggest change in the distribution of permanent water across the inland is attributable to groundwater exploitation. Very early in settlement, it was obvious that water was the major limiting factor for grazing across much of the LEB. Duncan-Kemp wrote that 'water in these regions is often more important than grass. Many runs have abundance of dry feed but no water…' (1934, p.53). Early settlers and travellers lamented the large expanses of 'splendid country' left unoccupied and ungrazed due to the paucity of reliable surface water (Sutherland 1913; Bennett 1927). Robert Christison dreamed of the day when 'water would sprout up and make the richly grassed waste available to great numbers of stock' (Bennett 1927, p.180).

Providentially, or so it must have seemed, the existence of water underneath much of the arid interior, meant that the country would not be destined to remain a 'wasteland', unsuitable for grazing (Sutherland 1913). Sinking of bores and wells was vital to the success of pastoralism in areas with very little permanent surface water. 'Wells' are traditionally dug by had to a relatively shallow aquifer, while 'bores' are drilled mechanically, usually to a great depth. Artesian bores are very deep, and produce hot water flowing under its own pressure, while sub-artesian bores are relatively shallow and the cold water has to be pumped to the surface.

The first recorded sinking of wells in the South Australian section of the LEB occurred in 1860 (Bell & Iwanicki 2002). Sinking wells does not necessarily guarantee a reliable supply of water – water may be too deep to reach, resulting in a 'dry well', or it may turn saline and be undrinkable to stock. Moreover, raising water from such wells can be labour-intensive, and in some cases required a full-time 'well lifter', who would use animals to operate a water whip to transport water from underground to a stock trough (Bell & Iwanicki 2002). By the 1920s, reliable steep windmills were becoming the most common means of raising water to tanks and troughs. There are numerous wells in areas with shallow aquifers across the Basin, including the Cordillo Downs and Tonkoro districts.

However, it has been bores that have transformed the pastoral industry and ecology of the inland. Groundwater in the Great Artesian Basin was first discovered in 1878 near Bourke, and subsequent tapping occurred rapidly throughout the Basin. Successful boring for sub-artesian water began in Queensland in 1882 near Cunnamulla, while a test bore at Tarkaninna north-east of Maree struck South Australia's first artesian water in 1883. Drilling for artesian water commenced at Blackall in 1886, and within a few years, pastoralists had proven that supplies were available at various depths over all of western Queensland. The first attempt at bore drilling in the Longreach area on Westlands was unsuccessful in 1885-6, and it wasn't until 1889 that the first successfully completed bores in the central-west were sunk on Darr River Downs (Moffat 1987). The number of bores across the district increased substantially following severe stock losses in the 1902 drought.

The discovery of artesian water meant that the biggest obstacle to squatting had been overcome, and paved the way for the spread of pastoralism throughout the rangelands. Properties such as Coorabulka, with no natural permanent surface water, took up this new technology with fervour: by 1913, there were already ten flowing bores spread across the property (Nolan 2003). The 1890s saw many wells and dams established on the virtually waterless Cordillo Downs. It was a condition of leases that by 1918 artesian bores must have been sunk. However, bore drilling remained an expensive and imprecise operation, and it was not until the 1950s that a large number of bores were established. During this decade, the combination of favourable seasons, high wool prices, improved technology and government subsidies gave pastoralists the opportunity to invest in capital improvements such as bores (Noble & Tongway 1983).

Much water-spreading has occurred in comparatively recent times. John te Kloot's reminiscences in Moffat (1987, p.312) demonstrate the centrality of water, and the changes in distribution over half a century: *'I drew Marmboo in a ballot on September 10 1946…For the first 35 years the limiting factor…had been water and the cost of water, but with the arrival of rural power five years ago and the advent of poly pipe, it is now economical to pump water for the bores for long distances and in any direction.'* Bores and troughs allowed grazing to be moved onto the most valuable grazing lands, previously rendered unusable due to a complete lack of surface water. Today, there are over 11 000 sources of artificial water mapped by Geoscience Australia, distributed in varying densities across the entire study area (Table 26; Figure 51).

Table 26: Artificial waterbodies by catchment

Catchment	Artificial Permanent (Bores)	Artificial Semi-Permanent (Tanks/dams)	Total Artificial Waterbodies
Cooper	2022	5895	7917
Diamantina	541	1598	2139
Georgina	747	540	1287
TOTAL	*3310*	*8033*	*11343*

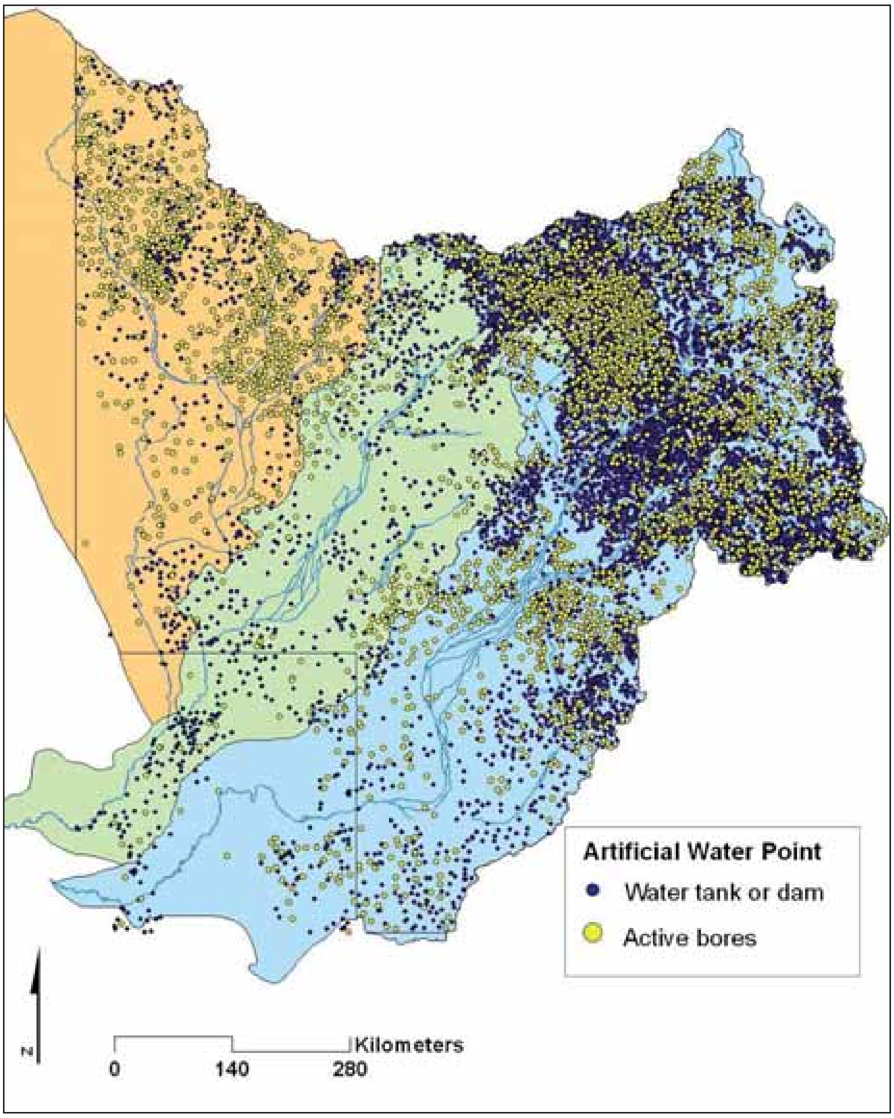

Figure 51: Artificial waters in Cooper, Diamantina and Georgina catchments, Queensland and SA, 2009

8.3.4 Distribution of natural versus artificial watering points

Today, few areas of potentially productive rangeland are greater than 10 kilometres from an artificial source of water, and most are much closer (Landsberg & Gillieson 1996). Table 27 shows the number of artificial and natural water sources in the study area by catchment.

Table 27: Natural and artificial waters by catchment*

Catchment	Natural Water	Artificial Water †	Total Waters	% Waters Artificial
Cooper	377 (833)	2022 (7917)	2399 (8750)	84% (90%)
Diamantina	99 (307)	541 (2139)	640 (2446)	85% (87%)
Georgina	56 (227)	747 (1287)	803 (1514)	93% (85%)
TOTAL	**532 (1367)**	**3310 (11343)**	**3782 (12710)**	**88% (89%)**

* Permanent waters recorded first; all waters >70% in brackets

† Semi-permanent artificial waters counted as mapped dams and tanks

There were about 530 permanent water points prior to 1870, mostly restricted to major river systems, discrete clusters of springs on the margins of the LEB, and small, often inaccessible rockholes and springs in the ranges. Today, there are 3310 active bores across the three catchments. The highest densities of these new permanent waters is in areas that naturally had few or no permanent waters, such as the upper Georgina catchment and northern Mitchell Grass Downs (Figures 50 and 51). Figure 52 shows the permanent natural and artificial waters in the 2009 landscape, while Figure 53 compares the distribution of permanent and semi-permanent water pre-1870 and today.

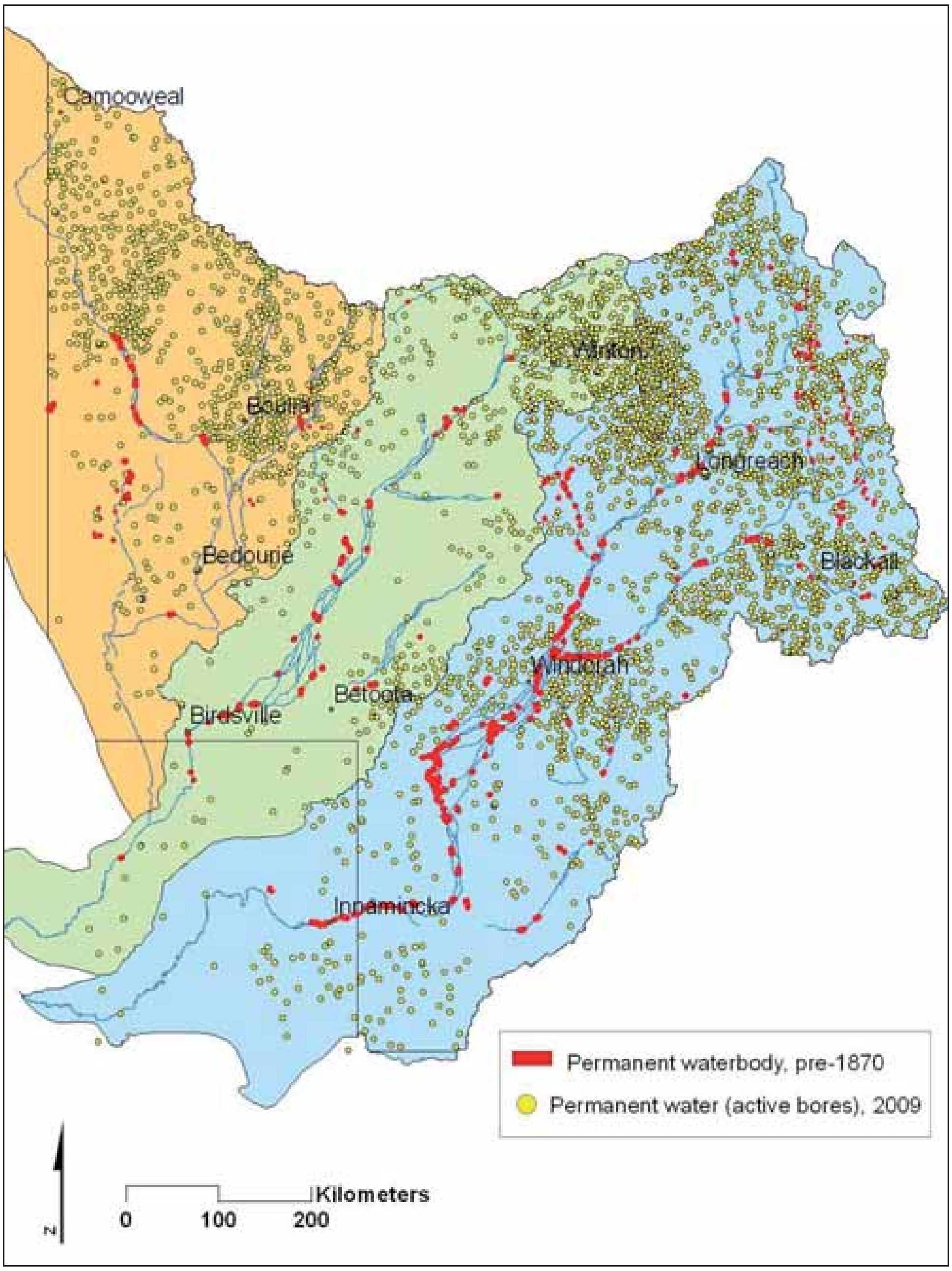

Figure 52: Permanent Water, pre-1870 vs 2009

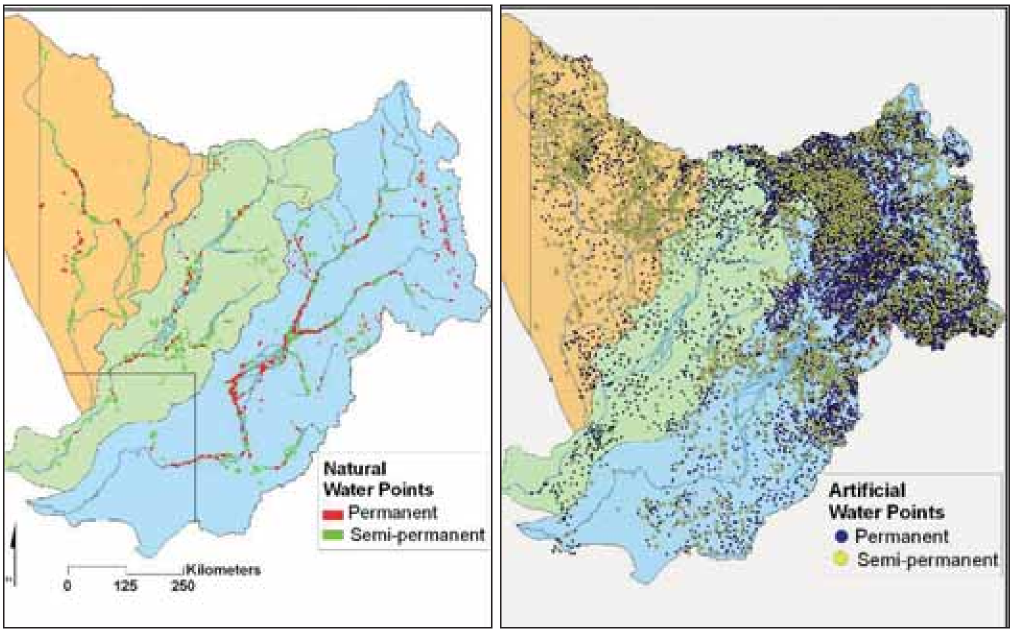

Figure 50 a-b: Natural vs artificial permanent and semi-permanent water

In areas with naturally high densities of reliable water, the proliferation of water sources has had little impact upon the distribution of water. The ecological effects of water spreading are likely to be most pronounced in the water remote areas identified in Section 8.1. The greatest proliferation of artificial waters has occurred on the productive clay-soil downs, encompassing the Northern and Central Mitchell Grass Downs, Upper Georgina and Burke & Hamilton regions (Table 28). These areas were completely devoid of natural permanent (and often semi-permanent) water.

Table 28: Naturally Water Remote Areas, 1870 and 2009

Name	Natural permenent & SP waters	Artificial permanent & SP waters	% Waters artificial	Max. distance to permanent water, 1870 & (2009)
Strzelecki dunefields^	0 (0)	58 (203)	100% (100%)	250km (60km)
Northern Mitchell Grass Downs^	0 (0)	380 (1340)	100% (100%)	140km (15km)
North-west LEB**	0 (15)	260 (445)	100% (97%)	180km (25km)
Mulligan/lower Eyre Creek system †^	0 (6)	19 (66)	100% (91%)	150km (70km)
Clifton Hills to Kalamurina^	0 (11)	10 (75)	100% (87%)	280km (130km)
Burke/Hamilton River catchments	5 (10)	316 (504)	98% (98%)	75km (20km)
Farrars Catchment (upper and mid)	1 (17)	65 (255)	98% (94%)	120km (40km)
Cordillo Downs area	0 (2)	15 (55)	100% (96%)	110km (45km)
Coorabulka plains	1†† (14)	36 (72)	97% (84%)	80km (25km)
Range country east of Cooper Creek	1 (3)	22 (109)	96% (97%)	60km (25km)
Central Mitchell Grass Downs	0 (0)	103 (551)	100% (100%)	60km (12km)

^ Only includes LEB section

8.4 Effects of increased permanent water

Artificial water is now so common and reliable in inland Australia that the term 'drought' has taken on a functionally different meaning from pre-European times (James *et al* 1995). The pastoralists and governments who lauded this 'inexhaustible supply' could scarcely have imagined the transformative effects of artesian water on the ecology of inland Australia. The effects of artificial watering points on biodiversity have been reviewed by various authors in recent years (Landsberg *et al.* 1997; Fensham & Fairfax 2008). A comprehensive review is not attempted here; rather, the following sections provide a brief overview of the literature with reference to the situation in the LEB.

8.4.1 Increasers and decreasers

Some species have benefited from artificial waters, including water-dependent birds and macropods, and are now more numerous and widespread than in pre-pastoral times (James *et al.* 1999). Bore drains and dams have also created artificial wetlands, which provide habitat for numerous native species, including the fascinating population of yellow chats in the heart of the Channel Country. This 'increaser' response was recognised as early as the 1930s, with Francis Ratcliffe observing that *'The coming of white man was… a great boon to the wild creatures, for in providing water for his stock, he unintentionally benefited the kangaroos and emus, the parrots and cockatoos, and all the other creatures which before his coming had only been able to make these regions a temporary home, but were now able to live there permanently'* (1938, p.206). In particular, the relationship between provision of watering points and increased macropod abundance in Australia's rangelands has been well documented (Department of Lands 1993; Johnston *et al* 1986; Newsome 1994).

Conversely, the widespread provision of artificial water has unintentionally disadvantaged a suite of vulnerable native species. Landsberg *et al.* (2003) found that there are substantially more species favoured by water-remoteness than disadvanted by it. Such 'decreaser' trends are alarming because, although the proportions of decreaser and increaser species are roughly comparable, the proportion of rangeland areas providing suitable habitat for them is not (Landsberg *et al* 1997). Therefore, it is decreaser species that today hold the chief implications for conservation of biodiversity in Australia's rangelands.

8.4.2 Waterless refuges?

> *'…The length to which the processes of change will ultimately go is not to be measured by head of population per square mile, nor even by the numbers of stock which the country will carry, but rather by the presence or absence of sanctuaries where conditions are such that stock and all the disturbing factors of settlement cannot operate. One of the tragedies of this country is that it is almost destitute of such natural sanctuaries'* (Finlayson 1943, pp. 16-17).

Refuges have been integral to the evolution of Australia's arid zone fauna (White 1994). Professor Ralph Tate, while on the 1894 Horn Scientific Expedition with Baldwin Spencer, was the first to write about the concept of refugia in arid Australia, describing such areas as favourable habitats created by a combination of topography, water and nutrients (Gibson & Cole 1988). Today, a number of arid-zone refuges are recognised, including caves, wetlands, gorges and ranges (Morton *et al.* 1995). The commonly-held perception of refuges in Australia's rangelands is of moist pockets or 'oases' in a waterless terrain, where biota can survive the hard times and recolonise surrounding areas (Shephard 1994; White 1994). However, with the widespread and increasing provision of artificial watering points, areas far enough away from watering points to be sheltered from grazing pressure and other concomitant impacts are increasingly being recognised as 'grazing-relief refuges'.

Australia also has a relatively light evolutionary history of grazing by large herbivores, therefore many of its biota are poorly equipped to cope with the elevated and continuous grazing that now predominates over most of the rangelands (Landsberg *et al* 2003). For species unable to tolerate even moderate grazing pressure, areas far enough away from watering points to be unaffected by grazing represent important refuges. It has been found that changes to biodiversity can occur as far away as 15 kilometres from water, long after the obvious impacts of groundcover and soil degradation have ceased (Landsberg *et al* 1997). Fensham & Fairfax (2008) suggest that buffers of at least 7km around water points will be required to achieve even tiny grazing-relief benefits.

