Department of Science, Information Technology and Innovation

Lake Eyre Basin Springs Assessment Project

Hydrogeology, cultural history and biological values of springs in the Barcaldine, Springvale and Flinders River supergroups, Galilee Basin and Tertiary springs of western Queensland

2016

Queensland Government

Prepared by

R.J. Fensham, J.L. Silcock, B. Laffineur, H.J. MacDermott

Queensland Herbarium
Science Delivery Division
Department of Science, Information Technology and Innovation
PO Box 5078
Brisbane QLD 4001

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Front Cover: Edgbaston Springs and a spring (imaginatively) called “New Big”. There is Spinifex in the foreground, free water in the mid-ground, with some scalding in front and the far right rear. Photo: Queensland Herbarium.

May 2016

Executive Summary

The Lake Eyre Basin Springs Assessment provides information on the history, ecology, hydrogeology and potential impacts of mines and proposed mining developments on spring ecosystems in the Barcaldine, Flinders River, Springvale supergroups (Eromanga and Carpentaria Basins), the Galilee Basin and springs in Tertiary sandstone in the current drainage area of the Lake Eyre Basin.

A database has been developed that includes attributes relating to their physical characteristics, biological values and water chemistry. The database links to a photo library, and historical and hydrogeology reports.

Springs can be distinguished as either outcrop (emanating under gravity through outcropping rocks) or discharge (flowing through an aquitard under artesian pressure) types. Discharge springs within the GAB are protected under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act). The discharge springs of the Barcaldine and Springvale supergroups which remain active have exceptionally high biological values including concentrations of endemic fish, snails, crustacea and plants that only occur in these habitats. There are also endemic plants that occur in the salt scalds around the spring wetlands. Pelican Creek near Aramac and Elizabeth Springs near Boulia are outstanding in terms of their biological significance and include multiple species that are restricted to those locations.

Our understanding of the cultural significance of the springs for Aboriginal people is extremely deficient. However, the patchy evidence we have compiled, stories from elsewhere, and the surface archaeological record reveal their significance both as water supplies and sacred sites.

The springs were critical to the European settlement of the Lake Eyre Basin, and they were a focus of attention for the early land surveyors. Homesteads and hotels were built on springs and roads traced the ground between them. The springs were also signposts to the vast aquifer that would later be named the Great Artesian Basin (GAB).

From the 1880s thousands of artesian bores were drilled to exploit the groundwater of the GAB. The bores transformed the productive potential of inland Australia, but most of the water flowed down open drains and was lost to evaporation. Declining aquifer pressure resulted in springs ceasing to flow. The current audit of spring complexes (clusters of springs in the same area within a single geomorphic setting) indicates that 31% of the discharge spring complexes in the Barcaldine supergroup; 77% of the Flinders River supergroup; and 50% of the Springvale supergroup have lost more than 80% of their springs. Outcrop springs in the Tertiary sandstone can become inactive without aquifer drawdown and some may require local excavation to maintain their flows.

The Great Artesian Basin Sustainability Initiative has provided large-scale investment into rehabilitating bores to stem the profligate waste of groundwater and restore aquifer pressure. This has not resulted in the reactivation of springs, but may serve to minimise further loss. Large free-flowing bores await capping in Queensland particularly in the area of the Flinders River supergroup.

Preservation and conservation effort should be directed to the spring wetlands which still support endemic species. The recovery efforts for the Critically Endangered red-finned blue-eye

(*Scaturiginichthys vermeilipinnis*) at the Pelican Creek Springs require ongoing support for an achievable outcome.

Coal beds within the Permian sediments of the Galilee Basin are the target of future development proposals. Springs discharge from aquifers within these sediments, and the largest and most significant is the Mellaluka Springs. Based on endemicity these springs are not of high conservation value and will probably become inactive if the cumulative impact of the development proposals is realised.

A complex of springs at Doongmabulla with very high conservation values, including many endemic plants, has ambiguous hydrogeology. The springs may have a groundwater source in Triassic sediments that are separated from the Permian coal-beds by an aquitard. There is also some potential for their source to be from Permian sediments. Further investigations of the potentiometric surface in the Triassic and Permian aquifers, fault structures and source aquifer chemistry may resolve the origin of the Doongmabulla Springs and contribute to determining the impact of the proposed Carmichael Mine development.

The methods developed here for collating the values of spring ecosystems and their aquifer sources should be extended to other regions so that future developments that impact on groundwater can be adequately informed.

Acknowledgments

We are grateful to the many landholders and managers who have allowed us access to their properties, provided hospitality and directions, and enriched our experience of the springs through their stories and interest. We also thank former landholders and long-term residents for sharing their knowledge of springs.

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Ashley Bleakley, John Webb, Tim Ransley and Daniel Larsen have provided valuable input into developing an understanding of the hydrogeology of the springs. Ashley in particular has been indispensable. Rien Habermehl, Bruce Radke, Steve Flook and Jim Kellett have also contributed to the hydrogeology presented here. Steve and Leon Leach provided helpful review of the Doongmabulla chapter.

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Contents

List of tables

List of figures

1 Introduction

All cultures honoured springs through offerings, sacrifices and rituals, at least until the Industrial era when the focus shifted to large-scale ‘improvement’ and exploitation of springs, often with destructive consequences (Fairfax and Fensham, 2002, p. 99; Powell et al., 2015). Recent decades have seen renewed interest in and appreciation of springs, especially from scientific and conservation perspectives. Biological surveys have revealed desert springs to be home to a dazzling diversity of specialised endemics – plants, fish and invertebrates, many as yet unknown to science – which are effectively stranded in their tiny but enduring shallow pools. Our understanding and appreciation of the cultural and ecological values of springs is expanding at a time when pressures on aquifers for human use, and our ability to exploit them on a large scale, have never been greater. This dilemma is epitomised by the LEBSA study area.

1.1 LEBSA and report overview

The Lake Eyre Basin Springs Assessment (LEBSA) was generated by concerns about the impact of proposed coal developments on groundwater and springs. LEBSA is being conducted through the states of Queensland and South Australia, and has two components: this report concerns a targeted study of groundwater springs, while the other component maps the full range of potential ground water dependent ecosystems (GDEs) and is the subject of a separate report titled the ‘LEBSA Ground Water Dependent Ecosystem Mapping Report’.