The notion that water-remote areas can provide refuges for grazing sensitive species makes intuitive sense. However, the link between water-remoteness and grazing sensitivity had not been clearly demonstrated for any species in Australia's arid zone (Fensham & Fairfax 2008). With regard to native plant species in the LEB, there is no compelling evidence that any listed species have an association with, or dependence upon, water remote refuges.

The impact of introduced predators on native mammals, and the predator-prey interactions, have been well documented (for example, Catling 1988; Newsome 1994; Kinnear *et al* 1988; Lundie-Jenkins *et al* 1993). The establishment and maintenance of relatively dense populations of feral cats, dingoes and foxes can be attributed, at least in part, to the widespread provision of artificial water (James *et al.* 1999), while artificial watering points may also act as focal areas for hunting by introduced predators (Ehmann & Tynan 1996; Blick 1997; James *et al.* 1999). There is some evidence that viable populations of the greater bilby (*Macrotis lagotis*) are only persisting in water-remote habitat in western Queensland (McRae 2004). While it is clear that medium-sized mammals have experienced a cataclysmic decline (Johnson 2006), the precise relationship between the decline of small and medium-sized mammal species and artificial watering points remains hazy (Landsberg *et al* 1997).

8.4.3 Ways forward for biodiversity conservation

The advent of polypipe, coupled with the Great Artesian Basin Sustainability Initiative (GABSI), has made piping water more popular and economical across the LEB. GABSI has been credited with saving water and increasing pressure in some of the Basin's key areas (Pegler *et al.* 2002). The implicit aim of bore rehabilitation and piping schemes is to increase the number of watering points, therefore the risks of extinction for decreaser species are likely to increase. As such, protection of existing water-remote areas against future development with artificial waters should be a priority. These areas are generally in low rainfall, infertile or inaccessible areas that have not been developed for pastoralism (Fensham & Fairfax 2008). The largest such areas in the study area are the Simpson and Strzelecki Deserts (Figure x). Other areas that are still have relatively low densities of bores include the stony plains of the Channel Country west of the Diamantina River and the low residual country east of the Diamantina and south of the Mayne River.

As Fensham & Fairfax (2008) point out, there is little benefit to pastoralism of water remoteness, at least at the scale required to achieve any positive biodiversity outcomes. As such, a conservation approach that seeks to achieve large water remote areas within the context of existing grazing properties is likely to achieve only limited results. In areas where macropod and feral animal densities are low, fencing of conservation reserves to exclude domestic stock will achieve grazing-relief. However, where feral and/or macropod densities are high, future reserve strategies must focus on large, contiguous areas to achieve grazing relief. In the meantime, water remoteness can be achieved by continuing decommissioning of artificial watering points on existing conservation reserves, especially in areas remote from natural permanent water.

Ultimately, however, there is scant evidence upon which to mount a case for the maintenance and establishment of water remote refuges for biodiversity conservation. Are there any threatened species that occur only in water remote areas? Do water remote areas provide refuges for species that have become rare because of their grazing sensitivity? What are the links between endangered or vulnerable native fauna species and artificial waters? Fensham & Fairfax (2008) suggest that an alternative approach to identifying grazing sensitive species would be to focus on species that are rare or appear to have declined, and examine their distributions and life history strategies to determine whether they may be dependent upon water-remote refuges. If any such species are proven to have an association with water-remote habitat, it would greatly bolster the argument for preservation of such areas.

9 CONCLUSIONS/RECOMMENDATIONS

It is obvious from explorer and early settler accounts that all waters they 'discovered' and named had been used, cared for and intellectualised by Aboriginal people for thousands of years. Aboriginal people had an encyclopaedic knowledge of all waters in their country, and often a good working knowledge of those in neighbouring areas. Similar knowledge has been garnered over the past 150 years of European settlement in the area. The present-day knowledge of graziers and land managers in the LEB parallels the traditional knowledge held by Aboriginal people. This knowledge, whilst remarkable to outsiders in its extent and detail, is completely unsurprising: waterbodies represent centres of life, survival and productivity in an otherwise harsh, hostile environment. Despite occupying such a miniscule proportion of the landscape, permanent and semi-permanent waterbodies play a major role both in ecological and human terms, and warrant our awe, respect and care.

All issues facing permanent waterbodies are embedded within, and therefore inseparable from, the wider landscape context. For example, waterholes must be viewed and managed as part of the LEB river systems, while rockholes must be considered as part of the inland range system. There is no point undertaking weed or feral animal control projects specifically targeted at waterbodies, as waterbodies are not discrete entities but are impacted by, and impact upon, the catchments in which they occur. Some broad recommendations flowing from the findings of this project are outlined below.

1. In the absence of large-scale hydrological modifications, LEB waterholes and lakes are resilient features. Flooding will always be the major disturbance, generally overriding anthropogenic perturbations in terms of impacts on ecosystem structure and function. The main factors currently undermining waterhole riparian condition in the LEB can generally be addressed through strategic weed control, controlled grazing pressure and mitigation of recreational impacts on more accessible and well-used waterholes.
2. Much of this resilience is due to lack of substantial flow modification and water extraction. The case of the Murray Darling Basin and other highly modified systems should serve as a warning of the consequences of large-scale water extraction and hydrological modifications.
3. Further research is needed regarding the aquatic biota of waterholes, including fish, invertebrates, amphibians and mammals. In particular, research should focus on the impacts of introduced aquatic species on native species in LEB waterbodies, especially gambusia and red-claw crayfish, and potential strategies for control. Examination of the biology and ecology of poorly-known and restricted species would also be beneficial. A long-term monitoring project would allow the dynamics of aquatic assemblages in relation to season and flow, as well as tracking the existence and spread of exotic species.
4. Springs represent the most vulnerable of the four types of semi-permanent and permanent waterbodies in the LEB, but also the one that offers perhaps the best opportunities for achieving practical conservation outcomes. Projects are

already underway at Edgbaston in central Queensland aimed at recovery of the endangered red-fin blue-eye, control of weeds and ferals and long-term springs monitoring. Protection has also been achieved through the work of GABSI, acquisition of some spring groups by conservation groups and signing of nature refuge agreements over springs on private property. Such projects and schemes must be continued and, where necessary, expanded.

5. Rockholes will largely look after themselves, occurring as they do in remote and often inaccessible areas. Goat control is the most urgent management requirement in inland range habitat, particularly in southern areas. Most importantly, this will protect the high diversity of rare and threatened plants that occur in these habitats, but a concomitant benefit would be to reduce grazing pressure in the vicinity of rockholes.
6. There are considerable opportunities for increasing the knowledge of rockholes. This was the first study to document the existence of rockholes in inland Queensland, and much remains to be learnt about their permanence, ecology and dependent biota. Ongoing observations of these features in a variety of seasons will shed more light on their permanence, while the surrounding habitat represents a potentially rich repository of rare and threatened species inhabiting a chronically understudied environment. In particular, the distribution and habitat preferences of numerous cryptic fauna species suggests that surveys concentrated around the more permanent rockholes during dry periods will be potentially fruitful.
7. Remaining water remote habitats must be protected from any future water spreading, while future reserve strategies should focus on large, contiguous areas that can potentially contain water-remote buffers of >7km. More detailed spatial analysis of the artificial and natural water databases across the LEB will identify such areas. Future research effort should focus on critically examining the case for grazing-relief refuges for the conservation of threatened species of plants and animals.
8. Community education and engagement should emphasise the significance of permanent water in an arid environment from both ecological and cultural perspectives. A brochure summarising findings from this project will be sent to all informants, as well as to Shire Councils and other outlets. It is especially important to highlight the current generally good condition of LEB waterbodies and encourage them to be valued accordingly. Any education program should include basic information on identifying native and non-native species of fish, and focus on preventing potentially catastrophic liberation or escape events.

The Cooper, Diamantina and Georgina catchments together present an enormous opportunity to maintain relatively ‘natural’ aquatic ecosystems. This opportunity has already disappeared in many major inland river systems through grievous misuse of water and land resources. The waterholes, lakes, rockholes and springs of the LEB should be cherished and afforded the respect and attention they deserve. This will entail remaining vigilant to potential threats and dealing with these threats before they compromise the ecology of this unique system.

ACKNOWLEDGEMENTS

This project would not have been possible without the assistance of the many pastoralists and land managers, past and present, who willingly shared their knowledge and observations of waterbodies. Such assistance ranged from answering a quick phone enquiry about a single waterhole to spending a day driving (or flying) around looking at and discussing waterholes. While there are too many to name, the following people assisted with especially large numbers of waterholes across vast areas, or took considerable time and effort to share their knowledge: John Rickertt, John Ferguson, Bill & Rhonda Alexander, David Brook, Graham Moffat, Sandy Kidd, Penny Button, Joe Owens, Don Rowlands, Harry Glasson, Kate Deane, Bill Scott, Laddie & Alison Milson, Ian Duncan, Alan Hubbard, Ian Groves, Bob Morrish, Lyle Morton, Geoff Morton, Waddy & Chris Campbell, Steve Bryce, Colin Tully, Garth Tully, Roger Oldfield, Chook Kath, Pat & Mark Fennell, Peewee Clarke, Craig Lasker, Maree & Graham Morton, Sharon Oldfield, Robert Teague, Peter McNiven, Anthony & Deb Desreaux, Steve Bryce, Rob Jansen, George Macqueen, Jeff Swanson, Lloyd Walker, Joe Herrod, John Kendall, Bill Graham, Michael Butler, Lynda Baker, Ted Fitzgerald, David Smith, Ian Lilburn, Bob Young, Alistair Malone, John Bryant, Peter & Ann Whiteman and Tony Stevenson, Billy Rice, Ralph & Beverley Ray, David Capel, Michelle Rogers, Geoff Schrader, Ken & Margie Ballinger, Ray Wilson, Harry George, Angus Cameron, Denise, Steve & Shane Hawe, Angus Emmott, Bruce Emmott, David Morton, Des & Helen Boyle, Brett Elliot, Duncan Lawton, Sam Brown, Angus Logan, Neil Rogers, Peter Magoffin, Johnny Avery, John Wagstaff, John Hughes, Vinnie & Jenny Richardson, Bob McDonald and Bob & Noela McConachy.

The project was funded by the South Australian Arid Lands NRM Board, through Henry Mancini. Paul Wainwright from the South Australian Department of Environment and Heritage generously provided his wetland mapping data and discussed methods and findings, as did Nick Cuff (Queensland Herbarium) for the Queensland Wetlands Mapping data. Rod Fensham provided advice and discussed ideas throughout the project. Peter McRae, Bruce Wilson and Russell Fairfax (all Queensland Department of Environment & Resource Management) are also thanked for sharing ideas and information. Justin Costelloe discussed the ARIDFLO findings and provided data for waterholes sampled during ARIDFLO. Adam Kerezsy helped to devise the condition assessment framework, and also willingly provided his driving, mechanical and conversational skills on numerous long field trips. Thanks to Jenny Milson and Maree Winter for suggestions of potential contacts (and much other information besides!). All photos in the report were taken by the author, except for Figures 5b, 27 and 48a&d, which were captured by Terry Beutel, Adam Kerezsy and Tracy Wattz, respectively. Tracy Wattz, Peter McRae, Maree Rich, Alicia Whittington, Rod Fensham, Rosie Kerr and Clare Silcock assisted with field work in various ways. Alastair Silcock, ever the resourceful librarian, hunted down some of the less accessible references cited in this report. The Triffids, Nick Cave, Iron and Wine and the Fleet Foxes provided an apt soundtrack to the lengthy mapping and writing process.

REFERENCES

Ah Chee, D. 2002, '*Kwatye* (water) in the Great Artesian Basin', *Environment South Australia*, vol.9, no.1, pp.20-21.

Allen, A.C.B. 1968, 'Marginal settlement – a case study of the channel country of southwest Queensland', *Australian Geographical Studies*, vol.6, no.1, pp.1-23.

Appleton, J., 1975: *The Experience of Landscape*. Wiley, London.

Armstrong, R.E.M. 1981, *The Kalkadoons: a study of an Aboriginal tribe on the Queensland frontier*, William Brooks & Co. Pty Ltd, Brisbane.

Armstrong, H. 2001, 'Investigating Queensland's cultural landscapes: whose heritage?', in *Heritage Landscapes: Understanding Places and Communities*, eds M.M. Cotter, W.E. Boyd & J.E. Gardiner, Southern Cross University Press, Lismore.

Arthington, A.H., Balcombe, S.R., Wilson, G.A., Thoms, M.C. & Marshall, J. 2005, 'Spatial and temporal variation in fish assemblage structure in isolated waterholes during the 2001 dry season of an arid-zone river, Cooper Creek, Australia', *Marine and Freshwater Research*, vol.56, pp.25-35.

Agriculture & Resource Management Council of Australia & New Zealand, Environment & Conservation Council and Forestry Ministers 2000, *Weeds of National Significance: Rubbervine* (Cryptostegia grandiflora) *Strategic Plan*, National Weeds Strategy Executive Committee, Launceston.

Agriculture & Resource Management Council of Australia & New Zealand, Environment & Conservation Council and Forestry Ministers 2001, *Weeds of National Significance: Parkinsonia* (Parkinsonia aculeata) *Strategic Plan*, National Weeds Strategy Executive Committee, Launceston.

Bailey, J. 2006, *Mr Stuart's Track: The Forgotten Life of Australia's Greatest Explorer*

Baker, D.W.A. 1998, 'Exploring with Aborigines: Thomas Mitchell and his Aboriginal guides', *Aboriginal History*, vol.22, pp.36-50.

Bandler, H. 1995, 'Water resources exploitation in Australian prehistory environment', *The Environmentalist*, vol. 15, pp.97-107.

Bayly, I.A.E. 1999, 'Review of how indigenous people managed for water in desert regions of Australia', *Journal of the Royal Society of Western Australia*, vol.82, pp.17-25.

Bayly, I.A.E. 2001, 'Invertebrate occurrence and succession after episodic flooding of a central Australian rock-hole', *Journal of the Royal Society of Western Australia*, 84: 29-32.

Bell, P. 2004, 'The explorers', in eds V. Donovan & C. Wall 2004, *Making Connections: a journey along Central Australian Aboriginal trading routes*, Arts Queensland, Brisbane.

Bell, P. & Iwanicki, I. 2002, 'Historical background', in Historical Research Pty Ltd, Austral Archaeology Pty Ltd, Leader-Elliot, L. & Iwanicki, I. 2002., *Heritage of the Birdsville and Strzelecki Tracks*, Department for Environment and Heritage, South Australia.

Bennett, M.M. 1927, *Christison of Lammermoor*, Alston Rivers Ltd, London.

Bernardo, J.M. & Alves, M.H. 1999, 'New perspectives for ecological flow determination in semi-arid regions: a preliminary approach', *Regulated Rivers: Research and Management*, vol.15, pp.221-229.

Blick, R. 1997, 'Managing rangelands better by managing artesian water', in *Saving Our Natural Heritage: The Role of Science in Managing Australia's Ecosystems*, Halstead Press.

Boulton, A.J., Sheldon, F. & Jenkins, K.M. 2006, 'Natural disturbance and aquatic invertebrates in desert rivers', in *Ecology of Desert Rivers*, ed. R.T. Kingsford, Cambridge University Press, Cambridge.

Boyd, W.E. 1990, 'Mound springs', in eds M.J. Tyler, C.R. Twidale, M. Davies & C.B. Wells, *Natural History of the North-East Deserts*, Royal Society of South Australia, Adelaide.

Box, J.B., Duguid, A., Read, R.E., Kimber, R.G., Knapton, A., Davis, J. & Bowland, A.E. 2008, 'Central Australian waterbodies: the importance of permanence in a desert landscape', *Journal of Arid Environments*, vol.72, pp.1395-1413.

Brock, M.A., Capon, S.J. & Porter, J.L. 2006, 'Disturbance of plant communities dependent on desert rivers', in *Ecology of Desert Rivers*, ed. R.T. Kingsford, Cambridge University Press, Cambridge.

Bunn, S.E., Balcombe, S.R., Davies, P.M., Fellows, C.S. & McKenzie-Smith, F.J. 2006, 'Aquatic productivity and food webs of desert river ecosystems', in *Ecology of Desert Rivers*, ed. R.T. Kingsford, Cambridge University Press, Cambridge.

Bunn, S.E., Davies, P.M. & Mosisch, T.D. 1999, 'Ecosystem measures of river health and their response to riparian and catchment degradation', *Freshwater Biology*, vol.41, pp.333-345.

Bunn, S.E. & Davies, P.M. 2001, 'Dryland river ecosystems and forest river ecology: implications for management', in *Report of Inland Rivers Workshop, 27-28 March 2001*, Alice Springs.

Capon, S.J. & Brock, M.A. 2006, 'Flooding, soil seed bank dynamics and vegetation resilience of a hydrologically variable desert floodplain', *Freshwater Biology*, vol. 51, pp.206-223.

Carnegie, D.W. 1898, *Spinifex and Sand: A narrative of five years' pioneering and exploring in Western Australia*, available online via Project Gutenburg (http://www.gutenburg.net).

Catling, P. 1988, 'Similarities and contrasts in the diets of foxes, *Vulpes vulpes*, and cats, *Felis catus*, relative to fluctuating prey populations and drought', *Australian Wildlife Research*, vol. 15, pp. 307-17.

Chilcott, C.R., McCallum, B.S., Quirk, M.F. & Paton, C.J. 2003, Grazing Land Management Education Package Workshop Notes – Burdekin, Meat and Livestock Australia Limited, Sydney.

Choy, S.G., Thomson, C.B. & Marshall, J.C. 2002: Ecological condition of central Australian arid-zone rivers. *Water Science and Technology* 45, 225-232.

Centre for Riverine Landscapes 2005, *Methods for Assessing the Health of Lake Eyre Basin Rivers – Assessment Methods Development Project*, Final Report to Land & Water Australia, Griffith University, Brisbane.

Cooperative Centre for Freshwater Ecology 2002, *Dryland River Refugia Newsletter – No.1*, Griffith University, Brisbane.

Costelloe, J.F. 2008, *Updating and Analysis of the ARIDFLO Water Level Data in the Lake Eyre Basin,* Draft Final Report (June 2008) to SA Dept of Water, Land and Biodiversity Conservation, Adelaide.

Costelloe, J.F., Hudson, P.J., Pritchard, J.C., Puckridge, J.T. & Reid, J.R.W. 2004, *ARIDFLO Scientific Report: Environmental Flow Requirements of Arid Zone Rivers with Particular Reference to the Lake Eyre Drainage Basin*, Final Report to SA Dept of Water, Land and Biodiversity Conservation and Commonwealth Department of Environment and Heritage, School of Earth and Environmental Sciences, University of Adelaide, Adelaide.

Costelloe, J.F., Shields, A., Grayson, R.B. & McMahon, T.A. 2007, 'Determining loss characteristics of arid zone river waterbodies', *River Research and Applications*, vol.23, pp.715-731.

Cumpston, J.H.L. 1964, *Inland Sea and the Great River: the story of Australian exploration*, Angus & Roberston, Sydney.

Department of Lands 1993, *Mulga Region Position Paper: A Study of the Inter-Dependence of the Environment, Pastoral Production and the Economy*, Queensland Government, Brisbane.

Donovan, V. & Wall, C. (eds) 2004, *Making Connections: a journey along Central Australian Aboriginal trading routes*, Arts Queensland, Brisbane.

Duguid, A., Barnetson, J., Clifford, B., Pavey, C., Albrecht, D., Risler, J. & McNellie, M. 2002, *Wetlands in the Arid Northern Territory: A Report to Environment Australia on the Inventory and Significance of Wetlands in the Arid Northern Territory*, Parks and Wildlife Commission of the Northern Territory, Alice Springs, available online at www.nt.gov.au/nreta/wildlife/nature/aridwetlands.html.

Duncan-Kemp, A. 1934: *Our Sandhill Country: Man and Nature in South-Western Queensland*. Angus & Robertson Ltd, Sydney, 2nd ed.

Duncan-Kemp, A. 1968: *Our Channel Country*. Angus & Robertson, Sydney.

Durack, M. 1959, *Kings in Grass Castles*, Transworld Publishers, Milsons Point.

Edwards, G.P., Dobbie, P.W., Berman, D.M. 2002, 'Population trends in European rabbits and other wildlife of central Australia in the wake of rabbit haemorrhagic disease', *Wildlife Research*, vol.29, pp.557-565.

Ehmann, H. & Tynan, R. 1996, 'Islands of grazing in seas of rangeland wildlife: a key element for sustainable pastoral management', in *'Focus on the Future – the Heat is on!':*

Australian Rangeland Society 9th Biennial Conference – Conference Papers, eds L.P. Hunt & R. Sinclair, Australian Rangeland Society, Port Augusta.

Environmental Protection Agency (EPA) 2005, *Wetland Mapping and Classification Methodology – Overall Framework – A Method to Provide Baseline Mapping and Classification for Wetlands in Queensland*, Version 1.2, Queensland Government, Brisbane (available online at http://www.epa.qld.gov.au/register/p01769aa.pdf).

Environmental Protection Agency (EPA) 2006, *The Desert Uplands: An Overview of the Desert Uplands Strategic Land Resource Assessment Package – Technical Report*, available online at http://www.epa.qld.gov.au/nature_conservation/biodiversity/desert_uplands_strategic land_resource_assessment/.

Eyre, T.J., Kelly, A.L. & Neldner, V.J. 2006, Methodology for the Establishment of Survey of Reference Sites for Biodiversity Conservation, vol.1.4, Biodiversity Sciences Unit, EPA, Brisbane.

Fairfax, R.J. & Fensham, R.J. 2002, 'In the footsteps of J. Alfred Griffiths: a cataclysmic history of the Great Artesian Basin springs in Queensland', *Australian Geographical Studies*, vol.40, pp.210-230.

Fairfax, R., Fensham, R., Wager, R., Brook, S., Webb, A. & Unmack, P. 2007, 'Recovery of the red-finned blue-eye: an endangered fish from springs of the Great Artesian Basin', *Wildlife Research*, vol.34, pp.156-166.

Fensham, R.J. & Fairfax, R.J. 2000, 'The effect of exotic pasture development on floristic diversity in central Queensland, Australia', *Biological Conservation*, vol.94, pp.11-21.

Fensham, R.J. & Fairfax, R.J. 2003: Spring wetlands of the Great Artesian Basin, Queensland, Australia. *Wetlands Ecology and Management* 11, 343-362.

Fensham, R.J. & Fairfax, R.J. 2008. 'Water-remoteness for grazing relief in Australia's arid lands', *Biological Conservation*, vol.141, pp.1447-1460.

Fensham, R.J., Fairfax, R.J. & Sharpe, P.R. 2004, 'Spring wetlands in seasonally arid Queensland: floristics, environmental relations, classification and conservation values', *Australian Journal of Botany*, vol. 52, pp.583-595.

Fensham, R.J. & Price, R.J. 2004, 'Ranking spring wetlands in the Great Artesian Basin of Australian using endemnicity and isolation of plant species', *Biological Conservation*, vol.119, pp.41-50.

Finlayson, H.H. 1943, *The Red Centre: Man and Beast in the Heart of Australia*, 4th edn, Angus and Robertson Limited, Sydney.

Forrest, P. & Forrest, S. 2005, *Vision Splendid: A History of the Winton District, Western Queensland*, Winton Shire Council and Winton District Historical Society & Museum Inc., Winton.

Freudenberger, D. & Barber, J. 1999, 'Movement patterns of feral goats in a semi-arid woodland in eastern Australia', *Rangeland Journal*, vol.21, pp.71-81.

Gee, P. 2000, *A History of Pastoralism in the Lake Eyre South Drainage Basin*, Royal Geographical Society of South Australia, Adelaide.

Gehrke, P., Gawne, B. & Cullen, P. 2003, 'What is the status of river health in the Murray-Darling Basin?', CSIRO Land and Water, available online at http://www.clw.csiro.au/staff/staffalpha.html.

Gibbs, L.M. 2006, *Valuing Water: variability and the Lake Eyre Basin, Central Australia*, unpublished PhD thesis, Australian National University, Canberra.

Gibson, D.B. & Cole, J.R. 1988, *A Biological Survey of the Northern Simpson Desert*, Consultancy Report to the Conservation Commission of the Northern Territory (Technical Report No. 20), Mala Enterprises, Alice Springs.

Giles, E. 1889: *Australia Twice Traversed*. Hesperian Press, Carlisle, Western Australia, 2nd ed.

Glover, C.J.M. 1990, 'Fishes', in eds M.J. Tyler, C.R. Twidale, M. Davies & C.B. Wells, *Natural History of the North-East Deserts*, Royal Society of South Australia, Adelaide.

Godwin, L. 2001, 'The bureaucracy, the law and Black's Palace: a history of management of one site in the Central Queensland Highlands', *Ngulaig*, vol.18, pp.1-26.

Greenwood-Smith, S.L. 2002, 'The use of rapid environmental assessment techniques to monitor the health of Australian rivers', *Water Science and Technology*, vol.45, pp.155-160.

Gregory, A.C. 1856, 'North Australian Expedition', published 2002, in *Journals of Australian Explorations 1846-1861*, Hesperian Press, Western Australia.

Hamilton, S.K., Bunn, S.E., Thoms, M.C. & Marshall, J.C. 2005, 'Persistence of aquatic refugia between flow pulses in a dryland river system (Cooper Creek, Australia)', *Limnology and Oceanography*, vol.50, pp.743-754.

Harrington, G.N. 1979, 'The effects of feral goats and sheep on shrub populations in a semi-arid woodland', *Australian Rangeland Journal*, vol.1, pp.334-45.

Harris, C.R. 1980, 'Oases in the desert: mound springs of northern South Australia', *Proceedings of Royal Geographic Society of Australia*, vol.8, pp.26-39.

Harris, C.R. 2004, 'Water in the desert: South Australia's mound springs as trade and communication routes', in eds V. Donovan & C. Wall, 2004, *Making Connections: a journey along Central Australian Aboriginal trading routes*, Arts Queensland, Brisbane.

Hercus, L.A. 1990, 'Aboriginal People', in eds M.J. Tyler, C.R. Twidale, M. Davies & C.B. Wells, *Natural History of the North-East Deserts*, Royal Society of South Australia, Adelaide.

Hercus, L.A. 2004,'In the Simpson Desert', in eds V. Donovan, V. & C. Wall 2004, *Making Connections: a journey along Central Australian Aboriginal trading routes*, Arts Queensland, Brisbane.

Hercus, L.A. & Sutton, P. (eds) 1986, *This Is What Happened: Historical Narratives by Aborigines*, Australian Institute of Aboriginal Studies, Canberra.

Hirst, J. 2006: *Sense and Nonsense in Australian History*, Black Inc., Melbourne.

Historical Research Pty Ltd, Austral Archaeology Pty Ltd, Leader-Elliot, L. & Iwanicki, I. 2002., *Heritage of the Birdsville and Strzelecki Tracks*, Department for Environment and Heritage, South Australia.

Holdaway, S.J., Fanning, P.C. & Witter, D.C. 2000, 'Prehistoric aboriginal occupation of the rangelands: interpreting the surface archaeological record of far western New South Wales', *Rangeland Journal*, vol. 22, no. 1, pp. 44-57.

Hughes, K.K. 1980, 'Physiography and geology', in *Western Arid Region Land Use Study – Part II*, Division of Land Utilisation, Brisbane.

Jackson, S., Stoeckl, N., Straton, A. & Stanley, O. 2008, 'The changing value of Australian tropical rivers', *Geographical Research*, vol.46, pp.275-290.

James, C.D., Landsberg, J. & Morton, S.R. 1995, 'Ecological functioning in arid Australia and research to assist conservation of biodiversity', *Pacific Conservation Biology*, vol. 2, pp. 126-142.

James, C.D., Landsberg, J. & Morton, S.R. 1999, 'Provision of watering points in the Australian arid zone: a review of the effects on biota', *Journal of Arid Environments*, vol. 41, no. 1, pp. 87-121.

Jansen, A. & Robertson, A.I. 2001, 'Relationships between livestock management and the ecological condition of riparian habitats along an Australian floodplain river', *Journal of Applied Ecology*, vol.38, pp.63-75.

Jansen, A., Robertson, A., Thomson, L. & Wilson, A. 2005, 'Rapid appraisal of riparian condition, version 2', River and Riparian Land Management Technical Guideline No. 4A, Land & Water Australia, Canberra.

Jenkins, L. 2001, *Lure of the Land: a brief history of the Quilpie Shire*, Quilpie Shire Council.

Johnson, B.J., Miller, G.H., Magee, J.W., Gagan, M.K., Fogel, M.L. & Quay, P.D. 2005, 'Carbon isotope evidence for an abrupt reduction in grasses coincident with European settlement of Lake Eyre, South Australia', *The Holocene*, vol.15, pp.888-896.

Johnson, C. 2006, *Australia's Mammal Extinctions: a 50 000 year history*, Cambridge University Press, Port Melbourne.

Johnston, P.J.M., Wellard, G.A. & Kirkpatrick, T.H. 1986, 'Commercial fauna – the kangaroo industry', in *The Mulga Lands*, ed. P.S. Sattler, Royal Society of Queensland, Brisbane.

Karr, J.R. 1999, 'Defining and measuring river health', *Freshwater Biology*, vol.41, pp.221-234.

Kavanagh, B.L. 1984, *Survival Water in Australia's Arid Lands*, Strategic and Defence Studies Centre, Research School of Pacific Studies, Australian National University, Canberra.

Kingsford, R.T. 2000, 'Ecological impacts of dams, water diversions and river management on floodplain wetlands in Australia', *Australian Journal of Ecology*, vol.25, pp.109-127.

Kingsford, R.T. (ed.) 2006: *Dryland Rivers*. Oxford University Press, Oxford.

Kingsford, R.T., Curtin, A.L. & Porter, J. 1999, 'Water flows on Cooper Creek in arid Australian determine 'boom' and 'bust' periods for waterbirds', *Biological Conservation*, vol. 88, pp.231-248.

Kingsford, R.T., Georges, A. & Unmack, P.J. 2006, 'Vertebrates of desert rivers: meeting the challenges of temporal and spatial unpredictability', in *Ecology of Desert Rivers*, ed. R.T. Kingsford, Cambridge University Press, Cambridge.

Kingsford, R.T. & Norman, F.I. 2002, 'Australia's waterbirds – products of the continent's ecology', *Emu*, vol.102, pp.47-69.

Kingsford, R.G. & Porter, J.L. 1994, 'Waterbirds on an adjacent freshwater lake and salt lake in arid Australia', *Biological Conservation*, vol.69, pp.219-238.

Kinnear, J.E., Onus, M.L. & Bromilow, R.M. 1988, 'Fox control and rock wallaby dynamics', *Australian Wildlife Research*, vol. 15, pp. 435-447.

Knight, A.W., McTainsh, G.H. & Simpson, R. 1995, 'Sediment loads in an Australian dust storm: implications for present and past dust processes', *Catena*, vol.24, pp.195-213.

Knighton, A.D. & Nanson, G.C. 1994, 'Waterholes and their significance in the anastomosing channel system of Cooper Creek, Australia', *Geomorphology*, vol.9, pp.311-324.

Knighton, A.D. & Nanson, G.C. 2000, 'Waterhole form and process in the anastomosing channel system of Cooper Creek, Australia', *Geomorphology*, vol. 35, pp.101-17.

Knuckey, G. & Kippen, K. 1992, 'The archaeology of Stonehenge – a preliminary survey', *Queensland Archaeological Review*, vol.9, pp.17-25.

Kotwicki, V. 1986, *Floods of Lake Eyre*, SA E&WS Department, Adelaide.

Kowald, M. & Johnson, W.R. 1992, *You Can't Make It Rain: the story of the North Australian Pastoral Company, 1887-1991*, Boolarong Publications, Brisbane.

Lamond, H. G. 1953, A stretch of the Georgina River, *Walkabout*, 1/11/1953, pp. 17-19.

Landsberg, J. & Gillieson, D. 1996, 'Looking beyond the piospheres to locate biodiversity reference areas in Australia's rangelands', in *Rangelands in a Sustainable Biosphere – Proceedings of the 5th International Rangeland Congress 1995*, ed. N.E. West, Society for Range Management, Denver.

Landsberg, J., James, C.D., Morton, S.R. & Muller, W.J. 2003, 'Abundance and composition of plant species along grazing gradients in Australian rangelands', *Journal of Applied Ecology*, vol.40, pp.1008-1024.

Landsberg, J., James, C.D., Morton, S.R., Hobbs, T.J., Stol, J., Drew, A. & Tongway, H. 1997, *The Effects of Artificial Sources of Water on Rangeland Biodiversity – Final Report to the Biodiversity Convention and Strategy Section of the Biodiversity Group, Environment Australia*, Environment Australia & CSIRO, Canberra.

Langton, M. 2002, 'Freshwater', in *Background Briefing Papers*, Lingiari Foundation, Broome.

Les, D.H., Crawford, D.J., Landolt, E., Gabel, J.D. & Kimball, R.T. 2002, 'Phylogeny and systematics of Lemnaceae, the duckweed family', *Systematic Botany*, vol.27, (2), pp.221-240.

Lewis, D. 2005, ‘Invaders of a peaceful country: Aborigines and explorers on the lower Victoria River, Northern Territory’, *Aboriginal History*, vol.29, pp.23-45.

Lewis, D. 2006, ‘The fate of Leichhardt’, *Historical Records of Australian Science*, vol.17, pp.1-30.

Lundie-Jenkins, G.L., Corbett, L.K. & Phillips, C.M. 1993, ‘Ecology of the rufous hard wallaby (*Lagorchestes hirsutus*) Gould (Marsupialia: Macropodidae) in the Tanami Desert, Northern Territory, III. Interactions with introduced mammal species’, *Wildlife Research*, vol. 20, pp. 495-511.

Macinnis, P. 2007, *Australia’s Pioneers, Heroes & Fools: the trials, tribulations and tricks of the trade of Australia’s colonial explorers*, Pier 9, Murdoch Books Australia, Millers Point.

Madigan, C.T. 1946, *Crossing the Dead Heart*, Georgian House, Melbourne.

Magoulick, D.D & Kobza, R.M. 2003, ‘The role of refugia for fishes during drought: a review and synthesis’, *Freshwater Biology*, vol.48, pp.1186-1198.

Maheshwari, B.L., Walker, K.F. & McMahon, T.A. 1995, ‘Effects of rivers regulation on the flow regime of the River Murray, Australia’, *Regulated Rivers: Research and Management*, vol.10, pp.15-38.

McBryde, I. 2000, ‘Travellers in storied landscapes: a case study in exchange and heritage’, *Aboriginal History*, vol.24, pp.152-174.

McKinlay, J. 1863, ‘Diary of Mr. J. McKinlay, Leader of the Burke Relief Expedition, fitted out by the Government of South Australia’, *Journal of Royal Geographical Society of London*, vol. 33, pp.13-61.

McMahon, T.A. & Finlayson, B.L. 2003, ‘Droughts and anti-droughts: the low flow hydrology of Australian rivers’, *Freshwater Biology*, vol.48, pp.1147-1160.

McMahon, T.A., Murphy, R.E., Peel, M.C., Costelloe, J.F. & Chiew, F.H.S. 2008a, ‘Understanding the surface hydrology of the Lake Eyre Basin: Part 1 – Rainfall’, *Journal of Arid Environments*, vol.72, pp.1853-68.

McMahon, T.A., Murphy, R.E., Peel, M.C., Costelloe, J.F. & Chiew, F.H.S. 2008b, ‘Understanding the surface hydrology of the Lake Eyre Basin: Part 2 – Streamflow’, *Journal of Arid Environments*, vol.72, pp.1869-86.

McRae, P.D. 2004, *Ecology of the Greater Bilby,* Macrotis lagotis, *in western Queensland*, unpublished Masters Thesis, University of Sydney.

McTainsh, G., Lynch, A. & Tews, E. 1998, ‘Climatic controls upon dust storm occurrence in eastern Australia’, *Journal of Arid Environments*, vol.39, pp.457-466.

Mensforth, L.J., Thorburn, P.J., Tyreman, S.D. & Walker, G.R. 1994, ‘Sources of water used by riparian *Eucalyptus camaldulensis* overlying highly saline groundwater’, *Oecologia*, vol.100, pp.21-28.

Mitchell, T.L. 1847: *Journal of an Expedition into Tropical Australia in Search of a Route from Sydney to the Gulf of Carpentaria*. University of Adelaide Library Electronic Texts Collection, Adelaide.

Moffat, A.G.I. 1987, *The Longreach Story: a history of Longreach and shire*, Jacaranda Press, Milton.

Mollemans, F.H. Reid, J.R.W., Thompson, M.B., Alexander, L. & Pedler, L.P. 1984, *Biological Survey of the Cooper Creek Environmental Association 8.4.4, North-Eastern South Australia*, Department of Environment & Planning, South Australia.

Morcombe, M. 2003, *Field Guide to Australian Birds*, 2nd edn, Steve Parish Publishing, Archerfield.

Morton, S.R., Short, J. & Baker, R.D. 1995, Refugia for biological diversity in arid and semi-arid Australia, *Biodiversity Series, Paper No.4,* Report to Biodiversity Unit of the Department of Environment, Sport and Territories, Canberra.

Murgatroyd, S. 2002, *The Dig Tree: the story of Burke and Wills*, The Text Publishing House, Melbourne.

Newsome, A.E. 1994, 'Vertebrate pests versus wildlife conservation in semi-arid New South Wales: a profound imbalance', in *Future of the Fauna of Western New South Wales*, eds D. Lunney, S. Hand, P. Reed & D. Butcher, Royal Zoological Society of New South Wales, Mossman.

New South Wales Agriculture 2004, 'Noogoora burr and California burr', NSW Department of Agriculture, available online at http://www.dpi.nsw.gov.au.

Noble, J.C. 1997, *The Delicate and Noxious Scrub*, CSIRO, Canberra.

Noble, J.C., Habermehl, M.A., James, C.D., Landsberg, J., Langston, A.C. & Morton, S.R. 1998, 'Biodiversity implications of water management in the Great Artesian Basin', *Rangeland Journal*, vol. 20, no. 2, pp. 275-300.

Noble, J.C. & Kimber, R.G. 1999, 'On the ethno-ecology of mallee root-water', *Aboriginal History*, vol.21, pp.170-202.

Noble, J.C. & Tongway, D.J. 1983, 'Pastoral settlement in arid and semi-arid rangelands', in *Australian Soils: the Human Impact*, eds J.S. Russell & R.F. Isbell, University of Queensland Press, St Lucia.

Nolan, C. 2003, *Sandhills and Channel Country*, Diamantina Shire Council, Bedourie.

Norris, R.H. & Thoms, M.C. 1999, 'What is river health?', *Freshwater Biology*, vol.41, pp.197-209.

Parks & Wildlife Commission of the Northern Territory 2002, *Anna's Reservoir Conservation Reserve: draft plan of management/conservation management plan*, Northern Territory Government, Alice Springs.

Pegler, L., Moore, R. & Bentley, D. 2002, 'Bore drain replacement in south-west Queensland: benefits and costs for land managers', *Rangeland Journal*, vol. 24, no. 2, pp. 185-206.

Perry, R.A. 1964, *General Report on Lands of the Leichhardt-Gilbert Area, Queensland, 1953-4*, Land Research Series No.11, Commonwealth Scientific and Industrial Research Organisation, Melbourne.

Phelps, D.G., Lynes, B., Connelly, P.T. & Horrocks, D.J. 2007, *Sustainable Grazing in the Channel Country Floodplains: Final Report*, Department of Primary Industries & Fisheries, Longreach.

Ponder, W.F. 2002, 'Desert springs of the Great Artesian Basin', in *Spring-Fed Wetlands: Important Scientific and Cultural Resources of the Intermountain Region – Conference Proceedings*, online at http://wetlands.dri.edu/2002/Ponder.pdf

Ponder, W.F 2003, 'Endemic aquatic macroinvertebrates of artesian springs of the Great Artesian Basin – progress and future directions', *Records of the South Australian Museum Monograph Series*, vol.7, pp.101-110.

Pople, A.R., Clancy, T.F., Thompson, J.A. & Boyd-Law, S. 1998, 'Aerial survey methodology and the cost of control for feral goats in western Queensland', *Wildlife Research*, vol.25, pp.393-407.