The aim of the spring component is to build a standard methodology for assessing and documenting springs in terms of their physical character, history, biological values and hydrogeology. The current study area includes the Barcaldine, Flinders River and Springvale GAB supergroups (section 1.2), as well as other springs that are not formally included in the GAB: the Galilee group to the east of the GAB boundary and springs emanating from local Tertiary aquifers in the sandstone ranges of semi-arid Queensland (Figure 1). The Doongmabulla Springs formerly included in the GAB are treated as a separate group because of their ambiguous source.

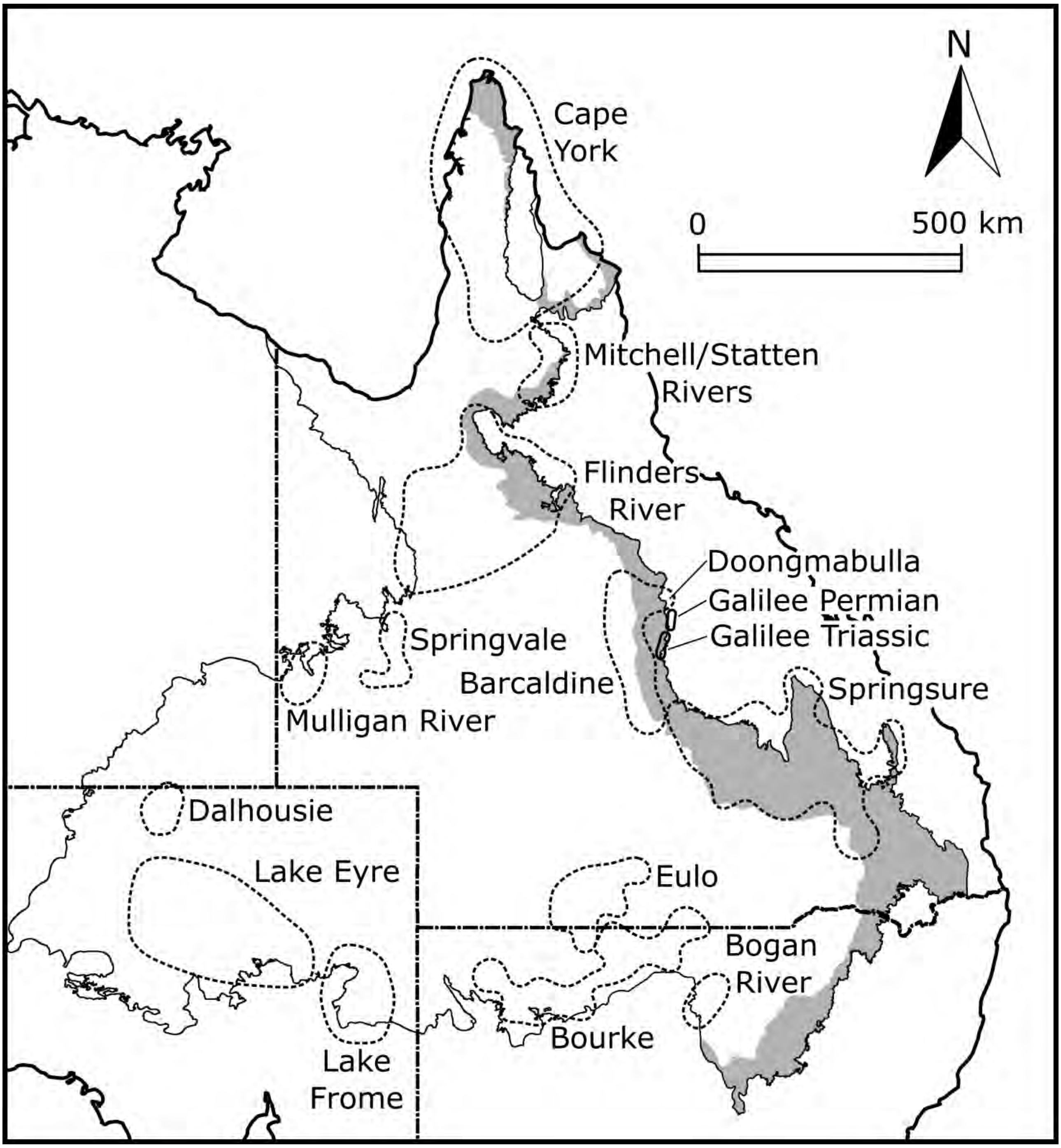

Figure 1. Great Artesian Basin with general location of eastern recharge areas (grey) with the extent of the spring supergroups identified, as well as the location of the Galilee Springs and the Doongmabulla Springs in the vicinity of the Barcaldine supergroup. The LEBSA project includes the Barcaldine, Flinders River, Springvale supergroups, the Galilee springs and Tertiary springs from throughout the GAB.

The LEBSA project builds on previous work in other parts of the Great Artesian Basin (GAB), including the Surat Basin supergroups (Pennay et al., 2012), and the Eulo, Bourke and Bogan River supergroups (Silcock et al., 2013). The Introduction and overall structure of this report borrow heavily from these previous reports, which should be viewed as companions to this document. The springs in the Mulligan River, Mitchell-Staaten and Cape York supergroups within the GAB are not yet covered by the assessment and are not included in the ever-expanding database. Other important spring areas with high conservation values, perhaps most notably the springs associated with the basalts of the Einasleigh Uplands area in Queensland, also require assessment using the procedures developed here.

The Lake Eyre Basin Springs Assessment (LEBSA) project will supply the latest scientific data on Groundwater Dependent Ecosystems (GDEs) for use in the Bioregional Assessment Programme. There are ancillary reports on other (non-springs) GDEs including the 'Groundwater dependent ecosystem mapping report' (Queensland) and similar reports from South Australia. The Bioregional Assessment Programme is a transparent and accessible programme of baseline assessments that increase the available science for decision making about potential water-related impacts of coal seam gas and large coal mining developments. Further information on the Bioregional Assessment Programme can be found at: http://www.bioregionalassessments.gov.au. LEBSA was delivered through parallel projects coordinated by the South Australian and Queensland Governments.