Porter, J.L., Kingsford, R.T. & Brock, M.A. 2007, 'Seed banks in arid wetlands with contrasting flooding, salinity and turbidity regimes', *Plant Ecology*, vol.188, pp.215-234.

Potcher, O., Goldman, D., Kadish, D. & Iluz, D. 2008, 'The oasis effect in an extremely hot and arid climate: the case of southern Israel', *Journal of Arid Environments*, vol.72, pp.1721-1733.

Powell, J.M. 1991, *Plains of Promise, Rivers of Destiny: Water Management and the Development of Queensland, 1824-1900*, Boolarong Publications, Brisbane.

Puckridge, J.T., Walker, K.F. & Costelloe, J.F. 2000, 'Hydrological persistence and the ecology of dryland rivers', *Regulated Rivers: Research and Management*, vol.16, pp.385-402.

Ratcliffe, F.N. 1938, *Flying Fox and Drifting Sand: the Adventures of a Biologist in Australia*, Chatto & Windus, London.

Reid, M.A. & Odgen, R.W. 2006, 'Trend variability or extreme event?: the importance of long-term perspectives in river ecology', *River Research and Applications*, vol.22, pp.167-177.

Reid, J. & Gillen, J. 1988, *The Coongie Lakes Study*, Department of Environment & Planning, Adelaide.

Reid, J.R.W. & Puckridge, J.T. 1990, 'Coongie Lakes', in eds M.J. Tyler, C.R. Twidale, M. Davies & C.B. Wells, *Natural History of the North-East Deserts*, Royal Society of South Australia, Adelaide.

Roberts, T. 2005, *Frontier Justice: a history of the Gulf Country to 1900*, University of Queensland Press, St Lucia.

Robertson, A.I. & Rowling, R.W. 2000, 'Effects of livestock on riparian vegetation in an Australian dryland river', *Regulated Rivers: Research & Management*, vol.16, pp.527-541.

Rose, D.B. 2004, 'Fresh water rights and biophilia: Indigenous Australian perspectives', *Dialogue*, vol.23, no.3, pp.35-43.

Sattler, P.S. & Williams, R.A. (eds) 1999, *The Conservation Status of Queensland's Bioregional Ecosystems*, Environmental Protection Agency, Brisbane.

Schmiechen, J. 2004: *Lake Eyre Basin Heritage Tourism: Future Directions*, Lake Eyre Basin Coordinating Group, available online at http://www.lakeeyrebasin.org.au.

Sheldon, F. 2005, 'Incorporating natural variability into the assessment of ecological health in Australian dryland rivers', *Hydrobiologia*, vol.552, pp.45-56.

Sheldon, F., Balcombe, S., Brunner, P. & Capon, S. 2003 *Ecological and Geomorphological Assessment for the Georgina-Diamantina River Catchment*, Centre for Riverine Landscapes, Griffith University, Brisbane.

Sheldon, F., Boulton, A.J. & Puckridge, J.T. 2002, 'Conservation value of variable connectedness: aquatic invertebrate assemblages of channel and floodplain habitats of a central Australian arid-zone river, Cooper Creek', *Biological Conservation*, vol.103, pp.13-31.

Sheldon, F., McKenzie-Smith, F. & Brunner, P. 2005, Methodology for Assessing the Health of Lake Eyre Basin Rivers, Final Report to Land and Water Australia, Canberra.

Sheldon, F. & Puckridge, J.T. 1998, 'Macroinvertebrate assemblages of Goyder Lagoon, Diamantina River, South Australia', *Transactions of the Royal Society of South Australia*, vol.122, pp.17-31.

Shephard, M. 1994, *The Simpson Desert: Natural History and Human Endeavour*, 2nd edn, Reed Books Australia Pty Ltd, Chatswood, New South Wales.

Simmons, A. 2007, *"Life in a Corridor": An Archaeological Investigation of the Diamantina Channel Country – A Western Queensland Corridor*, unpublished PhD thesis, University of Queensland, St Lucia.

Smith, M.J., Kay, W.R., Edward, D.H.D., Papas, P.J., Richardson, K.S.J., Simspon, J.C., Pinder, A.M., Cale, D.J., Horwitz, P.H.J., Davis, J.A., Yung, F.H., Norris, R.H. & Halse, S.A. 1999, 'AusRivAS: using macroinvertebrates to assess ecological condition of rivers in Western Australia, *Freshwater Biology*, vol.41, pp.269-282.

Spencer, C., Robertson, A.I. & Curtis, A. 1998, 'Development and testing of a rapid appraisal wetland condition index in south-eastern Australia', *Journal of Environmental Management*, vol.54, pp.143-59.

Stafford Smith, M. & Morton, S.R. 1990, 'A framework for the ecology of arid Australia', *Journal of Arid Environments*, vol.18, pp.255-278.

Stephens, K.M. & Dowling, R.M. 2002, *Wetland Plants of Queensland: A Field Guide*, CSIRO Publishing, Collingwood.

Sturt, C. 1849: *Narrative of an Expedition into Central Australia performed under the authority of Her Majesty's Government, during the years 1844, 5, and 6*, Corkwood Press (2001 ed.), North Adelaide.

Sutherland, G. 1913, 'Across the wilds of Queensland with sheep to the Northern Territory in the early sixties', in *Pioneering Days: Thrilling Incidents*, W.H. Wendt & Coy Ltd Printers, Brisbane.

Thoms, M.C. & Sheldon, F. 2000, 'Water resource development and hydrological change in a large dryland river: the Barwon-Darling River, Australia', *Journal of Hydrology*, vol.228, pp.12-21.

Thorley, P.B. 1998, 'Pleistocene settlement in the Australian arid zone: occupation of an inland riverine landscape in the central Australian ranges', *Antiquity*, 72, online at http://www.articlearchives.com/humanities-social-science/anthropology-archaeology/539298-1.html.

Tolcher, H.M. 1986, *Drought or Deluge: Man in the Cooper's Creek Region*, Melbourne University Press, Carlton.

Towner, E.T. Major 1955, 'Address on Lake Eyre and its Tributaries for the Royal Geographical Society of Australia (Queensland)', presented in Brisbane, 2 May.

Tyler, M.J. 1978, *Amphibians of South Australia*, South Australian Government, Adelaide.

Unmack, P.J. 2001, 'Fish persistence and fluvial geomorphology in central Australia', *Journal of Arid Environments*, vol. 49, pp. 653-669.

Veth, P.M. 1993, *Islands in the Interior: the dynamics of prehistoric adaptations within the arid zone of Australia*, International Monographs in Prehistory, Michigan.

Wainwright, P., Tunn, Y., Gibson, D. & Cameron, J. 2002, *Wetland Mapping in Channel Country Bioregion, South Australia*, Department for Environment & Heritage, South Australia, (www.environment.sa.gov.au/biodiversity/pdfs/wetlands/channel_country_mapping.pdf).

Watson, P.L. 1983, 'This Precious Foliage': a study of the Aboriginal psycho-active drug pituri', *Oceania Monograph 26* (UQ Honours Thesis).

Watson, P.L. 1998, *Frontier Lands & Pioneer Legends: how pastoralists gained Karuwali land*, Allen & Unwin, St Leonards.

White, I.A. 2001, *With Reference to the Channel Country*, Queensland Department of Primary Industries, Brisbane.

White, M.E. 1994, *After the Greening: the Browning of Australia*, Kangaroo Press Pty Ltd, Kenthurst.

White, M. 2002, *The Cooper Creek Turtle Persisting Under Pressure: a study in arid Australia*, Honours Thesis, University of Canberra.

White, P. 1960: *Voss*. Penguin, Harmondsworth.

Williams, W.D. 1990, 'The Limnology of Lake Eyre', in eds M.J. Tyler, C.R. Twidale, M. Davies & C.B. Wells, *Natural History of the North-East Deserts*, Royal Society of South Australia, Adelaide.

Wilson, G., Knight, A. & Liddle, L. 2004, ‘Increasing the numbers of wildlife preferred by Aboriginal communities in the Anangu Pitjantjatjara Lands, Australia’, *Game and Wildlife Science*, vol.21, no.4, pp.687-695.

Winnecke, C. 1884, ‘Mr Winnecke’s explorations during 1883 – Diary of Northern Exploration Party under the leadership of Mr Chas. Winnecke’, SA Parliamentary Papers.

APPENDICES

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Appendix 3: Inventory of Permanent Waterholes in Cooper Catchment

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Appendix 7: Inventory of Rockholes in Study Area

Appendix 8: Inventory of Non-GAB Springs in Study Area

Appendix 1: List of Informants

Name	Position	Address	Relevant Waterbodies	Catchment	Date/s Consulted	Method	Knowledge History
Graham Moffatt	Grazier (Camoola Park)	Longreach	Upper Thomson (Longreach-Muttaburra)	Cooper	24/07/2008, 17/08/2008	Phone + visit	Grandfather settled Camoola Park in 1898; Graham has lived there all his life
Jenny Milson	Scientist, DPI&F	Longreach	Bogewong area	Cooper	25/07/2008	Visit	Grew up on Bogewong + very good local knowledge
Llyod Walker	Retired grazier (Rio/Strathmore)	Longreach	Rio, Garden Hole (Strathmore) & Longreach WHs	Cooper	26/07/2008	Visit	In district for about 70 years and owned numerous properties
Joe Herrod	Grazier (Elba)	Torrens Creek	Upper Torrens Creek	Cooper	28/07/2008	Phone	Has been on Elba since 1965
Doug Langdon	Retired grazier (Angora Park)	Muttaburra	Upper Thomson and lower Cornish Creek	Cooper	28/07/2008	Phone	Angora Park in family for generations; grandfather overseer on Mt Cornish; family connection with district back to 1880
Angus Cameron	Grazier (Lillyarea)	Aramac	Cornish and Slashers Creeks	Cooper	28/07/2008; 28/08/2008	Phone + mail out	Family has been on property for 76 years
Maree Rich	Conservation Officer	Longreach	National Parks in western region	Cooper; Diamantina	1/08/2008	Visit	Has worked on Parks in region for past 8 years
Justin Costelloe	Research Fellow, University of Melbourne	Melbourne	Major refugia along stretches of Thomson, Cooper & Diamantina	Cooper, Diamantina, Warrego	28/07/2008	Phone and email	ARIDFLO work over past couple of years
Peter & Elizabeth Clarke	Leander	Longreach	Darr River waterholes	Cooper	4/08/2008	Phone	Has been on Leander since 1950s
Penny Button	Grazier (Crossmoor)	Longreach	Crossmoor and Welford waterholes	Cooper	4/08/2008	Phone + visit	On Crossmoor for 15 years (1993-2008); prior to that on Welford for 22 years (1971-1993)
Lance Thompson	Powella	Aramac	Waterholes on Powella (Aramac Creek)	Cooper	5/08/2008; 30/10/2008	Phone	On Powella 8 years, but through very dry period
Don Rowlands	Ranger, QPWS	Birdsville	Georgina (Birdsville to Glengyle) and Diamantina (Birdsville to Diamantina Lakes)	Diamantina, Georgina	5/08/2008	Visit	Lived in Birdsville 60 years (all his life)

Mark Kleinschmidt	DCQ	Longreach	Tonkoro, Koroit, Westerton and surrounding district	Cooper; Diamantina	5/08/2008	Visit	Grew up on Westerton; mustered on a number of properties; owned Koroit for a time
Simon & Christine Campbell	Norwood	Blackall	Norwood and Tarves waterholes, upper Barcoo (near Blackall)	Cooper	6/08/2008	Phone + mail out	Lived on Tarves; moved to Norwood in 1986
Joyce Rogers	Toobrack	Longreach	Holes on Toobrack on Thomson River and Katherine Creek; also Maneroo waterholes	Cooper	7/08/2008	Phone	Lived on Toobrack for 50+ years
Peter Whip	Grazier (Bandon Grove & Weeumbah)	Longreach	Holes on Weeumbah and Bandon Grove	Cooper	7/08/2008	Phone	On Bandon Grove/Weeumbah since 2000, including very dry time in 2006
Duncan Emmott	Grazier (Bulloo/Whitehill; grew up on Noonbah)	Longreach	Glendulloch to Iandra section of Thomson; Noonbah/Waterloo holes	Cooper	7/08/2008	Phone	Grew up on Noonbah/Waterloo; has been on Whitehill/Bulloo since 1991
Bruce Emmott	Retired grazier (Noonbah)	Longreach	Vergemont/Thomson waterholes in Noonbah/Waterloo area	Cooper	12/08/2008	Visit	Mother moved to Noonbah/Lochern in 1902; lived on Noonbah all his life until 7 years ago (1920-2000)
Fiona Russell	Grazier (Swan Hill)	Blackall	Swan Hill waterhole	Cooper	7/08/2008	Phone	Father-in-law (Terry) - 77 years of information
Chris Bailey	Local grazier (4 Mile Paddock)	Isisford	Isisford district, from 12 Mile down to about Gydia Park	Cooper	7/08/2008	Phone	Lived in Isisford all his life (57 years) + talked to many older locals about the river
Wayne Hooper	Grazier (West End)	Isisford	From Isisford to 30 Mile WH	Cooper	7/08/2008	Phone	Lived on river all his life (61 years)
Joe Owens	Grazier (Gydia Park)	Isisford	From Isisford to Smith's Lagoon	Cooper	13/08/2008	Visit	Family has been on Gydia Park since 1898; Joe has lived there all his life
Andy Dexter	Grazier (Avington)	Blackall	Avington WH (only significant WH on property)	Cooper	8/08/2008	Phone	On property 10 years, but knows history of Avington WH since settlement
Anita (& Jim) Turner	Graziers (Coolagh)	Blackall	Coolagh WH + smaller holes on Coolagh	Cooper	8/08/2008	Phone	Jim grew up on property (2 generations of knowledge about WHs =>60 years)
Kay (& Max) Albrand	Graziers (Wahroonga)	Isisford	30 Mile + other holes on Wahroonga	Cooper	8/08/2008	Phone	On property for 30 years

Desiree Jackson	Grazier (Goon Goon) & DPI Beef Extension Officer	Longreach	Goon Goon Waterholes	Cooper	5/08/2008	Email	Only on property for a few years, but during very dry time in 2003 when river didn't run and there was no rain
Ted Fitzgerald	Grazier (Carella)	Longreach	Waterholes on Carella and surrounding area	Cooper	8/08/2008; 24/11/2008	Phone	Wife's family property – cumulative knowledge stretches back about 80 years
Ken & Margie Ballinger	Graziers (Sedan)	Jundah	Sedan waterholes, lower Barcoo	Cooper	12/08/2008	Visit	On Sedan for about 50 years
John Rickertt	Ex-manager (AA Company)	Beerwah	Waterholes on Nappa Merrie and South Galway + some knowledge of surrounding districts	Cooper	11/08/2008; 20/08/2008; 24/11/2008	Phone + mail out	Managed Nappa Merrie for 14 years (1977-1990), then South Galway for 10 years (1995-2005)
Kate Deane	3/93 Crane Street	Longreach	Longreach-Muttaburra reach of Thomson River, especially Bimbah and Goodberry Hills	Cooper	13/08/2008	Visit	Great-grandfather settled Mount Cornish in 1878; lived on Bimerah/Goodberry Hills from 1950-2000
Bill Scott	Georgina Pastoral Company (128 Ibis Street)	Longreach	Tanbar/Mt Howitt; broad knowledge Keeroongooloo	Cooper	26/08/2008	Visit	Managed Tanbar from 1968-1998; Mount Howitt included from 1984
Laddie and Alison Milson	Graziers (Springvale, Bogewong, Somerset)	Longreach	Bogewong/Belmore on Thomson; Springvale and northern section of Diamantina Lakes on Diamantina	Cooper; Diamantina	13/08/2008	Visit	Laddie grew up on Springvale (b.1923) and lived there until 1955; on Bogewong from mid-1950s to 2000
Sam Coxon	Kateroy	Longreach	Waterholes from Longreach to Glendulloch	Cooper	12/08/2008	Visit	Family been on Kateroy for 126 years; Sam has lived there all his life
Doreen Pitman	Longreach information centre + grazier (Paradise)	Jundah	Jundah town waterhole	Cooper	14/08/2008	Phone	Has lived in Jundah area for about 50 years; parents also local residents and interested in history of area
Ray Wilson	Moyen	Jundah	Moyen waterholes	Cooper	25/08/2008	Phone + mail out	Has been on Moyen for about 20 years
Angus Emmott	Noonbah	Longreach	Waterholes on Noonbah/Waterloo/Lochern on Vergemont and Thomson	Cooper	15/08/2008	Visit	Has lived on Noonbah all his life (about 40 years memory)

Ian Duncan	Ex-manager (Isis Downs)	Longreach	Waterholes on Isis Downs	Cooper	22/08/2008	Visit	Manager of Isis Downs from 1987 to 2004
Harry George	Retired grazier (Glenvalley/ Romula/ Prarie/ Bonnie Doon)	Longreach	Waterholes on lower Thomson and Barcoo area	Cooper	15/08/2008	Visit	
Harry Glasson	Grazier (Greenlaw)	Yaraka	Waterholes from Smith Lagoon to Wandsworth/Mt Marlow	Cooper	14/08/2008; 16/09/2008; 26/02/2009	Phone + mail out	In area since early 1960s; lived on Mt Marlow from 1958-1979; currently lives at Greenlaw; very good local knowledge
Alan Hubbard	Grazier (Galway Downs)	Windorah	Waterholes on Galway Downs (Thomson/Cooper and Whitula Creek)	Cooper	15/08/2008; 18/08/2008	Phone + fax	Has owned and lived on Galway Downs for 12 years (1996-present)
Ian Groves	Haughton Vale	Jundah	Waterholes on Haughton Vale and Coniston (at junction of Thomson and Barcoo Rivers)	Cooper	19/08/2008; 23/09/22008	Phone + mail out	Has owned Haughton Vale for 30 years (1978-2008); brother on neighbouring Coniston
John Ferguson	Ex-manager (Durham Downs)	Cambooya	Durham Downs waterholes; also waterholes on Durrie	Cooper; Diamantina	18/08/2008; 25/08/2008; 23/10/2008	Phone + mail out	On Durham from 1975-2007; also lived on Durrie for 15 years in 1960s and early-1970s
David Smith	Owner (Hammond Downs)	Windorah	Hammond Downs & Ethabuka waterholes	Cooper, Georgina	17/09/2008; 02/10/2008	Phone + mail out	Have been on Hammond Downs for 10 years; family on Ethabuka for many years before it was bought by Bush Heritage
Bob Morrish	Grazier (Springfield)	Quilpie	Kyabra Creek, from Tenham to Kyabra	Cooper	19/08/2008; 28/08/2008	Phone + mail out	On Springfield for 30 years
Ian Lilburn	Manager (Thylungra)	Quilpie	Upper Kyabra Creek waterholes	Cooper	21/08/2008	Phone	On Thylungra for 23 years (1985-present), including very dry time in 2002-2003
Sandra Muir	Owner (Elderslie)	Winton	Conn Hole and smaller holes in Elderslie area	Diamantina	20/08/2008	Phone	On Elderslie off-and-on since 1954
Bill & Rhondda Alexander	Ex-manager (Marion Downs & Coorabulka)	Curramundi	Waterholes on Marion Downs and Coorabulka	Georgina	20/08/2008; 15/09/2008	Phone + mail out	On Coorabulka from 1964-1971; Marion Downs from 1971-2002
Trevor White	Manager (Kamaran Downs)	Bedourie	Waterholes on Kamaran Downs (Mulligan River and Eyre Creek)	Georgina	20/08/2008	Phone + mail out	On Kamaran Downs since 1986(?)