1.1.1 Geographical scope of LEBSA and hydrological overview

The initial brief for LEBSA in Queensland was to include springs that could be impacted by proposed developments in the Galilee and Cooper Basins. This report has taken a very broad interpretation of this study area, including springs up to 240km from the edge of these basins, because it sought to complete inventories and assessment of entire spring supergroups rather than only springs that may conceivably be impacted by development within these basins. An overview of the hydrogeology of these areas is useful to understand the scope of work and the priorities in relation to potential developments in these areas.

The Great Artesian Basin is composed of three partly connected geological basins, the Carpentaria, Eromanga and Surat basins (Figure 2). These are separated by basement structures, namely the Euroka Arch separating the Carpentaria and Eromanga Basins, and the Nebine Ridge separating the Eromanga and Surat Basins (Figure 2). It is recognised that there is some connectivity, in terms of groundwater flow, across these basement ridges. There are sedimentary units of the same name in more than one of the sub-basins (i.e. Hutton Sandstone in the Eromanga and Surat Basins), and units with different names are also considered equivalents (i.e. Gilbert River Formation in the Carpentaria Basin is the equivalent of the Hooray Sandstone in the Eromanga Basin). In many cases the sedimentary units have equivalents within the one basin and the reason for distinct names is obscure and may be simply historical artefact (e.g. the Ronlow Beds and the Hooray Sandstone). All of the units within the Carpentaria, Eromanga and Surat Basins are of Cretaceous-Jurassic age. The connectivity and the contemporary ages of the three separate geological basins justifies the single term 'The Great Artesian Basin'.

There is pressurised groundwater in the GAB and this resource has been exploited historically for pastoralism and human use. There are new demands on the water from the mining sector, and thus there have been efforts to rehabilitate bores to reverse profligate groundwater use, and to rationalise new allocations within a regulated framework.

Underlying the basins of the GAB are older basins also containing sediments including water-bearing sandstone and large reserves of oil and gas. The Cooper Basin has no surface expression (Figure 2b) but the Galilee Basin abuts the eastern rim of the Eromanga Basin (Figure 2b). The main water-bearing unit towards the top of the Galilee Basin is the Clematis Sandstone of Triassic age (Figure 2c). This sandstone unit has many similar qualities to the main sandstone unit towards the base of the Eromanga, the Precipice Sandstone, and contains large quantities of high quality groundwater under artesian pressure. Thus for management and regulatory purposes it was considered expedient to include the Clematis Sandstone and its overlying aquitard unit, the Moolayember Formation as part of the 'Great Artesian Basin' (Figure 2c). The definitive map of the Great Artesian Basin by Habermehl and Lau (1997)_ENREF_54 follows this scheme.