Sharon Roberts (Bill Pegler)	Owner (Bodella)	Eromanga	Kyabra Creek waterhole on Bodalla	Cooper	21/08/2008	Phone	Bill's family in area since 1940s
Bob Young	Manager (Brighton Downs)	Winton	Waterholes in Brighton Downs area	Cooper	21/08/2008	Phone + email	On Brighton Downs for 20 years
Alistair Malone	Manager (Coorabulka)	via Boulia	Waterholes on Coorabulka (Georgina River + a couple on Eyre Creek and Pigeongah Creek)	Georgina	21/08/2008;	Phone + mail out	Manager of Coorabulka from 2001 to present, through a very dry time
Lyle Morton	Owner (Roseberth)	Athol	Waterholes along Diamantina from Pandie Pandie to Mooraberrie	Diamantina	21/08/2008; 06/10/2008	Phone + mail out	84 years old, and was born and bred on Roseberth
Rodney Betts	Owner (Orientos)	Thargomindah	Waterholes in Orientos area on Wilson River (including bottom of Nappa Merrie and western section of Naryilco)	Cooper	21/08/2008	Phone	Family has been on Orientos since 1942; Rodney has lived there all his life
Garth Tulley	Manager (Cluny)	Bedourie	Waterholes on Cluny	Georgina	21/08/2008; 23/08/2008	Phone + mail out	Has lived most of his life on Cluny; father managed property from 1958
Ted Brown	Ex-manager (Naryilco); now on Omricon	Tibooburra	Waterholes on Naryilco	Cooper	23/09/2008	Phone	Managed Naryilco for 30 years (1977-2007)
Rob Jansen	Manager (Marion Downs)	Boulia	Waterholes on Marion Downs; also Orient/Bulloo Dows waterholes	Georgina, Bulloo	26/08/2008	Visit	On Marion Downs from 2002 to present; grew up and first worked on Rocklands; managed Bulloo Downs 1985-1988, and Orient from 1991-2001
John Bryant	Manager (Roxborough Downs)	Mt Isa	Waterholes on Roxborough Downs	Georgina	25/08/2008	Phone	Managed Roxborough Downs 1995-1997 + 2001 to present (including a very dry time in 2007/08 when river didn't run)
Geoff Schrader	Manager (Sandringham)	Bedourie	Waterholes on Sandringham (Mulligan River and Eyre Creek)	Georgina	22/08/2008	Phone	On Sandringham for 30 years (late 1970s to present)
John & Claire Steele	Owners (Kyabra)	Quilpie	Waterholes in Kyabra area, on Kyabra Creek	Cooper	25/08/2008; 09/01/2009	Phone + mail out	Family has owned Yapunyah since 1960 and Kyabra since 1986; John has knowledge going back to the early 1980s
Steve Bryce	Manager (Glenormiston)	Mt Isa	Waterholes on Glenormiston	Georgina	25/08/2008; 02/10/2008	Phone + mail	On Glenormiston for 7 years

						out	
Bob McDonald	Owner (Mt Windsor, Verdun Valley, Brightlands, Chatsworth, Devencourt, Stradbroke)	Cloncurry	Waterholes on Mt Windsor & Verdun Valley (Diamantina) + rockholes and waterholes from Cloncurry to Boulia	Diamantina	27/08/2008; 12/01/2009	Phone + mail out	Owned Mt Windsor since 1969
Waddy & Chris Campbell	Managers (Mt Windsor/Verdun Valley)	Winton	Waterholes on Mt Windsor (Mayne River), Verdun Valley/Verdun East (Diamantina/ Mackunda Creek) + rockholes in area	Diamantina	29/10/2008; 22/04/2009	Phone + visit	Lived on Verdun Valley since 1991; moved to Mt Windsor five years ago
Brian Tully	Owner (Tenham)	Quilpie	Waterholes in Tenham area (Kyabra Creek)	Cooper	28/08/2008	Phone	Has lived on Tenham since he left school in 1963
Colin Tully	Ex-manager (Diamantina Lakes)	Oakey	Waterholes on Diamantina Lakes	Diamantina	29/08/2008; 06/10/2008	Phone + mail out	Lived on Diamantina Lakes from 1958 to early 1960s, but oversaw its management from Cluny until 1991
John Ahern	Owner (Maylands)	Longreach	Waterholes on Maylands (Cornish Creek)	Cooper	28/08/2008	Phone	Lived on Maylands from 1949; now lives in Longreach, but son manages Maylands
Anne Ballinger	Owner (Stockholm)	Muttaburra	Waterholes in Stockholm area (Cornish Creek)	Cooper	28/08/2008	Phone	Has been on Stockholm for 20 years
Bill Ferguson	Ex-owner (Politic)	Barcaldine	Waterholes on Aramac Creek	Cooper	28/08/2008	Phone	Family owned Politic for 62 years (1945-2007)
John Kendall	Owner (Birricannia)	Prairie	Waterholes on Birricannia (Tower Hill Creek)	Cooper	28/08/2008	Phone + mail out	Family has had Biricannia for 100 years; John has lived there all his life (30-40 years?)
Loch Harrison	Owner (Ashton/Curragilla)	Prairie	Waterholes on Curragilla/Ashton (Tower Hill Creek)	Cooper	28/08/2008	Phone	Has been on Ashton for 30 years (bought Curragilla 22 years ago)
Bill Graham	Owner (Tijuana)	Muttaburra	Waterholes on Tijuana (Cornish Creek)	Cooper	28/08/2008	Phone + mail out	Has been on Tijuana for 43 years

Bernie Dickson	Owner (The Lake)	Aramac	Lake Dunn and waterholes in the area	Cooper	28/08/2008	Phone	Memory of Lake Dunn and waterholes spanning past 50 years
Dan Hoch	Acting manager (The Springs)	Aramac	Bullock Creek waterholes and Lake Huffer	Cooper	28/08/2008	Phone	Looking after place for Stewie Allan, but grew up in area
Roger & Debbie Oldfield	Owners (Currawilla)	Windorah	Waterholes on Currawilla (Farrars Creek)	Diamantina	29/08/2008; 23/09/2008	Phone + mail out	Owned Currawilla since 1981; lived there permanently since 1989
Chook Kath	Manager (Mt Leonard)	Windorah	Waterholes in Mt Leonard area	Diamantina	29/08/2008; 02/10/2008	Phone + mail out	Manager of Mt Leonard since 2002; association with area going back to 1989
Tony Rayner	Owner (Vera Park); Deputy DG, DPI	Longreach	Waterholes on Vera Park	Cooper	15/09/2008	Email + visit	Tony has owned Vera Park since 1993
Peter McRae	Zoologist, Environmental Protection Agency	Charleville	Waterhole on Astrebla Downs (Mooradonka)	Diamantina	5/08/2008	Phone	Has been working on Astrebla Downs for about 20 years
Earle & Isabel	Ex-owners (Lorna Downs)	Witta	Waterholes on Lorna Downs (Hamilton River)	Georgina	16/09/2008	Phone	Lived on Lorna Downs for nearly 40 years (1960-1995)
Shane McGlintchy	Owner (Bodalia)	Boulia	Waterholes in Boulia area on Bourke & Georgina River	Georgina	17/09/2008	Phone	Lived in area for 60 years
Mark & Pat Fennell	Ray White Rural	Mt Isa	Waterholes on upper Georgina, from NT border to Glenormiston	Georgina	17/09/2008; 05/11/2008	Phone + mail out + visit	Grew up on Verdun Valley (Diamantina); worked on then owned numerous properties along the Georgina, including Linda Downs and Roxborough Downs for 40 years (1955-1995)
Ruby Saltmere	3 Morrison Street	Camooweal	Waterholes in Camooweal area (mostly on Rocklands)	Georgina	17/09/2008; 06/11/2008	Phone + visit	Has been in Camooweal all her life; worked in station camps around the area from 1940s onwards
David Brook	Adelaide Street	Birdsville	Waterholes on lower Georgina (Kamaran Downs, Adria Downs, Alton Downs, Cordillo Downs)	Georgina	17/09/2008; 24/10/2008	Phone + mail out	Family has owned Adria Downs since 1939; bought Kamaran Downs in 1975 and Cordillo Downs in 1981; interest in Alton Downs since 1981
Don Rayment	Manager (Adria Downs)	Birdsville	Waterholes on Adria Downs	Georgina	17/09/2008	Mail out	Has been managing Adria Downs for past three years
Charles Elliot	Owner (Warra)	Boulia	Bulla Bulla Waterhole (Hamilton River)	Georgina	22/09/2008	Phone	Family has been on Warra since 1950s

Robert Banning	Owner (Jarvisfield)	Winton	Waterholes along Diamantina from Jarvisfield to Cork	Diamantina	22/09/2008; 03/11/2008	Phone + mail out + visit!!	Family has been on Cork for three generations; Robert has lived there all his life
Peewee Clarke	Ex-manager (Glengyle)	Toowoomba	Waterholes on Glengyle	Georgina	16/09/2008; 07/10/2008	Phone + visit	Managed Glengyle for 30 years (1970-2001)
Maree & Graham Morton	Managers (Innamincka Station)	Innamincka	Waterholes on Innamincka Station	Cooper	23/09/2008; 14/11/2008; 2/12/2008	Phone + mail out	Have been on Innamincka Station for 16 years
Craig Lasker	Manager (Morney Plains)	Windorah	Waterholes on Morney, Mooraberrie and Cuddapan	Diamantina	23/09/2008; 20/11/2008	Phone + mail out	Has been on Morney Plains since 2000 (including very dry time in 2002); lived at Mooraberrie for a year prior to that
Janet (& Anthony) Brook	Managers (Cordillo Downs)	Birdsville	Waterholes on Cordillo Downs	Diamantina	29/09/2008	Phone	Have lived on Cordillo Downs for about 8 years; Brook family has owned property since 1981
Andrew Kingston	Senior Ranger (Western Rivers)	Longreach	Waterholes on Moorinya NP (Bullock Creek)	Cooper	29/09/2008	Visit	Was on Moorinya for two years
Michael Butler	Owner (Athol)	Blackall	Waterholes on Athol (Ravensborne Creek)	Cooper	29/09/2008	Phone + mail out	Have been on Athol for 8 years (2000-2008), including during an extremely dry time in 2002-03
Lynda Baker	Owner (Moorlands)	Blackall	Waterholes on Moorlands (Ravensborne Creek + one on Barcoo)	Cooper	29/09/2008; 23/10/2008	Phone + mail out	Property has been in family for years; Linda and Peter have lived there since 2001, including an extremely dry time in 2002-03
Owen Stockwell	Owner (Inveress)	Blackall	Waterholes on Malvern Hills (Ravensborne & Wooloorah Creeks	Cooper	29/09/2008	Phone	On Malvern Hills for 10 years (1996-2006), including during very dry period
Robert Teague	Ex-manager (Nockatunga)	Scone, NSW	Waterholes on Nockatunga (Wilson River)	Cooper	30/09/2008; 21/10/2008	Phone + mail out	Managed Nockatunga for 7 years (2000-2007), including for driest year on record (2002; 52mm)
Anthony & Deb Desreaux	Managers (Monkira)	Mt Isa	Waterholes on Monkira (Diamantina River)	Diamantina	30/09/2008; 22/10/2008	Phone + mail out	Have managed Monkira (NAPCO property) since 2002
Bruce Rayment	Owner (Connemara, Onoto & Kurran)	Connemara, Longreach	Waterholes on Connemara, Onoto & Kurran (Farrars Creek + tributaries)	Diamantina	30/09/2008	Phone + visit	Has lived in area all his life (on Connemarra for a year); family has been in area for three generations

Peter & Ann Whiteman and Tony Stevenson	Manager (Mt Margaret/Belalie); Tony works on property	Quilpie	Waterholes on upper Wilson River and tributaries	Cooper	2/10/2008; 3/12/2008	Phone + mail out	Peter and Ann have been there for a year, but Tony has been on Mt Margaret for 14 years + in the district for many years
Geoff Morton	Manager/owner (Roseberth)	Birdsville	Waterholes on Roseberth	Diamantina	16/10/2008; 27/10/2008	Phone + mail out	Has lived on Roseberth for 50 years
Sharon Oldfield	Owner (Cowarie)	Adelaide	Waterholes on Cowarie	Diamantina	16/10/2008; 30/10/2008	Phone + mail out	Lived on Cowarie since 1986; managed since early 1990s; now lives in Adelaide
Mark (& Tess) McLaren	Managers (Kalamurina, AWC)	via Mungerannie	Waterholes on Kalamurina	Diamantina	17/10/2008	Phone + mail out	Has only been on Kalamurina since July 2007, but doing research/reading into native wells and waterholes etc
Peter McNiven	Ex-manager (Davenport Downs/Palparara)	Colwell, McKinlay	Waterholes on Davenport Downs and Palparara (Diamantina and Farrars Creek)	Diamantina	17/10/2008; 04/11/2008	Phone + mail out + visit	Managed Davenport Downs from 1970s to 1985, including a very dry period
Ross McPherson	Owner (Bexley)	Longreach	Sandstone springs/seeps on Bexley	Cooper	17/10/2008	Phone	Has lived on Bexley since 1983
Paul Smith	Owner (Spring Vale); also Smith Brothers Hardware	Longreach	Sandstone springs/seeps on Spring Vale	Cooper	17/10/2008	Phone	Has owned Spring Vale for about 10 years
Chris Mitchell	Acting Planner, EPA	Longreach	Waterholes on Diamantina Lakes	Diamantina	17/10/2008	Visit	Ranger on Diamantina Lakes from 1991-2004?
David Morton	Owner (Pandie Pandie)	Birdsville	Waterholes on Pandie Pandie	Diamantina	21/10/2008; 30/10/2008	Phone + mail out	Has lived on Pandie Pandie all his life (about 50 years)
Steve & Jeena Kramer	Manager (Glengyle)	Bedourie	Major waterholes on Glengyle	Georgina	27/10/2008	Phone	Only on Glengyle for a year, but during an almost-unprecedented dry time
George Macqueen	Ex-manager (Monkira)	Wollongbar, NSW	Waterholes on Monkira (Diamantina River)	Diamantina	21/10/2008; 28/10/2008	Phone + mail out	Managed Monkira from 1961-76, including during the 1960s drought
Jeff Swanson	Ex-owner (Budgerygar)	Bexhill, Tambo	Powell's Creek area (Hell Hole, Budgerygar,	Cooper	22/10/2008; 15/12/2008	Phone + mail	On Budgerygar for 44 years (1960-2004)

			Jedburgh)			out	
Billy Rice	Owner (Prarie Vale)	Torrens Creek	Waterholes on Prairie Vale (Prairie Creek)	Cooper	22/10/2008	Phone	Family has had property for 85 years; Billy has been there for 60-odd
Denise & Steve Hawe and Shane	Owners (Spring Plains)	Longreach	Ex-springs and rockholes on Spring Plains	Cooper	25/10/2008	Visit	Have been on property for four years; very keen interest in history of property etc
Ralph & Beverley Ray	Owner (Aberfoyle)	Mirtna, Charters Towers	Waterholes on Aberfoyle (Torrens Creek)	Cooper	27/10/2008; 28/10/2008	Phone + email	Has owned Aberfoyle since 1991, including during very dry years in early 1990s
Sue (& Shorty) Cuppitt	Ranger (Diamantina Catchment)	Bladensburg National Park, Winton	Waterholes and rockholes on Bladensburg	Diamantina	28/10/2008	Phone	Grew up on Bladensburg; between Sue and Shorty they have always had an association with the area
Chris & David Capel	Owners (Evesham)	Longreach	Waterholes on Evesham (Maneroo Creek)	Cooper	28/10/2008	Phone + email	Has been in David's family for generations - knowledge of what has happened on property dating back to early 1970s
Gavin Miller	Manager (Rocklands)	Camooweal	Waterholes on Rocklands	Georgina	05-06/11/2008	Visit	Has managed Rocklands for 7yrs, but grew up on property and has worked there off and on at various times
Roley & Brigid Hughes	Owners (Autumn Vale)	Thargomindah	Waterholes on Autumn Vale (Bulloo) and Retreat (Barcoo)	Bulloo; Cooper	21/11/2008; 27/01/2009	Phone + mail out	Managed Retreat from 1979-1983, including very dry period in eary 1980s; has lived on Autumn Vale for 25 years
Evan Acton	Owner (Barkly Downs, Millungera); Acton Super Beef	Millungera Station, Julia Creek	Waterholes on Barkly Downs (Georgina, Buckley and Templeton Rivers) and Millungera (Flinders & Saxby Rivers and Mundjuro Creek	Georgina + Gulf Rivers	24/11/2008; 23/02/2009	Phone	Has been on Millungera for 24 years; owned Barkly Downs since September 2004, but has discussed waterholes with 'old-timers' in area
Henry Burke	Manager (Brunette Downs) + regional manager for AA properties including Headingly	Brunette Downs, Tablelands, Northern Territory	Waterholes on Headingly & Carandotta	Georgina	25/11/2008	Phone	Started working on Headingly in 1986; returned to the Territory in 2002, but has remained as overseer of AA's northern properties, including Headingly and Carandotta

Des & Helen Boyle	Ex-owners (Cambeela)	Cotswold Hills	Waterholes on Cambeela (Cadell Creek and Diamantina River)	Diamantina	25/11/2008; 01/12/2008	Phone + mail out	Lived on Cambeela from 1977 to 2001
Harry George (junior)	Owner (Glen Valley)	Jundah	Waterholes on Thomson River south of Jundah (Braidwood and Longford)	Cooper	2/12/2008; 14/12/2008	Phone + mail out	Has lived in area all his life (about 40 years)
Gary Muehling	DPI&F Fisheries	Longreach	Good general knowledge of major waterholes across western Queensland	LEB rivers + Bulloo & Paroo	15/07/2008; 2/12/2008	Visit	Has done Fisheries Patrols for past few years, so good general knowledge of major waterholes
Steve Hagan	AA Manager, Headingly & Carandotta	Mt Isa	Waterholes on Headingly & Carandotta	Georgina	8/01/2009	Phone	Has managed Headingly/Carandotta for past 6 years (2002-2008), including a very dry period
Al & Judy Warby	Owners (Raymore/Wheeo)	Quilpie	Waterholes on Raymore and Wheeo (Kyabra Creek)	Cooper	9/01/2009; 05/02/2009	Phone + mail out	Have owned Raymore/Wheeo for 8 years and lived there for five, including very dry time in 2002/03
John Jones	Manager (Chatsworth)	Boulia	Waterholes and rockholes on Chatsworth	Georgina	9/01/2009	Phone	Has been managing Chatsworth (owner is Bob McDonald) for 30 years
Mike McNamara	Owner (Mt Guide)	Mt Isa	Waterholes and rockholes on Mt Guide	Georgina	9/01/2009	Phone	Has been on Mt Guide for 18 years
Bob & Noela McConarchy	Owner (Ashover)	Duchess	Waterholes and rockholes on Ashover	Georgina	9/01/2009	Phone	Bob has been on Ashover all his life; spoke to his wife, who has lived there since 1979
Ron Cundy	Manager's brother-in-law (Malbonvale)	Mt Isa	Waterholes and rockholes on Malbonvale	Georgina	12/01/2009	Phone	Has been working in the area for years
Luke Daniels	Manager (Ardmore);Daniels Pastoral Company (also owns Toolebuc)	Cloncurry	Waterholes and rockholes on Ardmore and Toolebuc	Georgina	12/01/2009	Phone	Has been on Ardmore for 5 years
Max Brogan	Owner (Pathungra)	Pathungra Proprietors, Boulia	Waterholes and rockholes on Pathungra (Hamilton River)	Georgina	12/01/2009	Phone	Has been on Pathungra for 10 years
Brett Elliot	Owner (Belfast)	Winton	Waterholes on upper Diamantina + general knowledge of rockholes in	Diamantina	12/01/2009	Phone	Has lived on Belfast all his life + has been in family for generations

			area				
Sue Pegler	Owner (Alni)	Winton	Waterholes on Alni (Diamantina River)	Diamantina	13/01/2009	Phone	Has been on Alni for some years; only semi-permanent hole (<12 months) has been dug out and rock wall put up
Michelle Roberts	Owner (Fermoy)	Winton	Waterholes and rockholes on Fermoy (upper Vergemont)	Cooper	13/01/2009; 02/02/2009	Phone + mail out	Have been on Fermoy for 8 (mostly dry) years
John Hamilton	Owner (Denton)	Longreach	Waterholes on Denton (Maneroo Creek)	Cooper	13/01/2009	Phone	Has been on Denton for 6 years
Frank Blackett	Owner (Alderley)	Boulia	Waterholes on Alderley (Cottonbush Creek)	Georgina	14/01/2009	Phone	Has lived on Alderley all his life
Will Hacon	Hacon & Sons (own Buckingham Downs)	Granada Station, Cloncurry	Waterholes and rockholes on Buckingham Downs (Sulieman Creek, Wills River)	Georgina	14/01/2009	Phone	Hacon & Sons have owned Buckingham Downs since 2000, plus have waterhole knowledge of previous manager
Ron Power	Owner (Bushy Park)	Mt Isa	Waterholes and rockholes on Bushy Park	Georgina	14/01/2009	Phone	Family has owned Bushy Park since 1927; Ron has lived there permanently since 1999
D Grimshaw	Owner (Windsor Park & Digby Peaks)	Boulia	Waterholes on Windsor Park/Digby Peaks (Burke & Wills Rivers + Middle Creek)	Georgina	14/01/2009	Phone	Has lived on Windsor Park since about 1970
Ian Allan	Owner (Highlands)	Absentee landowner	Rockholes on Highlands	Cooper	14/01/2009	Phone	Has owned Highlands for 20 years, but does not live there
Kylie McAuliffe	Owner (Llorac)	Muttaburra	Waterholes on Llorac (Landsborough River)	Cooper	14/01/2009	Phone	No waterholes of any permanence at all along this section of Landsborough Channels
Duncan Lawton	Owner (Brackenburgh)	Winton	Waterholes and rockholes on Brackenburgh (upper Diamantina Catchment)	Diamantina	14/01/2009; 12/02/2009	Phone + mail out	Has been 'riding around in the hills' around Brackenburgh since the 1960s
Keith Gordon	Owner (El Kantara)	Longreach	Waterholes and springs on El Kantara, Campsie & Parkdale (Katherine Creek)	Cooper	15/01/2009	Phone	Has lived on El Kantara all his life

Peter Britton	Owner (Mt Landsborough/Moutain View)	Mt Landsborough, Winton	Rockholes on Mt Landsborough	Diamantina	21/01/2009	Phone + mail out	Has owned Moutain View since 1996; Mt Landsborough since 2002
Mal Lorimer	Principal Conservation Officer, EPA	Townsville	Desert Uplands lakes and associated waterholes	Cooper	29/01/2009	Phone	Has been working in the Desert Uplands for the past 15 years
Tina Hoch	Owner (Lake Huffer)	Aramac	Lake Huffer	Cooper	29/01/2009	Phone	Has lived on Lake Huffer since 1998
Bob Marshall	Owner (Swanlea/Blandfield)	18 Gordon Street, Aramac	Lakes Barcoorah and Galilee + 4 Mile Waterhole (Reedy Creek)	Cooper	29/01/2009	Phone	Has owned Swanlea for 36 years
John Murray	Owner (Uanda)	Prairie	Waterholes on Prairie Creek in Uanda area	Cooper	30/01/2009	Phone	Family has been on Uanda for 100 years in 2011; John has lived there all his life
Sam Brown	Owner (Lammermoor)	Prairie	Waterholes on Lammermoor, Towerhill Creek	Cooper	30/01/2009	Phone	Has lived on Lammermoor for 30 years + very good knowledge of history of area
Meryl Schultz	Owner (Inveresk)	Muttaburra	Waterholes on Inveresk, Towerhill Creek	Cooper	30/01/2009	Phone	Have owned Inveresk since 2001, including some very dry years
Angus (& Mel) Logan	Helicopter pilot	NRW, Longreach (Mel)	Waterholes and rockholes on Vergemont (Vergemont Creek & tributaries; headwaters of Mayne River)	Cooper; Diamantina	3/02/2009	Visit	Angus's parents have owned Vergemont since 2000, including extremely dry years in 2001/02; Angus and Mel lived there in 2007; Angus is also a chopper pilot, so has flown over area many times
Vinnie Richardson	Owner (Leopardwood Park)	Adavale	Waterholes on Bullo Lakes, Leopardwood Park & Gilmore	Bulloo; Cooper	5/02/2009	Phone + mail out	Richardson family have been on Bulloo Lakes for three generations; Vinnie has been there all his life
Wendy Sheehan	Owner (Trinidad)	Quilpie	Rockholes and spring on Trinidad	Cooper	5/02/2009	Phone	Family has been on Trinidad for generations; Wendy grew up there and has lived there most of her life
Neil Rogers	Owner (Toobrack)	Longreach	Waterholes on Toobrack and Maneroo (Katherine and Maneroo Creeks + Darr and Thomson Rivers)	Cooper	6/02/2009	Phone + visit	Family has been on Toobrack for 111 years; Neil has been there all his life

Peter Klem	Ex-owner (Storm Hill); now Stock Routes officer, NRW Longreach	Longreach	Waterhole on 8 Mile Reserve, Thomson River (+ general knowledge of waterholes across region)	Cooper	6/02/2009	Phone	Has lived and worked on various western Qld properties; used to own Storm Hill and agisted cattle on 8 Mile Reserve during very dry period in early 1980s
Greg Bowden	Manager (Tees Brothers, Baratria/Hartree)	Baratria, Longreach	Waterholes on upper Maneroo Creek and Alice Creek on Hartree and Baratria	Cooper	12/02/2009	Phone	Has managed and lived on Baratria for 5 years, and managed Hartree for two years
Peter Magoffin	Owner (Tonkoro, Melrose, Corona)	Corona, Longreach	Waterholes and rockholes on Melrose, Corona and Tonkoro/Carcara/Goneaway	Cooper; Diamantina	17/02/2009	Visit	Tonkoro and Melrose have been in family for generations; bought Corona about 5 years ago; has been flying around area for 20yrs
Peter Russell	Caretaker/opal miner/local historian, Winton/Opalton area	Po Box 20, Winton	Major waterholes and rockholes across upper Diamantina area	Cooper; Diamantina	18/02/2009	Phone	Has been in the area for 30 years, including opal mining and caretaking for various properties
Grace (& John) Jones	Manager (Marie Downs)	Aramac	Waterholes on Torrens Creek, Marie Vale	Cooper	26/02/2009	Phone	Have been managing Marie Vale for 8 years; no reliable water in Torrens Creek on property
Cam Tindall	Owner (Darr River Downs)	Longreach	Waterholes on Darr River	Cooper	26/02/2009	Phone	Has been on Darr River Downs since 1989
Pat Saunders	Ex-owner (Manfred)	13 Ilfracombe Road, Longreach	Waterholes on Darr River	Cooper	26/02/2009	Phone	Has been observing the Darr River since 1950
Johnny Avery	Retired grazier	Post Office, Emmet	Rockholes and springs in ranges around Emmet	Cooper; Bulloo	26/02/2009; 03/03/2009	Phone + visit	Has mustered on many properties through the area for many years
John Wagstaff	Manager (Mt Enniskillen)	Blackall	Springs and waterholes on Mt Enniskillen/Kelpum (upper Barcoo tributaries)	Cooper	27/02/2009	Phone + mail out	Has been on Mt Enniskillen since the 1970s + good knowledge of history of property
Trevor Jones	Owner (Wirrilyerna)	Boulia Hotel Motel	Waterholes on lower Burke River in Boulia/Wirrilyerna district	Georgina	27/02/2009	Phone	Has lived in Boulia all his life
Sandy Kidd	Owner (Ourdel)	Windorah	Waterholes on Cooper in Windorah area, including Ourdel and Keeroongooloo	Cooper	2/03/2009; 20/03/2009	Phone + visit	Has lived on Ourdel all his life and been mustering/flying down the Cooper for decades

Chris Crafter	EPA, Longreach; ranger at Innamincka for seven years	Longreach	Waterholes on Strzelecki and Cooper Creeks	Cooper	24/04/2009	Visit	Was ranger at Innamincka for seven years until 2003; good general knowledge of both Strzlecki and Cooper systems in area
John Hughes	General Manager, CliftonHills Pastoral Co	Adelaide	Waterholes on Clifton Hills	Diamantina	22/05/2009; 29/05/2009	Phone + mail	Family has owned Clifton Hills since 1962
John Maconochie	Scientific Officer (Rangelands)	Dept Water,Land & Biodiversity, Adelaide	Broad information on location, names and permanence of waterholes on Kalamurina;	Diamantina	28/05/2009	Phone + email	Has worked in SA rangelands for many years
Mike & Patrice Elliot	Owner (Karoola)	Winton	Rockholes in ranges between Karoola and Mt Rourke, including Cathedral, Castle Hill, Boolbie and Woodstock	Diamantina	29/05/2009	Phone	Has been on Karoola for years, leases Boolbie and owns Mount Rourke, so flies over range country regularly
Stony Kane	Helicopter pilot + Middleton Hotel owner	Boulia Road, Middleton	Rockholes in ranges south of Middleton	Diamantina	29/05/2009	Phone	Has been helicopter mustering in Middleton district for many years; good broad knowledge of range country
Kelsey Neilsen	Owner (Two Rivers)	Boulia	Waterholes on Burke and Wills Rivers in Two Rivers district	Georgina	19/06/2009	Phone	Has been on Two Rivers for 20 years
Rick Britton	Owner (Goodwood) + Mayor of Boulia Shire	Boulia	Waterholes on Burke River in Boulia River	Georgina	19/06/2009	Phone	Has lived in Boulia all his life + father there before him

Appendix 2: Metadata

Dataset TITLE
Permanent and Semi-Permanent Waterbodies of the Lake Eyre Basin (Queensland and South Australia) (DRAFT)

Dataset COMPILER
J. Silcock

Dataset CUSTODIAN
Queensland Herbarium, Environmental Protection Agency

Dataset JURISIDICTION
Queensland and South Australia

Description ABSTRACT
This dataset presents information about the distribution and permanency of waterholes, springs, rockholes and lakes in the Queensland and South Australian sections of the Lake Eyre Basin. Data was collected in 2008-2009, mostly from surveys of people with long-term knowledge of certain water bodies. Wetland mapping programs in both states provided the baseline data for waterholes and lakes (EPA 2005; Wainwright *et al.* 2006), while springs data was compiled by Fensham & Fairfax (2005).

Dataset DATE
30/06/2009

Access STORED DATASET FORMAT
Polygon and point locations
PROJECTION: Universal Transverse Mercator
DATUM: GDA94

Access AVAILABLE FORMAT TYPES
Excel spreadsheet
ArcView shapefile

Dataset FIELDS/DEFINITIONS
Location
Waterholes and lakes were mapped from Landsat imagery and are represented as polygons. Springs and rockholes are represented as point locations.

Water Name
Names of waterbodies are based on local knowledge and/or topographic maps. Where these two sources are in conflict, local names take precedence and other name/s are recorded in brackets.
Water Type
Each waterbody is classified as riverine waterhole, lake, spring or rockhole (see Duguid *et al.* 2002 for definitions of these terms).

'Naturalness'
This field records whether the hydrology or permanence of a waterbody has been altered by human actions, such as dams/weirs, excavation or addition of bore water. A score of 1 indicates some form of modification, while 0 indicates no anthropogenic modifications (disturbance from grazing is not included). If a waterbody would not have met the 70% criteria prior to being excavated or modified, it is not included in the dataset.

Property
The property (or properties) where the waterhole is located is recorded from the Pastoral Holdings Access Database.

Watercourse and Catchment
Each waterbody occurs in one of four major Lake Eyre Basin Catchments: Cooper, Diamantina, Georgina or Neales Creek.

Permanency
Provides an assessment of permanency, defined as the percentage of time a waterbody contains water. This is calculated from the information gathered about water-holding capacity, frequency of drying and landscape position. Estimates of permanency vary between waterholes, depending upon accessibility (information for waterholes on major property tracks or near houses is more detailed than highly inaccessible waters such as remote rockholes), proximity to other sources of water (determines the importance of a water for pastoral use), timespan and level of available knowledge. Where waterholes have been de-silted or dammed, permanency is recorded as its current permanence (often 100% since de-silting). Other parameters (frequency of drying and months that it holds water) are also recorded as per its current status. However, 'naturalness' is given a value of 0, and its previous characteristics prior to de-silting (i.e. frequency of drying, 'natural' permanence, months that it would hold water) are recorded in the notes column.

Months
Provides an estimate of how many months a waterbody would typically hold water without some input (from local run-off or river flow).

Frequency of Drying
Records how many times a waterbody has been dry over the time of observation; ranges from 1/1 (goes dry every year) to 0/150 (has not gone dry since white settlement).

Timeframe
Records the timeframe spanned by observations or knowledge for each waterhole. This may be continuous or discontinuous, depending on the knowledge history of informants.

Years
Records the timespan (number of years) of observations or knowledge for each waterbody; ranges from 10 years to 150+ years, depending upon availability of sources.

Permanency Notes
This field contains other information relevant to the permanency of a waterbody, including frequency of flooding, landscape/catchment position, size and shape, and human use.

Informants
This field records the names of 'experts' who provided information on particular waterbodies. A separate Excel spreadsheet contains details and knowledge history of each informant, and the waterbodies for which they provided information.

Other Notes
This field contains any other notes about the waterhole, including ecological or hydrological information, Indigenous significance, explorer visits/camps, importance in early settlement, current use and human impacts.

References

Duguid, A., Barnetson, J., Clifford, B., Pavey, C., Albrecht, D., Risler, J. & McNellie, M. 2002, *Wetlands in the Arid Northern Territory: A Report to Environment Australia on the Inventory and Significance of Wetlands in the Arid Northern Territory*, Parks and Wildlife Commission of the NT, Alice Springs, (www.nt.gov.au/nreta/wildlife/nature/aridwetlands.html).

Environmental Protection Agency (EPA) 2005, *Wetland Mapping and Classification Methodology – Overall Framework: A Method to Provide Baseline Mapping and Classification for Wetlands in Queensland (Version 1.2)*, Queensland Government, Brisbane.

Fensham, R.J. & Fairfax. R.J. 2005, *Springs of Queensland – Distribution and Assessment (Version 4.0)*, Queensland Herbarium, Environmental Protection Agency, Brisbane.

Wainwright, P., Tunn, Y., Gibson, D. & Cameron, J. 2006, *Wetland Mapping, Channel Country Bioregion, South Australia*, Department of Environment and Heritage, Adelaide.

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Appendix 3: Cooper Catchment Natural Permanent Waterholes

(arranged alphabetically by watercourse then property)

WATER_NAME	PROPERTIES	WATERCOURSE	TIMEFRAME	YEARS
Yarraman Waterhole	Vera Park	Aramac Creek	15	1993-2008
Avington Waterhole	Avington	Barcoo River	140	1870-2008
Charley's Hole	Coolagh	Barcoo River	60	1950-2008
Coolagh WH	Coolagh	Barcoo River	60	1950-2008
??	Haughton Vale	Barcoo River	30	1978-2008
??	Hauhgton Vale	Barcoo River	30	1978-2008
Honan Hole	Honan Downs	Barcoo River	15	1987-2002
Jedburgh Waterhole	Jedburgh	Barcoo River	130	1880-2008
Big Bull Waterhole	Mt Marlow	Barcoo River	50	1958-2008
17 Mile Waterhole	Norwood	Barcoo River	50	1958-2008
18 Mile Waterhole	Norwood	Barcoo River	50	1958-2008
5 Mile Waterhole	Norwood	Barcoo River	50	1958-2008
12 Mile Waterhole	Oma	Barcoo River	60	1950-2008
Oma Waterhole	Oma/West End	Barcoo River	60	1950-2008
Retreat Waterhole	Retreat	Barcoo River	130	1880-2008
Shed Hole	Retreat	Barcoo River	130	1880-2008
Rosehill Waterhole	Rosehill/Welford	Barcoo River	130	1880-2008
Stony Channel	Sedan	Barcoo River	50	1960-2008
Swan Hill WH	Swan Hill	Barcoo River	77	1930-2008
30 Mile	Wahroongha	Barcoo River	100	1898-2008
Trafalga Waterhole	Welford National Park	Barcoo River	0	1870-2008
Boomerang Waterhole	Welford/Retreat	Barcoo River	130	1880-2008
Killman WH	West End	Barcoo RIver	50	1950-2008
Nooracoo Rockhole	Moorinya NP	Bullock Creek	140	1870-2008
The Dardanelles	Moorinya NP	Bullock Creek	140	1870-2008
Currareva Waterhole	Coniston/Currareva	Cooper Creek	130	1880-2008
Durham Waterhole	Durham Downs	Cooper Creek	130	1880-2007
Meringhina Waterhole	Durham Downs	Cooper Creek	130	1880-2007
Nacowlah Waterhole	Durham Downs	Cooper Creek	130	1880-2008
Nacowlah Waterhole	Durham Downs	Cooper Creek	130	1880-2008
Goonbabinna Waterhole	Durham Downs/Nappa Merrie	Cooper Creek	130	1880-2007
Currareva Waterhole	Hammond Downs/Currareva	Cooper Creek	130	1880-2008
Burke Waterhole	Innamincka Station	Cooper Creek	16	1992-2008
Cullyamnurra Waterhole	Innamincka Station	Cooper Creek	150	1860-2008
Marpoo Waterhole	Innamincka Station	Cooper Creek	16	1992-2008
Minkie Waterhole	Innamincka Station	Cooper Creek	16	1992-2008
Nappaoonie Waterhole	Innamincka Station	Cooper Creek	16	1992-2008
Queerbidie Waterhole	Innamincka Station	Cooper Creek	16	1992-2008
Tilcha Waterhole	Innamincka Station	Cooper Creek	16	1992-2008
Tilcha Waterhole	Innamincka Station	Cooper Creek	16	1992-2008
??	Keeroongooloo	Cooper Creek	60	1950-2008
??	Keeroongooloo	Cooper Creek	60	1950-2008
??	Keeroongooloo	Cooper Creek	60	1950-2008
??	Keeroongooloo	Cooper Creek	60	1950-2008
??	Keeroongooloo	Cooper Creek	60	1950-2008
Back Wallinderry WH	Keeroongooloo	Cooper Creek	60	1950-2008
Binjula Waterhole	Keeroongooloo	Cooper Creek	60	1950-2008
Birts Dip Yard Waterhole	Keeroongooloo	Cooper Creek	60	1950-2008
Burleway WH (north)	Keeroongooloo	Cooper Creek	60	1950-2008

Burleway WH (south)	Keeroongooloo	Cooper Creek	60	1950-2008
Homier Waterhole	Keeroongooloo	Cooper Creek	60	1950-2008
Homler Waterhole	Keeroongooloo	Cooper Creek	60	1950-2008
Ouimmanroo Waterhole	Keeroongooloo	Cooper Creek	60	1950-2008
Pig Channel	Keeroongooloo	Cooper Creek	60	1950-2008
Prolpirree Five Mile WH	Keeroongooloo	Cooper Creek	60	1950-2008
Tanborough Waterhole	Keeroongooloo	Cooper Creek	60	1960-2008
Unnamed	Keeroongooloo	Cooper Creek	60	1950-2008
Unnamed	Keeroongooloo	Cooper Creek	60	1950-2008
Unnamed	Keeroongooloo	Cooper Creek	60	1950-2008
Unthill Waterhole	Keeroongooloo	Cooper Creek	60	1950-2008
Wombunderry WH	Keeroongooloo	Cooper Creek	130	1880-2008
??	Mt. Howitt	Cooper Creek	14	1984-1998
Battleship Waterhole	Mt. Howitt	Cooper Creek	30	1968-1998
Brumby Waterhole	Mt. Howitt	Cooper Creek	14	1984-1998
Bullringa Waterhole	Mt. Howitt	Cooper Creek	30	1968-1998
Bulltarkaninny WH	Mt. Howitt	Cooper Creek	30	1968-1998
Dinner Camp Waterhole	Mt. Howitt	Cooper Creek	30	1968-1998
Eulolean Waterhole	Mt. Howitt	Cooper Creek	30	1968-1998
Ingellina Waterhole	Mt. Howitt	Cooper Creek	14	1984-1998
Lignum Hole	Mt. Howitt	Cooper Creek	30	1968-1998
Lost Hole	Mt. Howitt	Cooper Creek	14	1984-1998
Maroo Waterhole	Mt. Howitt	Cooper Creek	14	1984-1998
Maroo Waterhole	Mt. Howitt	Cooper Creek	14	1984-1998
Toolayana Waterhole	Mt. Howitt	Cooper Creek	14	1984-1998
Nardoo Waterhole	Mt. Howitt/Tanbar	Cooper Creek	30	1968-1998
Oven Hole	Mt. Howitt/Tanbar	Cooper Creek	30	1968-1998
Tarquoh Waterhole	Mt. Howitt/Tanbar	Cooper Creek	30	1968-1998
Tarquoh Waterhole	Mt. Howitt/Tanbar	Cooper Creek	30	1968-1998
Tinkarka Waterhole	Mt. Howitt/Tanbar	Cooper Creek	30	1968-1998
Bilpa Waterhole	Nappa Merrie	Cooper Creek	14	1977-1990
Maapoo Waterhole	Nappa Merrie	Cooper Creek	110	1990-2008
Nappa Merrie Waterhole	Nappa Merrie	Cooper Creek	110	1900-2008
Nappa Merrie Waterhole	Nappa Merrie	Cooper Creek	110	1900-2008
Nappapethera WH	Nappa Merrie	Cooper Creek	110	1990-2008
Skull Hole	Nappa Merrie	Cooper Creek	14	1977-1990
Tooroogee Waterhole	Nappa Merrie	Cooper Creek	14	1977-1990
Yantabulla Waterhole	Nappa Merrie	Cooper Creek	14	1977-1990
Mayfield (Murken) WH	Ourdel	Cooper Creek	140	1870-2008
??	South Galway	Cooper Creek	10	1995-2005
Arnings Waterhole	South Galway	Cooper Creek	10	1995-2005
Bungera Waterhole	South Galway	Cooper Creek	10	1995-2005
??	Tanbar	Cooper Creek	30	1968-1998
??	Tanbar	Cooper Creek	30	1968-1998
??	Tanbar	Cooper Creek	30	1968-1998
??	Tanbar	Cooper Creek	30	1968-1998
??	Tanbar	Cooper Creek	30	1968-1998
??	Tanbar	Cooper Creek	30	1968-1998
??	Tanbar	Cooper Creek	30	1968-1998
??	Tanbar	Cooper Creek	30	1968-1998
Curraonga Waterhole	Tanbar	Cooper Creek	130	1880-2008
Eulbertie Waterhole	Tanbar	Cooper Creek	130	1880-2008