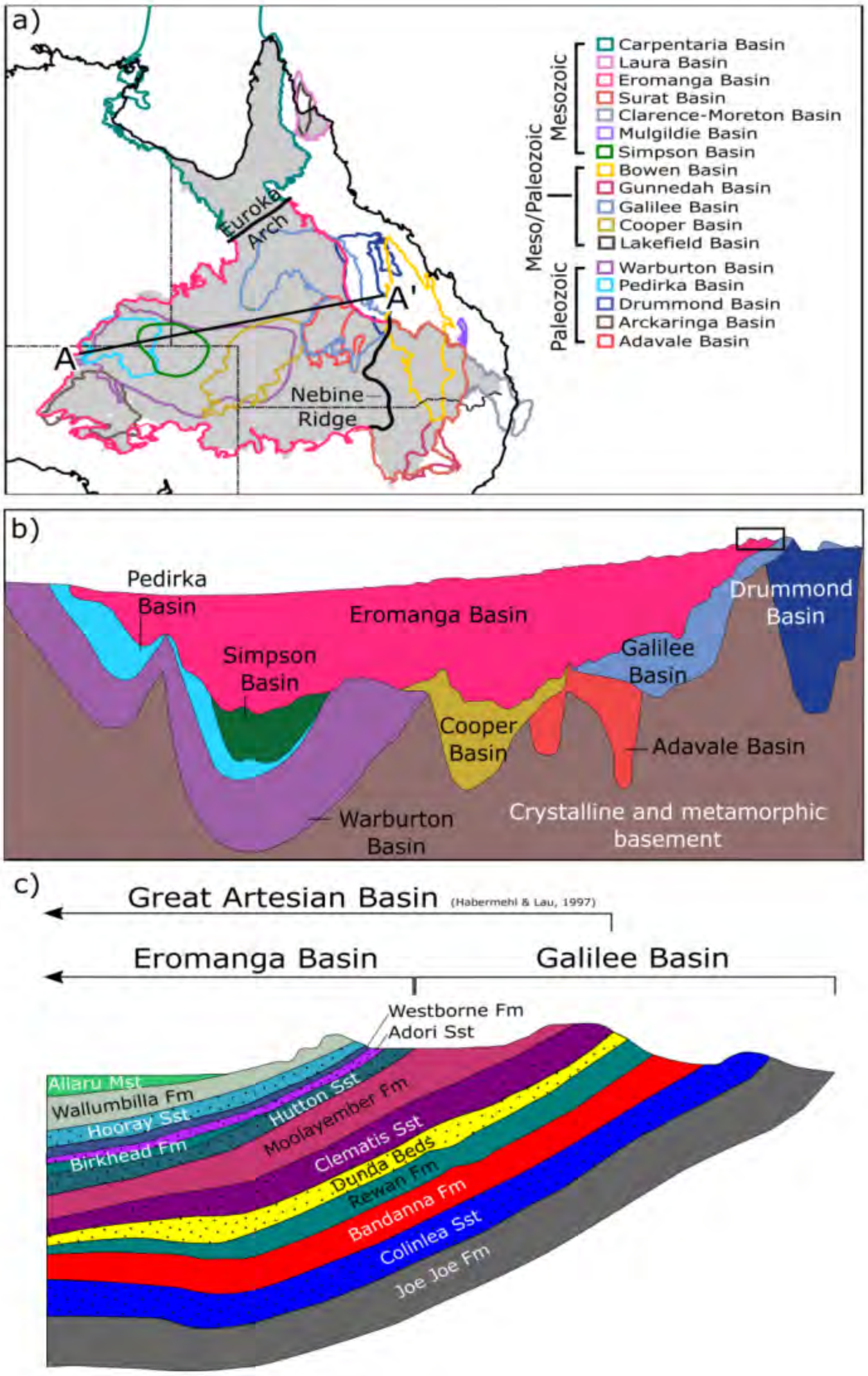

Figure 2. Geological basins in the eastern half of the continent.
a) Plan view of geological basins. Superimposed in grey is the spatial extent of the Great Artesian Basin (Figure 2a). The general location of the stratigraphy represented in Figure 2b is identified; b) Generalised cross section (A-A', Figure) showing the vertical position of various basins associated with the Eromanga Basin. The age of the basins are Warburton: Cambrian-Ordovician; Adavale: Early Devonian-Early Carboniferous; Drummond Basin: Late Devonian-Early Carboniferous; Pedirka: Carboniferous-Permian; Cooper: Late Carboniferous-Middle Triassic; Galilee: Late Carboniferous-Middle Triassic; Simpson: Triassic; Eromanga: Jurassic-Early Cretaceous. The detail within the black rectangle is presented on Figure 2c) and represents the stratigraphy where the Eromanga Basin adjoins the Galilee Basin. The water-bearing aquifer units are identified by stippling. The units included in the definition of the Great Artesian Basin from (Habermehl and Lau, 1997) is indicated.

These variations on defining the extent of the Great Artesian Basin have relevance for springs conservation because the listed ecological community under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act), the ' community of native species dependent on natural discharge of groundwater from the Great Artesian Basin', includes springs with their source in the Clematis Sandstone that would not be captured by a strict hydrogeological interpretation of the Great Artesian Basin including only units within the Carpentaria, Surat and Eromanga basins of Jurassic-Cretaceous age.

The geographical extent of this project includes the Galilee Basin Springs (emanating from the Colinlea Sandstone, which contains coal deposits that are currently the subject of planned development), the Barcaldine Supergroup in the eastern Eromanga Basin, the Doongmabulla Springs that have been included as part of the GAB, the Flinders River supergroup in the southern Carpentaria Basin, the Springvale supergroup in the north-western Eromanga Basin and the Tertiary Springs in the central part of the GAB but hydrologically disconnected from its aquifers (Figure 1).

Some of these groundwater systems are hydrologically isolated from potential developments in the Cooper and Galilee Basin but are within their broad geographic proximity.

1.1.2 Report outline

This document reports on the hydrogeology and cultural and biological values of springs in the LEBSA region. We begin with an overview of spring sources and types in the study area, and their cultural and biological values. Section 2 details our methodology for locating and documenting springs, with particular emphasis on the Queensland Springs Database and individual spring reports which are linked to the database. Sections 3 to 7 explore the hydrogeology, cultural history, biological values and threats to each spring group in the LEBSA region, based on desktop assessments and research and extensive on-ground surveys. Section 8 provides a summary of our findings and considers the future threats and opportunities for spring conservation.

1.2 Springs in LEBSA region

1.2.1 Great Artesian Basin springs

Although there are springs throughout inland Australia, the largest clusters are those emanating from the Great Artesian Basin (GAB). Underlying one-fifth of mainland Australia, it comprises numerous aquifers laid down within three partially connected hydrological basins. Major regional clusters of spring-complexes with some consistent hydrogeological characteristics form twelve 'supergroups' in the Great Artesian Basin (Figure 1).

GAB springs can be divided into two broad categories: outcrop (Fensham et al., 2011), and discharge (Fensham and Fairfax, 2003). Outcrop springs have also been referred to as 'recharge' springs (Fensham and Fairfax, 2003). Outcrop springs occur within outcrop areas of sandstone formations on the eastern margins of the Basin, before the aquifer rocks dip underground. Water drains out of the rocks under gravity or through the intersection of the ground surface with a saturated aquifer rather than welling upwards under artesian pressure. The water has a relatively short residence time in the aquifer and tends to be neutral or slightly acidic with low levels of dissolved solids. Spring-flows in recharge areas can exhibit dynamism related to recent rainfall history.

Discharge springs emanate where the confining bed or aquitard is thin or weakened by faults or folds and where aquifers abut against impervious basement rocks, mainly in relatively arid areas remote from the recharge zones. Typically the vents are less than 5m across, occur in flat landscapes, and are upwelling in a vertical direction. The vertical conduits are clearly evident as squelchy areas where, in the case of large vents, a person can sink up to their neck. The artesian nature of the discharge springs is also clearly evident by the presence of artesian pressure in the underlying aquifer (i.e. there are flowing bores at similar or higher elevations). Spring flows are not related to recent rainfall, although the size of a spring wetland may fluctuate depending on seasonal conditions. Waters are generally alkaline with high levels of dissolved solids, reflecting the long residence time of the groundwater within the aquifer, and because the groundwater gains salts moving upwards from the artesian aquifer through the overlying predominantly clayey aquitards.

Surrounding the wetland, where groundwater percolates to the surface, salts are precipitated as groundwater evaporates. This leaves characteristic scalds in the vicinity of springs. Scalding is exaggerated in low rainfall environments and in local depressions that are not flushed by overland flow. The chemistry of groundwater provides an environment around springs that is distinct from other salt scalds and there are indicator plant species known only from groundwater scalds.

There are three broad types of discharge springs: mud, water and peat. Mud springs form where the groundwater has mixed with fine sodic sediments that are highly soluble. A mud slurry rather than water emanates from the spring vent. The slurry may not flow to the surface for long periods and dry surface layers can form a ‘skin’ over the soupy interior material. In contrast, water springs have clear water and their permanent soak areas often support wetland vegetation. The water emanates from a discrete vent or vents, and saturates the surface over an extent determined by flow and evaporation. Within the vegetation there may be pools of free water formed where the vegetation or sediment has created an obstruction to flow, forming a dam. Mud springs can develop into water springs when there is adequate discharge or where the sodic substrate forming the soupy slurry has been sufficiently cleared out to flow free water. Mud springs require soluble substrates (usually highly sodic) to form. Water springs can form with variable substrates including those of high sodicity.