Gilpippi Waterhole	Tanbar	Cooper Creek	30	1968-1998
Hookamurra Waterhole	Tanbar	Cooper Creek	30	1968-1998
New Yard Hole	Tanbar	Cooper Creek	30	1968-1998
Tea-tree holes	Tanbar	Cooper Creek	30	1968-2998
Tea-tree holes	Tanbar	Cooper Creek	30	1968-1998
Tea-tree holes	Tanbar	Cooper Creek	30	1968-1998
Tub Hole	Tanbar	Cooper Creek	60	1950-2008
Wirrawonga Waterhole	Tanbar	Cooper Creek	30	1968-1998
??	Tanbar/Durham Downs	Cooper Creek	32	1975-2007
Angellina Waterhole	Tanbar/Durham Downs	Cooper Creek	32	1975-2007
Tirrawarra Waterhole	Innamincka Station	Cooper Creek	150	1860-2008
Bucksleas Waterhole	Lillyarea	Cornish Creek	60	1950-2008
Alivinna Waterhole	Mt. Howitt	Curralle Creek	140	1870-2008
Darr Waterhole	Reserve/Dahra	Darr River	60	1950-2008
8 Mile Waterhole	Romula	Eight Mile Ck (Barcoo)	10	1978-1988
Bellalie Waterhole	Belalie	Ginniappa Creek	14	1994-2008
Unnamed	Vergemont	Gum Creek (Vergemont)	8	2000-2008
Unnamed	Vergemont	Gum Creek (Vergemont)	8	2000-2008
Unnamed	Vergemont	Gum Creek (Vergemont)	8	2000-2008
Unnamed	Vergemont	Gum Creek (Vergemont)	8	2000-2008
Bodella/Cumbroo WH	Bodella	Kyabra Creek	140	1868-2008
Springfield Waterhole	Springfield	Kyabra Creek	140	1870-2008
Gummomo Waterhole	Thylungra	Kyabra Creek	140	1868-2008
Yapunyah Waterhole	Bulloo Lakes	Nutting Creek	95	1914-2009
Kokana Waterhole	Bulloo Lakes	Powell Creek	90	1914-2009
Beechah Beechar WH	Gooyeah	Powell Creek	40	1970-2009
Hell Hole Waterhole 1	Hell Hole Gorge NP	Powell Creek	50	1960-2008
Old Gooyea Waterhole	Milo	Powell Creek	95	1914-2008
4 Mile Waterhole	Adelong/Reedy Creek	Reedy Creek	40	1970-2008
Hell Hole Waterhole 2	Hell Hole Gorge NP	Spencer Creek	50	1960-2008
8 Mile	8 Mile Reserve	Thomson River	30	1980-2008
Bottom 6 Mile	Bonnie Doon	Thomson River	40	1970-2008
??	Bonnie Doon	Thomson River	40	1970-2008
Braidwood Waterhole	Braidwood	Thomson River	58	1950-2008
Camoola Hole	Camoola Park	Thomson River	110	1898-2008
Carella WH	Carella	Thomson River	150	1860-2008
Carella WH, Outside Ch.	Carella	Thomson River	150	1860-2008
Dinah WH	Evengy	Thomson River	23	1979-2002
Mahoney Waterhole	Evengy	Thomson River	23	1979-2002
Turtle Waterhole	Evengy	Thomson River	23	1979-2002
Flaggy Waterhole	Glenariff	Thomson River	80	1930-2008
Goodberry/Dillulla B/w	GoodberryH/Yanburra	Thomson River	140	1880-2008
GoonGoon WH	Goon Goon	Thomson River	100	1910-2008
Little Goongoon WH	Goon Goon	Thomson River	23	1979-2002
??	Haughton Vale	Thomson River	30	1978-2008
??	Haughton Vale	Thomson River	30	1978-2008
Junction Hole	Haughton Vale	Thomson River	130	1880-2008
Mill Hole	Haughton Vale	Thomson River	30	1978-2008
Haughton's Hole	Haughton Vale/Bonnie Doon	Thomson River	130	1880-2008
Jundah Waterhole	Jundah Common	Thomson River	140	1870-2008
Kateroy Lagoon	Kateroy	Thomson River	130	1880-2008
Lochern Broadwater	Lochern National Park	Thomson River	130	1880-2008

Lochern Fish Hole	Lochern National Park	Thomson River	130	1880-2008
??	Longford	Thomson River	40	1970-2008
??	Longford	Thomson River	40	1970-2008
WHs below Scour Hole	Moyen/Galway Downs	Thomson River	40	1970-2008
WHs below Scour Hole	Moyen/Galway Downs	Thomson River	40	1970-2008
WHs below Scour Hole	Moyen/Galway Downs	Thomson River	40	1970-2008
WHs below Scour Hole	Moyen/Galway Downs	Thomson River	40	1970-2008
Woolscour Waterhole	Moyen/Galway Downs	Thomson River	120	1890-2008
Muttaburra Broadwater	Muttaburra Common	Thomson River	140	1870-2008
Jimmy's Shoe WH	Prarie	Thomson River	58	1950-2008
White's Island WH	Prarie	Thomson River	58	1950-2008
Longreach WH	Reserve	Thomson River	70	1870-2008
Longreach WH (upper)	Reserve	Thomson River	70	1870-2008
Rio WH	Rio/Strathmore	Thomson River	70	1940-2008
Waterloo Hole	Waterloo	Thomson River	130	1880-2008
Thomson R	Wuringle	Thomson River	150	1860-2008
Wuringle Waterhole	Wuringle	Thomson River	150	1860-2008
Toodooldoo Waterhole	Mt. Margaret	Tintaburra Creek	14	1994-2008
Fisheries Waterhole	Aberfoyle	Torrens Creek	17	1991-2008
Old Station Waterhole	Aberfoyle	Torrens Creek	17	1991-2008
Top Hole	Lammermoor	Towerhil Creek	30	1980-2008
Kirby's Waterhole	Birricannia	Towerhill Creek	90	1917-2008
Bottom Hole	Lammermoor	Towerhill Creek	30	1980-2008
Koorinya Racetrack WH	Lammermoor	Towerhill Creek	30	1980-2008
Lammermoor Waterhole	Lammermoor	Towerhill Creek	30	1980-2008
Shed Hole	Lammermoor	Towerhill Creek	30	1980-2008
Big Hole	Noonbah	Vergemont Creek	130	1880-2008
Native Hole	Noonbah	Vergemont Creek	130	1880-2008
3 Mile Waterhole	Vergemont	Vergemont Creek	8	2000-2008
5 Mile Waterhole	Vergemont	Vergemont Creek	8	2000-2008
8 Mile Waterhole	Vergemont	Vergemont Creek	8	2000-2008
Billa Billa Waterhole	Vergemont	Vergemont Creek	8	2000-2008
Fish Hole	Vergemont	Vergemont Creek	8	2000-2008
Red Rock Hole	Vergemont	Vergemont Creek	8	2000-2008
Unnamed	Vergemont	Vergemont Creek	8	2000-2008
Unnamed	Vergemont	Vergemont Creek	8	2000-2008
Vergemont House Hole	Vergemont	Vergemont Creek	8	2000-2008
Whitula Waterhole	South Galway	Whitula Creek	10	1995-2005
Mt Margaret Waterhole	Mt. Margaret	Wilson River	14	1994-2008
??	Nappa Merrie	Wilson River	14	1977-1990
Noccundra Waterhole	Nockatunga	Wilson River	140	1870-2008
Nockatunga Waterhole	Nockatunga	Wilson River	140	1870-2008
Nocoura Waterhole	Nockatunga	Wilson River	140	1870-2008

Appendix 4: Diamantina Catchment Permanent Waterholes

WATER_NAME	PROPERTIES	WATERCOURSE	TIMEFRAME	YEARS
??	Brackenburgh	Diamantina River	50	1960-2008
Conn Hole	Elderslie	Wockingham Creek	120	1882-2008
Five Mile WH	Cambeela	Cadell Creek	25	1977-2001
Mundurin Waterhole	Cambeela	Diamantina River	25	1977-2001
Tail Yard Hole	Cambeela	Diamantina River	25	1977-2001
Mitta Mitta Waterhole	Wyoming	Diamantina River	100	1910-2008
Old Cork Waterhole	Cork	Diamantina River	140	1870-2008
Old Brighton Waterhole	Verdun Valley	Diamantina River	140	1870-2008
Rocky Crossing	Mt. Windsor	Mayne River	17	1991-2008
Mundaweira	Diamantina National Park	Diamantina River	140	1870-2008
Wangrei	Diamantina National Park	Diamantina River	140	1870-2008
Warracoota Waterhole	Springvale/DiamantinaNP	Spring Creek	130	1878-2008
Papaputcheri Waterhole	Diamantina National Park	Spring Creek	50	1958-2008
Mooradonka Waterhole	Davenport Downs	Spring Creek	30	1980-2008
Coota Waterhole	Davenport Downs	Spring Creek	10	1975-1985
Peleenah Waterhole	Davenport Downs	Spring Creek	10	1975-1985
Conanghera Waterhole	Davenport Downs	Diamantina River	10	1975-1985
Davenport Pump Hole	Davenport Downs	Diamantina River	10	19750-1985
Mackhara Waterhole	Monkira	Diamantina River	140	1870-2008
Ningga Waterhole	Monkira	Diamantina River	25	61-762002-
Tooracoompa Waterhole	Monkira	Diamantina River	25	61-762002-
Council or Long Hole	Monkira	Diamantina River	25	61-762002-
Crowbar Waterhole	Mooraberrie	Diamantina River	8	2000-2008
Poural Waterhole	Currawilla	Spring (Cungabulla) Creek	27	1981-2008
Alleogera Waterhole	Morney Plains	Morney Creek	25	1983-2008
Big Moorathulla WH	Morney Plains	Morney Creek	50	1960-2008
Montapiria Waterhole	Mooraberrie/Durrie	Diamantina River	130	1880-2008
Cooningheera Waterhole	Durrie	Diamantina River	130	1880-2008
Old Mooraberree WH	Durrie	Diamantina River	60	1940-2000
Stony Crossing Waterhole	Durrie	Diamantina River	130	1880-2008
Wyeroo Waterhole	Durrie	Diamantina River	130	188-2008
Nerathella Waterhole	Roseberth/Durrie	Diamantina River	130	1880-2008
Dicky Dicky	Roseberth	Diamantina River	80	1930-2008
Jardine's	Roseberth	Diamantina River	80	1930-2008
Water Carting Hole	Roseberth	Diamantina River	80	1930-2008
Pandie Channel	Pandie Pandie	Diamantina River	50	1960-2008
Pandie Channel	Pandie Pandie	Diamantina River	50	1960-2008
Pandie Channel	Pandie Pandie	Diamantina River	50	1960-2008
Yammakira Waterhole	Clifton Hills	Diamantina River	90	1920-2008

Appendix 5: Georgina Catchment Permanent Waterholes

WATER_NAME	PROPERTIES	WATERCOURSE	TIMEFRAME	YEARS
Walkabee/Jimboola WH	Carandotta	Georgina River	140	1870-2008
Grindstone Waterhole	Roxborough Downs	Georgina River	13	1995-2008
Lake Katherine	Roxborough Downs	Georgina River	140	1870-2008
Lemo Waterhole	Roxborough Downs	Georgina River	80	1930-2008
Smokey Waterhole	Roxborough Downs	Georgina River	140	1870-2008
Weaner Waterhole	Roxborough Downs	Georgina River	140	1870-2008
Yanko Waterhole	Roxborough Downs	Georgina River	70	1940-2008
??	Glenormiston	Georgina River	7	2001-2008
??	Glenormiston	Georgina River	7	2001-2008
??	Glenormiston	Georgina River	7	2001-2008
??	Glenormiston	Georgina River	7	2001-2008
Aldey's Waterhole	Glenormiston	Georgina River	7	2001-2008
Basin Waterhole	Glenormiston	Georgina River	7	1880-2008
Little Jewlerry WH	Glenormiston	Georgina River	7	2001-2008
Midgingar Waterhole	Glenormiston	Georgina River	7	2001-2008
Toko Gorge	Glenormiston	Linda Creek	7	2001-2008
Dignum Waterhole	Glenormiston	Pituri Creek	7	2001-2008
Paravituari Waterhole	Marion Downs/Wirrilyerna	Georgina River	130	1880-2008
Barracks Waterhole	Strathelbiss	Burke River	60	1950-2008
Beantree Waterhole	Boulia Town Common	Burke River	60	1950-2008
Bulla Bulla Waterhole	Warra	Hamilton River	60	1950-2008
Tomydonka Waterhole	Glengyle	Eyre Creek	40	1970-2008

Appendix 6: LEB Waterhole Condition Assessment Template

WH Name:________________ **River/System:**______________/_____________
Property:____________ **Tenure:**__________________ **Date:** __________ **No. sites:**_______ **Photo Nos.:**______________

Site	GPS Start	GPS End
1		
2		
3		

Conditions preceding and during sampling (flooding temperature, local rainfall etc):
____
____
____

Stocking Rate/Grazing Regime:

Stocking rate (past year)	Stocking rate (general/historical)	Dung count Site 1: A.________ B._______ Site 2: A.________ B._______ Site 3: A.________ B._______

General Waterhole Description:____
____
____

Major Species:

Overstorey	Midstorey	Ground layer	Aquatic

Water:

Turbidity		pH		Dissolved oxygen		Conductivity	

Parameter	Site	A	B	C	D	Notes
RIPARIAN CONDITION						
Bank stability	1					
	2					
	3					
	Average					
Groundcover	1					
	2					
	3					
	Average					
Woody species health	1					
	2					
	3					
	Average					
Terrestrial woody debris	1					
	2					
	3					
	Average					
Introduced species	1					
	2					
	3					
	Average					
OVRALL (RIPARIAN)						
AQUATIC CONDITION						
Native fish assemblage						
Exotic species						
OVERALL (AQUATIC)						
WH CONDITION						

Appendix 7: Rockhole Inventory

Name	Catchment	Region	Property	Landscape Position	Latitude	Longitude	Precision	Permanence rating	Permanence (%)	Permanency_Notes	Confidence Level	Informant/s
Green Creek Rockhole	Georgina	NWH	Bushy Park	In rocky creekline	-21.219167	139.914167	5km	Semi-permanent	70	Barely semi-permanent - will last year if regular rain; if creek stops running in March would be dry by end of August	Medium	Ron Power
Mt Guide Rockhole	Georgina	NWH	Mt Guide	In ranges, associated with tributary of Moonah Creek	-21.048333	139.514167	1km	Almost-permanent	95	8-10 month rockhole; usually gets topped up before it goes dry, so almost permanent	High	Mike McNamara
Moonah Creek Rockhole 1	Georgina	NWH	Mt Guide	In ranges, associated with tributary of Moonah Creek	-21.039444	139.494722	2km	Semi-permanent		Semi-permanent rockhole - dry most years by August	Medium	Mike McNamara
Moonah Creek Rockhole 2	Georgina	NWH	Mt Guide	In ranges, associated with tributary of Moonah Creek	-21.030833	139.485833	2km	Semi-permanent	80	Semi-permanent rockhole - dry most years by August	Medium	Mike McNamara
Moonah Creek Rockhole 3	Georgina	NWH	Mt Guide	In ranges, associated with tributary of Moonah Creek	-20.999444	139.496944	2km	Semi-permanent	80	Semi-permanent rockhole - dry most years by August	Medium	Mike McNamara
Moonah Creek Rockhole 4	Georgina	NWH	Mt Guide	In ranges, associated with tributary of Moonah Creek	-20.987222	139.491389	2km	Semi-permanent	80	Semi-permanent rockhole - dry most years by August	Medium	Mike McNamara
Moonah Creek Rockhole 5	Georgina	NWH	Mt Guide	In ranges, associated with tributary of Moonah Creek	-20.979444	139.491667	2km	Semi-permanent	80	Semi-permanent rockhole - dry most years by August	Medium	Mike McNamara
Upper Bustard Creek Rockhole 1	Georgina	NWH	Squirrel Hills (Cowie)	Rocky creekline in Selwyn Ranges	-21.608611	140.747222	1km	Permanent	100	Permanent rockholes but extremely inaccessible	High	Bob McDonald
Upper Bustard Creek Rockhole 2	Georgina	NWH	Squirrel Hills (Cowie)	Rocky creekline in Selwyn Ranges	-21.624722	140.745000	1km	Permanent	100	Permanent rockholes but extremely inaccessible	High	Bob McDonald
Waverley Creek Rockhole 1	Georgina	NWH	Ashover	Incised creekline in ranges	-21.352778	139.490000	1km	Semi-permanent	70	Sheltered, so lasts 6-7 months; usually dry by July-August	High	Bob & Noela McConachy
Waverley Creek Rockhole 2	Georgina	NWH	Ashover	Incised creekline in ranges	-21.362222	139.478611	1km	Semi-permanent	70	Sheltered, so lasts 6-7 months; usually dry by July-August	High	Bob & Noela McConachy
Spring Creek Oasis	Diamantina	GT	Goneaway NP boundary	Along creekline (tributary of Mayne River)	-23.751667	142.345556	0km	Semi-permanent	75	Assumed to be semi-permanent based on shelter, depth and surrounding country	Medium	
Man Hole	Diamantina	WP	Bladensburg NP	Rocky gully	-22.615000	143.112778	0km	Permanent	100	Protected/not accessible to animals, so has not gone dry in past couple of decades	High	Sue Cupitt
Cave Hole	Diamantina	WP	Bladensburg NP	Rocky gully	-22.728889	143.092778	0km	Permanent	100	Seen low but not dry	High	Sue Cupitt
Scrammy Rockholes	Diamantina	WP	Bladensburg NP	Small drainage depression on plateau	-22.566667	143.133889	0km	Semi-permanent	70	Lasts about 6 months, so dry regularly	High	Sue Cupitt
Dog Hole	Diamantina	WP	Bladensburg NP	In rocky creekline, at base of small 'cliff'	-22.686944	143.037500	0km	Semi-permanent	70	Semi-permanent - goes dry quite regularly	High	Sue Cupitt
Mt Landsborough Rockhole (Scrammy)	Diamantina	WP	Mt Landsborough	Taprock in range	-22.533611	143.144444	5km	Semi-permanent	90	Go dry during prolonged dry periods	Medium	Peter Britton
Mt Landsborough Rockhole (Winnebah 1)	Diamantina	WP	Mt Landsborough	Taprock in range	-22.679167	143.211111	5km	Semi-permanent	90	Go dry during prolonged dry periods	Medium	Peter Britton
Mt Landsborough Rockhole (Winnebah 2)	Diamantina	WP	Mt Landsborough	Taprock in range	-33.632500	143.218333	5km	Semi-permanent	90	Go dry during prolonged dry periods	Medium	Peter Britton
Brackenburgh Rockhole 1	Diamantina	KP	Brackenburgh	Gully in rocky range	-21.777500	141.388889	1km	Almost-permanent	90	Lasts about 14 months; dry occasionally in very dry periods	High	Duncan Lawton
Brackenburgh Rockhole 2	Diamantina	KP	Brackenburgh	Gully in rocky range	-21.819722	141.338056	1km	Semi-permanent	80	Lasts about 8 months after rain; dry for much of past 10 years, but previous decade would have had	High	Duncan Lawton

										water in for most of time		
Brackenburgh Rockhole 3	Diamantina	KP	Brackenburgh	Gully in rocky range	-21.826944	141.358056	1km	Semi-permanent	80	Lasts about 10 months after rain; dry for much of past 10 years, but previous decade would have had water in most of time	High	Duncan Lawton
Brackenburgh Rockhole 4	Diamantina	KP	Brackenburgh	Gully in rocky range	-21.884167	141.426389	1km	Permanent	100	Permanent - holds water for 20 months and Duncan has not seen dry in 50 years	High	Duncan Lawton
Brackenburgh Rockhole 5	Diamantina	KP	Brackenburgh	Gully in rocky range	-21.942778	141.368611	1km	Permanent	100	Permanent - holds water for 20 months and Duncan has not seen dry in 50 years	High	Duncan Lawton
Brackenburgh Rockhole 6	Diamantina	KP	Brackenburgh	Gully head in rocky range	-21.966111	141.379722	1km	Permanent	100	Permanent - holds water for 20 months and Duncan has not seen dry in 50 years	High	Duncan Lawton
Brackenburgh Rockhole 7	Diamantina	KP	Brackenburgh	Near head of gully in rocky range	-21.965278	141.446667	1km	Permanent	100	Permanent - holds water for 24 months and Duncan has not seen dry in 50 years	High	Duncan Lawton
Brackenburgh Rockhole 8	Diamantina	KP	Brackenburgh	Gully head in rocky range	-22.024444	141.377222	1km	Semi-permanent	80	Semi-permanent ; holds water for about 8 months	High	Duncan Lawton
Brackenburgh Rockhole 9	Diamantina	KP	Glenmore	Gully head in rocky range	-22.063611	141.392222	1km	Semi-permanent	90	Lasts about 12 months - semi-permanent	High	Duncan Lawton
Brackenburgh Rockhole 10	Diamantina	KP	Glenmore	Gully head in rocky range	-22.080000	141.377778	1km	Semi-permanent	80	Lasts about 8 months after rain; dry for much of past 10 years, but previous decade would have had water in for most of time	High	Duncan Lawton
Brackenburgh Rockhole 11	Diamantina	KP	Brackenburgh	Gully head in rocky range	-22.079167	141.556944	1km	Permanent	100	Permanent - holds water for 20 months and Duncan has not seen dry in 50 years	High	Duncan Lawton
Brackenburgh Rockhole 12	Diamantina	KP	Brackenburgh	Gully head in rocky range	-21.870833	141.589722	1km	Permanent	100	Permanent - holds water for 20 months and Duncan has not seen dry in 50 years	High	Duncan Lawton
Ju Ju Rockhole	Diamantina	GT	Tonkoro	Gully head with cliff dropping into rockhole	-23.867222	142.185278	0km	Semi-permanent	85	Semi-permanent - goes dry most years	High	Peter Magoffin
Limestone Rockhole	Diamantina	GT	Tonkoro	Gully head with cliff dropping into rockhole	-23.810278	142.273333	0km	Semi-permanent	95	Semi-permanent; would go dry during dry spells, perhaps every few years	Medium	Peter Magoffin
Spring Creek/Rocky Waterhole	Diamantina	GT	Tonkoro	Gully head in rocky range	-23.783611	142.359444	1km	Almost-permanent	95	Most permanent of rockholes in area - dry about once in 20 years (2006); may have soak/spring in bottom of it	High	Peter Magoffin
Goneaway Rockhole 2	Diamantina	GT	Goneaway NP	Gully head	-23.761944	142.191389	5km	Semi-permanent	80	Would be semi-permanent but rarely seen	Low	Peter Magoffin
Goneaway Rockhole 3	Diamantina	GT	Goneaway NP	Gully head	-23.791944	142.163889	5km	Semi-permanent	80	Would be semi-permanent but rarely seen	Low	Peter Magoffin
Honeymoon Rockhole	Diamantina	GT	Goneaway NP	Gully head of rocky creek	-23.809444	142.282222	0km	Semi-permanent	70	Judging by size and vegetation would be semi-permanent	Low	
Debil Debil Rockhole	Diamantina	VR	Bareeda	Gully head	23.254000	142.675000	1km	Almost-permanent	97	Almost permanent rockhole - dry once in past 30 years, when all the opal miners were using it	Medium	Peter Russell

										during a very dry time		
Policeman's Rockhole	Diamantina	VR	Vergemont	Gully head	-23.500833	142.808333	1km	Permanent	100	>2m deep; big rockhole, still lots of water in 2002	High	Angus Logan
Unnamed	Diamantina	VR	Vergemont	Gully head	-23.605833	142.813611	1km	Semi-permanent	90	Angus assumes it would be semi-permanent	Low	Angus Logan
Binburi Creek Rockhole	Diamantina	VR	Vergemont	Gully head	-23.741667	142.516389	1km	Semi-permanent	90	Would last about 6 months and probably goes dry every few years	Low	Angus Logan
Bingle Hole	Diamantina	GT	Tonkoro	Rocky creekline	-23.705833	142.460000	1km	Semi-permanent	85	Lasts 8 months but only takes a bit to fill it so only goes dry once every 2-3 years	High	Peter Magoffin
Parsons Creek Rockhole	Diamantina	GT	Mt Windsor	Gully head	-23.918889	142.048056	5km	Almost-permanent	99	Usually has water in - would be close to permanent	Low	Waddy Campbell
Murphy's Rockhole	Cooper	NGR	Idalia NP	Rocky gully head	-24.741389	144.633611	1km	Almost-permanent	100		Medium	Rosie Kerr
Crayfish Rockhole	Cooper	NGR	Idalia NP	Rocky gully head	-25.022500	144.566667	1km	Semi-permanent	100		Medium	
Budgerygar Rockhole 1	Cooper	NGR	Budgerygar	Edge of escarpment	-25.255556	144.217778	1km	Semi-permanent	90	Lasts 6-8 months; goes dry in drought (perhaps once or twice a decade)	High	Jeff Swanson
Budgerygar Rockhole 2	Cooper	NGR	Budgerygar		-25.333333	144.075833	1km	Permanent	100	Jeff did not see dry in 44 years	High	Jeff Swanson
Godsend Rockhole	Cooper	NGR	Budgerygar	Three rockholes in upper reaches of Powell Creek tributary	-25.331111	144.113056	1km	Almost-permanent	98	Dry once in 44 years - virtually permanent	High	Jeff Swanson
Budgerygar Rockhole 3	Cooper	NGR	Budgerygar	Three rockholes in upper reaches of Powell Creek tributary	-25.333333	144.116111	1km	Semi-permanent	80	Good rockholes, but will go dry during extended dry periods	High	Jeff Swanson
Budgerygar Rockhole 4	Cooper	NGR	Budgerygar	Three rockholes in upper reaches of Powell Creek tributary	-25.335278	144.119444	1km	Semi-permanent	80	Good rockholes, but will go dry during extended dry periods	High	Jeff Swanson
Budgerygar Rockhole 5	Cooper	NGR	Budgerygar	Rocky gully head	-25.495556	144.105833	1km	Semi-permanent	80	Good, handy rockholes; last 6-8 months, but go dry if it doesn't rain within this time	High	Jeff Swanson
Budgerygar Rockhole 6	Cooper	NGR	Budgerygar	Rocky gully head	-25.488611	144.108889	1km	Semi-permanent	80	Good, handy rockholes; last 6-8 months, but go dry if it doesn't rain within this time	High	Jeff Swanson
Trinidad Rockhole 1	Cooper	NGR	Trinidad	In steep, rocky gully	-25.563056	143.902500	2km	Almost-permanent	95	Would usually have water in it as large rockhole, but gets very low	Medium	Wendy Sheehan
Trinidad Rockhole 2	Cooper	NGR	Trinidad	In gully	-25.505278	143.903056	2km	Almost-permanent	95	Thought to be close to permanent by old-timers in area	Medium	Wendy Sheehan
Mountain Hole	Cooper	VR	Spring Plains	Rocky gully head	-23.706111	143.237500	0km	Permanent	100	Has never been known to go dry - has possibly been excavated years ago	High	Denise Hawe
Fish Hole_barren	Cooper	VR	Spring Plains	In middle of rocky sandstone plateau; carved into sheer rock	-23.706111	143.211111	0km	Semi-permanent	90	Inaccessible and not visited regularly; Denise expects it would go dry infrequently	Medium	Denise Hawe
Fish Hole _vegetated	Cooper	VR	Spring Plains	In rocky gully; small red gum drainage line	-23.705000	143.209444	0km	Semi-permanent	90	Inaccessible and not visited regularly; Denise expects it would go dry infrequently	Medium	Denise Hawe

Quart Pot Hole	Cooper	VR	Spring Plains	Rocky head of small drainage line	-23.744444	143.233056	0km	Semi-permanent	90	Has been dry once in past four years (very dry years)	High	Denise Hawe
Pigeon Hole	Cooper	VR	Spring Plains	Rocky gully head; upper catchment of drainage line	-23.665278	143.330278	0km	Semi-permanent	90	Has been dry once in past four years (very dry years)	High	Denise Hawe
Bucket Hole	Cooper	VR	Spring Plains	Creekline on stony plateau	-23.737222	143.325833	0km	Semi-permanent	85	Has been extremely low in past four years; Denise thinks it would be semi-permament	Medium	Denise Hawe
Picnic Hole	Cooper	VR	Spring Plains	Veritable lagoon in rocky creekline!	-23.705278	143.308611	0km	Semi-permanent	75	Denise has seen it dry once, but thinks it would go dry regularly, as it is not very deep	Medium	Denise Hawe
Darr Hole	Cooper	VR	Melrose	Gully head in rocky range	-22.848333	143.217778	1km	Permanent	100	Permanent - 'cleaned out' years ago, but would be good natural rockhole anyway	High	Peter Magoffin
Gilgunyah Rockhole	Cooper	NGR	Gilgunyah	Gully head	-24.932778	144.261944	2km	Almost-permanent	95	Very large - would not go dry very often	Medium	John Avery
Bramble Creek Rockholes	Cooper	NGR	Bramble Creek	Gully head	-25.060556	144.188611	2km	Almost-permanent	95	Very large - would not go dry very often	Medium	John Avery
Unnamed	Cooper	VR	Vergemont	Gully head	-23.462500	142.842778	1km	Permanent	100	Regarded by locals as permanent; did not go dry in 2002 drought	High	Angus Logan
Florida Rockhole	Cooper	VR	Vergemont	Gully head	-23.649444	142.942778	1km	Permanent	100	Angus thinks it is probably permanent, as didn't go dry in 2002 drought + old yards and windmill indicate some degree of permanence	Medium	Angus Logan
Unnamed	Cooper	VR	Vergemont	Gully head	-23.851944	142.807222	1km	Permanent	100	Didn't go dry in 2002 drought	Medium	Angus Logan
Green Hole	Cooper	VR	Vergemont	Rocky creekline	-23.763333	143.051667	1km	Almost-permanent	99	Dry for one week in past century (1890-2008); extremely close to permanent	High	Mark Kleinschmidt
Mistake Creek Rockhole	Cooper	VR	Vergemont	Rocky creekline	-23.856944	143.083611	1km	Semi-permanent	90	Lasts 6-8 months, so will last through normal seasons but goes dry every couple of years	Medium	Angus Logan
Mitchell's Rockhole	Diamantina	GT	Mt Windsor	Gorge at base of cliff	-23.381944	141.855556	1km	Semi-permanent	75	Waddy doesn't regard this as a long-lasting rockhole, but Peter remembers it as one of the biggest he's seen and expects it would be quite permanent	Low	Waddy Campbell; Peter Russell
Carisbrook Rockhole	Diamantina	WP	Carisbrook	Gorge near headwaters of Williams Creek	-22.621667	142.628056	1km	Semi-permanent	90	Big rockhole - would usually have some water in it	Medium	Peter Russell
Skull Hole	Diamantina	WP	Bladensburg NP	Bottom of cliff on plateau	-22.557440	142.999830	0km	Ex-semi-permanent?	<50%	No longer semi-permanent, but Aborignal art around rockhole suggests it may have been more permaennt - gravel has fallen in	Low	Peter Russell

Appendix 8: Non-GAB Springs Inventory

Name	Catchment	Property	Landscape Position	Latitude	Longitude	Permanence summary	Pre-1880 Permanence	Currnent Permanence	Permanency Notes	Confidence Level	Other/Notes	Informant_1
Durack	Cooper	Galway Downs	Incised gully	-25.154722	142.570833	Almost permanent	99%	99%	Spring dried up in 2004 - first time in living memory	High	Surface water but no discernible flow; fish and snails not seen	Allan Hubbard; Rod Fensham
Alice	Cooper	New Haven	Incised gully	-24.893333	144.240278	Permanent	100%	100%	Flow is permanent	High	Water emanating from up to 5m above gully bottom from site slopes as well as vents in gully; fish seen	John Avery; Rod Fensham
Stonehenge	Cooper	Near Stonehenge	Incised gully	-24.403056	143.315833	Unknown	??	<70%		Low	Locals assume that water would be found with digging; filled with gravel	Rod Fensham
Koala Spring	Cooper	Idalia NP	Side slope of gorge leading to gully	-24.733056	144.661111	Permanent	100%	100%	Apparently contracted in recent years	High		Rosie Kerr
Twin Sister Spring I	Cooper	Idalia NP		-24.855278	144.598611	Permanent	100%	100%		High		John Avery
Twin Sister Spring II	Cooper	Idalia NP		0.000000	0.000000	Permanent	100%	100%		High		John Avery
Wagon Spring	Cooper	Idalia NP	Probably in incised gully	-24.825278	144.777778	Unknown	??	??		Low	Apparently cattle could go for months without coming into water in this area; thought to be a spring in ranges	Rosie Kerr; John Avery
Ian's	Cooper	Highlands	Side slope	-24.921389	144.501389	Permanent	100%	100%		High	Discernible flow. Ex-spring 100m to east - has been excavated with tractor	John Avery; Rod Fensham
Little Hancock	Cooper	Highlands	Foot slope	-24.994444	144.547778	Permanent	100%	100%		High	Surface water but no discernible flow; tadpoles present	John Avery; Rod Fensham
Dripping	Cooper	Highlands	Incised gully	-25.195000	144.251111	Permanent	100%	100%		High	SSpring is partially fenced	John Avery; Rod Fensham
Big	Cooper	Highlands	Incised gully	-25.138611	144.366111	Permanent	100%	100%		High	Spangled perch; discernible flow	John Avery; Rod Fensham
Mt Remarkable	Cooper	Mt Remarkable	Incised gully	-25.024167	144.313056	Permanent	100%	100%		High	Spangled perch; discernible flow; spring pools damed by Melaleuca piped and troughed in past	John Avery; Rod Fensham
Glenara/Mt Remarkable boundary springs	Cooper	Mt Remarkable	Incised gully	-25.088889	144.291111	Permanent	100%	100%		High	Location approximate only	John Avery
Westerton Spring	Cooper	Westerton	In creek	-24.058380	143.043660	Permanent	100%	100%		Moderate	Approximate location only	Mark Kleinschmidt
Quart Pot Soak	Cooper	Vergemont	Tributary of Quart Pot Creek	-23.937500	142.909167	Permanent	100%	100%	Always moisture there, but dries back to small patch	High	Approximate location only	Angus Logan
Vergemont Spring	Cooper	Vergemont		-23.913320	142.925967	Permanent	100%	100%		Moderate	Approximate location only	Mark Kleinschmidt
Noonbah Spring	Cooper	Noonbah	In sandy creekline	-24.024444	143.211111	Permanent	100%	100%	Has not been dry since 1902	High		Angus Emmott
Springvale/Bexley Springs	Cooper	Springvale and Bexley		-23.212500	144.313611	Ex-semi-permanent	90%?	<70%	Used to be quite permanent, but have not flown very well in past couple of decades;now <70%	Moderate		
Thylungra Spring I	Cooper	Thylungra		-25.406000	143.401000	Permanent	100%	100%	Always have water in them	Low	Three springs in this area - locations only accurate to within 50km	Ian Lilburn
Thylungra Spring II	Cooper	Thylungra		-25.430000	143.730000	Permanent	100%	100%	Always have water in them	Low	Three springs in this area - locations only accurate to within 50km	Ian Lilburn

Thylungra Spring III	Cooper	Thylungra		25.350000	143.570000	Permanent	100%	100%	Always have water in them	Low	Three springs in this area - locations only accurate to within 50km	Ian Lilburn
Poural WH Spring	Diamantina	Currawilla	In creek - flows into waterhole	-24.996190	141.600100	Permanent	100%	100%	Feeds permanent waterhole - hasn't been dry in past 30 years	High		Roger Oldfield
Currawilla Spring 2	Diamantina	Currawilla	Rocky ledge in creek	-25.009940	141.659200	Almost permanent	95%	95%	Has been dry once in past 30 years	High		Roger Oldfield
Connemara Spring	Diamantina	Connemara		-24.380000	141.950000	Unknown	??	??		Low	Bruce has been told it's there, but has been looking for it in a chopper and can't find it	Bruce Rayment
Budgerygar Spring I	Cooper	Budgerygar		-25.326389	144.042500	Permanent	100%	100%	Permanent spring	High		Jeff Swanson
Budgerygar Spring II	Cooper	Budgerygar	Gorge	-25.322500	144.020833	Permanent	100%	100%	Permanent spring	High		Jeff Swanson
Budgerygar Sping III	Cooper	Budgerygar		-25.338056	144.061389	Almost permanent	90%	90%	Dry a couple of times in 44 years - lasts 9-10 months without rain	High		Jeff Swanson
Budgerygar Spring IV	Cooper	Budgerygar		-25.358333	144.002361	Permanent	100%	100%	Permanent spring	High		Jeff Swanson
Spring Plains Spring	Cooper	Spring Plains	Base of sandstone escarpment	-23.647000	143.274000	Ex-permanent	100%	10%	Used to be permanent	High	Although spring no longer flows, rockhole is still about 1m deep when filled from rainfall	Denise and Steve Hawe
Selwyn Park Spring 1	Diamantina	Selwyn Park		22.779000	143.214000	Ex-semi-permanent	90%	0%	Used to be quite permanent	Low	Lyn has never been to spring and doesn't know exact location, but remembers her late husband talking about it	Lyn Frazer
Selwyn Park Spring 2	Diamantina	Selwyn Park		-22.728000	143.214000	Semi-permanent	90-100%	90-100%	Goes dry in very dry times	Low	Lyn has never been to spring and doesn't know exact location, but remembers her late husband talking about it	Lyn Frazer
Trinidad Spring	Cooper	Trinidad	Near head of gully	-25.582222	143.918333	Permanent	100%	100%	Permanent water, but extremely small volume	High	Under gum tree	Wendy Sheehan
Mt Guide Spring	Georgina	Mt Guide	In Moonah Creek	-21.053000	139.446000	Permanent	95%	95%	Goes dry in very dry times, e.g. 2-3 times in past 60 years	High	Feeds waterhole	Mike McNamara; Bob McConachy
Crossmoor Spring	Cooper	Crossmoor	Sandy rise	-22.912000	144.632000	Semi-permanent	95%	95%	Dries right back but has only been completely dry once in past 20 years	Moderate		Penny Button
Welford Spring	Cooper	Welford NP	Stony ranges	-24.881000	143.520000	Unknown	??	??		Low	Spring marked on map but no information known	
Fig Tree Rockhole	Diamantina	Camping and water reserve, Ayrshire Hills	Base of escparment	-21.963056	142.631944	Ex-semi-permanent	>95%	<50%	Apparently used to be quite permanent (spring?) and overflow as far as road	Low	Now has filled in with gravel and only holds water for 2-3 months after rain	Brett Elliot
Carisbrook Spring	Diamantina	Carisbrook	Base of stony hills	-22.653333	142.533889	Ex-permanent	100%	<50%	Apparently used to be permanent	Medium		Peter Russell