Peat springs are those where peat formed from the wetland vegetation is a dominant substrate Peat from the base of Native Dog Spring in the Flinders River supergroup was dated to 16 000 years before present (J. Luly pers. comm.). Peat is most common in cold climates where low temperatures limit decomposition. The peat-forming springs have a relatively low pH with sulphurous mineral deposits and rotten-egg gas odour suggesting an origin for the acid chemistry. Peat formation in the tropical spring wetlands may be occurring because of reduced decomposition in the acid groundwater environment.

1.2.2 Galilee group

The Galilee group of springs occur where the eastern edge of the Galilee Basin outcrops or approaches the surface beneath Cainozoic sediments. They emanate through these Cainozoic sediments and probably have their source in the Colinlea Sandstone.

1.2.3 Tertiary springs

Springs emanating from fractures in local sandstone aquifers occur in clusters throughout semi-arid Queensland. They often occur at the base of cliffs or escarpments, where they are fed by water tables from higher terrain under gravitational pressure. Groundwater residence times vary considerably but are generally relatively short, and some springs can dwindle to seepages or disappear completely in dry times. Some feed quite large waterholes and streams, while others form small shallow pools or soaks. Water is generally slightly acidic and has low conductivity, reflecting its relatively short residence time.

1.3 Cultural history overview

1.3.1 Aboriginal history

Springs have been intimately known, used and cared for by Aboriginal people for millennia. The Aboriginal names of some springs have been preserved across the Great Artesian Basin – Pigeongah, Mommedah, Muk Quibunya, Bookera and Allawonga, to name a few of the more poetic – but the stories and significance of most individual springs (Potezny, 1989) have not been revealed in Queensland. Indigenous belief systems have parallels with spring mythologies worldwide, including the presence of supernatural beings and oracles and the healing power of the waters. Rainbow Serpents of Aboriginal Australia remain an ongoing, living presence in some springs, keeping the water pure and punishing anyone who transgresses laws or rites (McDonald et al., 2005). In Western Australia, springs, soaks and wells are all viewed as being connected to the underlying groundwater, which is referred to as *kurtany*, literally 'mother' (Yu, 2002).

Dalhousie Springs in South Australia are collectively known as *Irrwanyere*, or 'the healing spring'(Ah Chee, 2002), while an oracle dwelt in a purportedly bottomless spring near the Mulligan River in far western Queensland. This 'big fellow masser' was consulted in a peculiar manner, as recounted by surveyor Twisden Bedford (Bedford, 1886):

> *'…one Aboriginal taking a big stone in each hand, dived head first into the bubbling water. A second Aboriginal jumped in immediately afterwards, and catching hold of his predecessor's legs, which appeared above the surface of the water, forced him further down. A third Aboriginal then jumped in and forced the second down, all remaining under the water for as long a time as they could hold their breath in abeyance. They then all came to the surface, when the leading native gravely announced that he had interviewed the big fellow masser, and that big fellow flood come up along a one-fellow moon. And what is more, the flood did come in another month as predicted.'*

As well as being intrinsically sacred, springs were of vital importance in an arid land, as campsites and nodes in continent-wide trade and communication routes (Boyd, 1990; Harris, 2002). Archaeological remains associated with one camp site at Dalhousie extend for almost three kilometres (Bayly, 1999), while the scalded plain surrounding Youleen Springs in south-western Queensland has a rich and complex surface archaeology dating back at least 13 000 years (Robins, 1998). In May 1876, explorer William Hodgkinson met a group of 30-40 people west of the Diamantina River near a group of permanent springs, possibly Pathungra Springs. The country was showing signs of drought and people were congregating around the few remaining permanent waters (Hodgkinson, 1877). Stone tools are abundant across the claypans surrounding Pathungra Springs, and other springs along the Hamilton River. Mysteriously, artefacts are in very low densities at other springs, including a large group in otherwise waterless country north of Aramac in central Queensland.

1.3.2 European history

Pastoral settlement of inland Australia was profoundly limited by the availability of water. Pioneering squatters concentrated their runs and grazing activities on permanent waterholes along major rivers and the sparse network of artesian springs. Beyond these tiny nodes, however, vast tracts of land remained 'untrodden by hoof' (Jack, 1900). The GAB springs to the west and south of Lake Eyre played a vital role in 'opening up' the country (Harris, 2002). Explorer 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 used them on his six expeditions. His eventual triumphant transcontinental crossing in 1861-62 was only successful because of these springs (Bailey, 2006). The reliable water supply provided by the springs, coupled with favourable reports of grazing land, soon enticed pastoralists into the region. Later, two significant infrastructure developments, the

Overland Telegraph Line (completed in 1872) and Central Australian Railway (commenced in 1878) followed the arc of mound springs from the south to north-west of Lake Eyre (Gibbs, 2006).

Similarly, many roads and tracks in Queensland and New South Wales follow lines of springs. Although not as numerous or widespread as riverine waterholes (Silcock, 2009), 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).

When taking stock from the Channel Country to the Gulf, droving parties used Parker [Elizabeth] Springs as a vital stopover between the Diamantina and Georgina Rivers, and a man was engaged for the specific duty of maintaining the groundwater supply and its delivery through a network of drains (Nolan 2003).

Water was not merely a vital resource; it was also a blessed relief from the inland heat and the silence, holding out ‘the sweet, cool promise that things could be otherwise’ (Cathcart, 2009). Nevertheless, the utilitarian focus on springs almost completely nullified the sacred. Rather than ‘building altars and offering sacrifices’ as counselled by Roman philosopher Seneca, springs were drilled, drained and dug out in attempts to ‘improve’ them, although many were also fenced to stop stock becoming bogged. While the honest yeomanry of the frontier were not by nature given to superstition, their interferences with springs did sometimes seem to awaken dark spirits of the earth.

In a letter to the *Sydney Morning Herald* in 1882 J.E. Kelley provided a vivid description of his attempts at ‘improving’ a mud spring through drilling into a mound about two feet below its base:

> *‘All went well till the outside crust and sound ground were tunnelled through; but at the first dive of the bar into the ‘pudden’ the whole mound groaned and surged like a large hole in agony, and the first thing I saw was my man floating out the mouth of the drive at the rate of 10 knots on a small sea of cold, white, watery lava. The whole hill continued to groan and shake as it appeared to gather vent, and after every groan it discharged ton upon ton of this white batter from the drive. A superstitious person would have believed that the thing was alive’* (Kelley, 1882)

GAB springs also provided tantalising clues as to the existence of a vast supply of water below the parched inland, and played a wider role in the discovery, development and scientific understanding of the Basin. They were signposts to their own demise. The 1884 NSW Royal Commission on water conservation collected information on springs to examine the potential extent of groundwater supplies (Gilliat, 1885). Initially shallow bores were sunk near the springs where success was assured – the first of these was in 1879 at Wee Wattah Spring north of the Darling River, and others soon followed (Percy, 1906). While clean flowing water from these early bores could be conveniently directed into drains and troughs, this was only a modest improvement on springs and failed to capture public imagination or provide adequate proof for groundwater theorists.

More adventurous drilling to greater depths and at further distances from the springs through the 1880s gradually revealed a vast underground basin stretching from Richmond in Queensland to Oodnadatta in South Australia and Moree in New South Wales. Water was obtained at Thurulgoona Station south of Cunnamulla in 1886, and this success was quickly mirrored in other areas (Powell, 2012). This seemingly providential and boundless aquifer would come to be known as the Great Artesian Basin and delivered precious water from the bowels of the earth at enormous pressure.

Sinking of bores increased rapidly following severe stock losses in the Federation Drought (1898-1902) and it was a condition of pastoral 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 the combination of favourable seasons, high wool prices, improved technology and government subsidies gave pastoralists the opportunity to invest extensively in bores (Noble et al., 1998). By

1960, 18 000 (flowing artesian and non-flowing artesian or sub-artesian) bores had been drilled across the Great Artesian Basin, resulting in a drastic loss of pressure in the aquifer. Total recorded discharge from free-flowing artesian bores in the Basin was >2000 MegaLitres (ML) per day from 1700 bores in 1916, but by 1998 <1000 ML/day was discharging from 3400 bores (GABCC, 2000).

Spring flows across the Basin and in the discharge areas of the GAB declined in concert. By the 1920s, it was obvious that the bores had an impact on the springs. An article in the Longreach Leader titled ‘Artesian Waters: where do they come from?’ noted:

> *…There are also extinct mound springs, which flowed before the artesian waters were tapped. More and more of the western mound springs are giving out as the drain on the artesian basin is increased* (February 1923, p.4)

Existing data indicate that some 40% of discharge spring groups (in Queensland) have become completely inactive since pastoral settlement, while some springs within another 14% of groups are inactive (Fairfax and Fensham, 2002; Fensham et al., 2004). The loss of springs in Queensland, as a result of aquifer draw-down has been most severe in the Flinders River, Bourke, Springvale, Barcaldine and Eulo supergroups (Figure 1).

Though the springs continued to be utilised by pastoralists, the seemingly inexhaustible supplies obtained from flowing and non-flowing artesian bores meant that springs played an increasingly peripheral role. Bores were celebrated in both folklore and the annals of the colonial scientific literature. The vision of towering rigs and water gushing up from the depths of the earth (Figure 3) became the stuff of legend as powerfully encapsulated in Banjo Paterson’s poem *Song of the Artesian Water* (Paterson 1896). The miracle of groundwater was easier to appreciate in the form of clear gushing fountains as opposed to muddy, wobbling quagmires. Springs, once the life blood of early settlement, faded into obscurity, a mere footnote in the historical development of one of the world’s largest artesian basins.

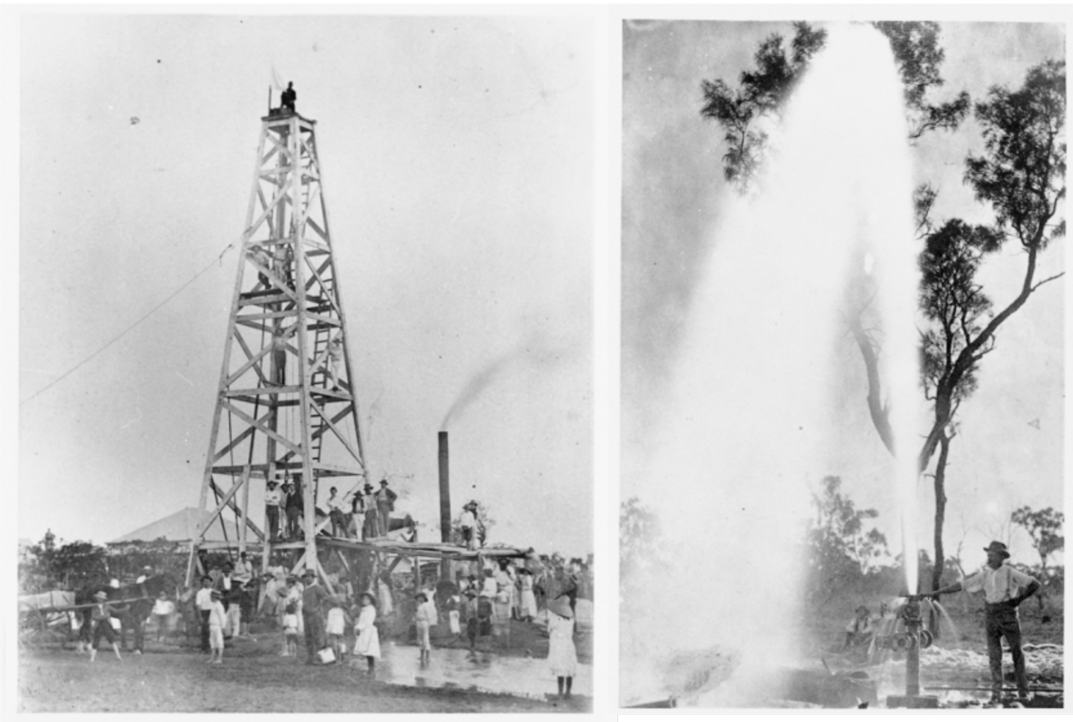

Figure 3. Drilling rigs and gushing bores: the stuff of Australian legend

In some respects mirroring the global resurgence of spring pilgrimages, well-dressings and health spas, Australia’s Great Artesian Basin springs have re-entered the public and scientific consciousness over the past three decades. Desert springs in South Australia, notably Blanche Cup, The Bubbler and Dalhousie Springs have become popular tourist destinations (Schmiechen, 2004), while elsewhere artesian spas, artesian mud baths and nature drives have been established. Traditional owners and pastoralists continue to tell stories about the springs, and there are even (unconfirmed) nymph sightings from time to time. Springs have also become the focus of biological surveys, which have revealed an astounding diversity of specialised and strange life forms.

1.4 Biological values

Globally, wetlands tend to have low levels of endemism, and favour plants and animals that are mobile or readily dispersed (Junk, 2006; Horwitz et al., 2009), because they are relatively ephemeral ecosystems. Wetlands that have persisted through glacial periods of aridity provide habitat for relictual species that were more widespread in wetter times (De Deckker, 1986; Davis et al., 1993; Murphy et al., 2010). GAB discharge springs are distinctive wetlands that have (Fensham et al., 2011):

- permanent and relatively constant water levels
- an unusual water chemistry
- great antiquity
- isolation from other wetlands.

These factors have combined to create a remarkable concentration of specialised endemics from this habitat, which have persisted despite the extinction of many springs and more recent local disturbances from excavation, invasive species and introduced herbivores. GAB discharge spring wetlands are listed as a nationally endangered ecological community under the *Environment Protection and Biodiversity Conservation Act 1999* (Cwlth).

Fourteen vascular plant species are endemic to GAB discharge spring wetlands. Some are widespread across numerous supergroups (e.g. *Eriocaulon carsonii, Myriophyllum artesium*), and others are restricted to a single spring or spring complex, e.g. *Eriocaulon giganteum* and *E. aloefolium* in the Pelican Creek complex; and *Panicum* sp. (Doongmabulla RJ Fensham 6555) at Doongmabulla). As permanently wet habitats in an arid land, discharge springs also support extremely disjunct populations of some plant species, including *Gahnia trifida* and *Baumea juncea* in South Australia (Clarke et al., 2013), and *Cenchrus purpurascens* (formerly *Pennisetum alopecuroides*) and *Schoenus falcatus* in Queensland (Fensham et al., 2010).

Sodic and salty groundwater scalds are often associated with discharge springs, and these areas have a specialised non-aquatic flora. Two species endemic to this habitat occur only on Edgbaston Reserve in the Barcaldine supergroup: *Gunniopsis* species (RJ Fensham 5094) is known from three populations within a two-square-kilometre area, totalling just 80 plants, while the recently-described *Pluchea alata* (Bean, 2013b) is patchily common in restricted areas around the margins of springs. Four other species are also endemic to scalds adjacent to springs in the Barcaldine supergroup: *Chloris* sp. (Edgbaston RJ Fensham 5694), *Dissocarpos sp.* (Doongmabulla E.J. Thompson+GAL21), *Calocephalus* sp. (Edgbaston J.Silcock JLS800) and an undescribed *Sclerolaena* species. The Eulo supergroup is also home to an undescribed *Calocephalus* sp. (ME Ballingall MEB2590). The near threatened (Queensland Nature Conservation Act 1992) *Sporobolus partimpatens* is known from groundwater scalds across five supergroups, while *Trianthema* sp. (Coorabulka R.W. Purdie 1404) is a widespread scald indicator across the Basin.

Eight fish species are endemic to the GAB: five are recorded only from Dalhousie in South Australia (Glover, 1989), two are restricted to a single spring complex in the Barcaldine supergroup and one to Elizabeth Springs in the Springvale supergroup (Wager, 1995; Fairfax et al., 2007). The radiation of molluscs is especially remarkable, with 38 species endemic to GAB discharge springs, including 26 that are restricted to a single spring group (Ponder et al., 1989; Ponder and Clark, 1990; Ponder, 1995; Worthington-Wilmer et al., 2008; Fensham et al., 2010). Discharge springs are also centres for other specialised biota, including spiders, beetles, leeches, crustaceans and flatworms, many of which have very restricted distributions (Zeidler, 1997; Fensham et al., 2010). Bacteria-like organisms occur in GAB aquifers (Kanso and Patel, 2003), however spring microorganisms remain extremely poorly characterised.

In contrast, the neutral or acidic water chemistry, and greater temporal fluctuations of GAB outcrop springs and Tertiary springs seem to have limited the evolution of specialised endemics. These springs tend to emanate from sandstone gullies and are dominated by generalist wetland species from this habitat, including a variety of ferns and sedges (Fensham et al., 2011). They do, however, provide habitat for very isolated populations of species otherwise restricted to much wetter climates, but some in the Springsure supergroup contain endemic species.

1.5 General threats and management actions

1.5.1 Groundwater use and preservation

Following the sinking of Wee Wattah bore near Bourke in 1878, subsequent tapping of the Great Artesian Basin occurred rapidly (Powell et al., 2015). Within a few years, pastoralists had proven that supplies were available at various depths across vast expanses of inland eastern Australia. The number of bores increased substantially following severe stock losses in the ‘Federation Drought’ (1898-2902) and it was a condition of pastoral 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 and Tongway, 1983). By 1960, 18 000 bores had been drilled across the GAB (Fisher and Hahn, 1963). This mass exploitation of GAB groundwater resulted in a drastic loss of pressure in the aquifers. This is reflected by the fact that total recorded discharge from free-flowing artesian bores in the Basin was >2000 MegaLitres per day from 1700 bores in 1916, but by 1998 <1000 ML/day was discharging from 3400 bores (GABCC 1988).

Spring flows in the discharge areas of the GAB have also declined dramatically with diminished aquifer pressure. Existing data indicate that 40 percent of discharge spring complexes in the GAB have become completely inactive during the period of pastoral settlement. Some springs within another 14 percent of spring complexes are inactive. The loss of springs as a result of aquifer draw-down has been most severe in the Flinders River, Bourke, Springvale, Barcaldine and Eulo supergroups.

The Great Artesian Basin Sustainability Initiative (GABSI) provides a substantial level of Australian Government and State Government assistance to landholders to rehabilitate flowing artesian bores and replace the open earth bore drains of free-flowing artesian bores with piped water distribution systems throughout the GAB.

The Great Artesian Basin Bore Rehabilitation Program preceded the GABSI program from 1989 to 1999, when 345 bores were rehabilitated during the period 1989 to 1997, at a cost of $A15.18 million, and 1,385 km piping was installed (Reyenga et al., 1998). GABSI funding for the period 1999 to 2014 amounted to $A 110.694 million, which was matched by the State and Territory governments. A further $A 15.9 million allocation will be available from the Australian Government over 3 years from 2015. The number of water-bores controlled under GABSI during the period 1999-2014 was 695 bores and 20,736 km of open bore drains were eliminated, and 30,672 km of piping was installed. Groundwater ‘savings’ have been estimated at 219,872 ML/year during the 1999-2014 period (pers. comm. Australian Government Department of Environment, 2015). GABSI assists the implementation of the Great Artesian Basin Strategic Management Plan prepared by the Great Artesian Basin Coordinating Committee (GABCC 2000). The Plan provides for the restoration of the environmental assets of the Great Artesian Basin with an emphasis on springs (GABCC 2000).

Curiously there are no examples, from Queensland at least, where previously extinct springs have become reactivated because of restored aquifer pressure. However, it is possible some springs have been preserved against further diminishment because of the restoration of aquifer pressure in some areas as a result of GABSI.

1.5.2 Conservation through tenure security

In Queensland, Nature Refuge Conservation Agreements are signed between landholders and the State. These agreements may allow for continued production and land management activities such as sustainable grazing and water use, but prohibit further excavation, the introduction of exotic species to the springs and groundwater extraction that will impact on spring flows. It is possible for extension officers to undertake property assessments, negotiation of the conservation agreement and provide follow-up advice and assistance with management. Some springs with high conservation values are already covered by Nature Refuges, notably Doongmabulla Springs.

1.5.3 Total grazing pressure and fencing

Total grazing pressure from domestic (cattle and sheep), feral (goats, pigs and horses) and native (macropods) animals can be considerable around the margins of springs. While some springs are fenced to exclude domestic stock and prevent them from getting bogged, over two-thirds of springs surveyed by Fensham & Fairfax (2003) had some trampling damage. The effects of grazing and trampling can be particularly severe in small spring wetlands where animals can gain unrestricted access. The interior of some large spring wetlands are generally unaffected by grazing because the amorphous substrates are often boggy and can be a death trap for large animals. As well as the physical impact of grazing and trampling, spring water can become contaminated by stock urine and faeces.

However, the impact of domestic stock is not as disruptive to springs vegetation as rooting by feral pigs. Pigs are capable of upturning and killing large areas of vegetation in a single feeding frenzy, and seem to have a particular preference for areas of *Eriocaulon* species. Pigs may also degrade the habitat for specialised fauna which depend upon shallow clear pools and/or spring wetland vegetation. Paradoxically, however, pigs may have some role in maintaining open water habitat for endemic fish species.

The standard management response to stock and feral animal disturbance is fencing of individual springs or groups of springs. There are numerous examples where this has greatly improved the health of springs. Wetland recovery can be rapid following stock removal. For example, the salt pipewort population has expanded substantially at West Finniss Springs since the removal of stock from ‘Finniss Springs’ Station in South Australia (Fatchen, 2000). Similarly, endemic aquatic invertebrate numbers have been observed to drastically decline in heavily stock-damaged springs but can recover quickly once stock are removed if some resident populations survive (Kinhill–Stearns, 1984). The fencing of springs in the Eulo supergroup has resulted in rapid recovery of groundcover, including the endemic poached-egg daisy *Calocephalus* sp. (Eulo M.E.Ballingall MEB2590).

Ironically, however, fencing can also have negative impacts. Fatchen (2000) has reviewed the effects of fencing on the natural values of springs and clearly demonstrates results peculiar to individual sites. The total exclusion of grazing from stock and feral animals either by fencing or de-stocking has resulted in the proliferation of the tall reed *Phragmites* in some spring wetlands. At Big Cadna–Owie Spring (Fatchen, 2000) in the Lake Eyre Supergroup, the proliferation of *Phragmites* in the spring vent has altered habitat and may be the cause of the local extinction of endemic snails. At Hermit Hill spring complex the growth and spread of *Phragmites* has resulted in the substantial decline in the area covered by salt pipewort particularly around vents (Fatchen & Fatchen 1993). Impacts of *Phragmites* proliferation seem to have stabilised over the last five years of monitoring at Hermit Hill with tall beds of *Phragmites* on small springs and the vents of the larger springs, and short herbfields occupying the tails of the larger spring wetlands. Fensham et al. (2004b) suggest that this may not be a universal phenomenon with grazing relief even when *Phragmites* and the salt pipewort are both present at a site. Low levels of pig disturbance can also maintain open water habitats required by endemic fish species, such as the Elizabeth springs goby and red-finned blue-eye., however the associated muddying of the clear, shallow water may somewhat undermine this benefit.

These issues raise the question of how open habitats within springs were maintained prior to the arrival of introduced herbivores. Although springs would have been a focal point for macropods, especially in more arid areas, Niejalke (1998) argues that the density of native herbivores prior to European settlement would have been too low to maintain open areas. It is possible that Aboriginal people burnt dense swards of vegetation on some springs, however monitoring in South Australia suggests that stands of *Phragmites* recover rapidly after burning, and that grazing is a more effective means of controlling this species in springs. Aboriginal people actively managed, maintained and in some cases augmented water supplies across inland Australia, including digging wells and cleaning out rockholes (Hercus and Clarke, 1986; Bayly, 1999; Wilson et al., 2004). On the 14 January 1860 while traversing the Lake Eyre supergroup, John McDouall Stuart 'Discovered a spring in one of the creeks that runs east from Mount Margaret. The natives had cleared it out, and the water, which was very good, was about two feet from the surface' (Stuart, 1865). This observation suggests there was an established practice of maintaining water-flow in GAB springs, through manual excavation and perhaps indirectly through harvesting of plants for weaving and edible tubers. Moreover, given the massive declines in aquifer pressure, many springs would have had greater discharge and therefore larger pools of water prior to bore drilling. These factors mean that the area of clear pools has almost certainly been substantially reduced since European settlement, and the protection of these microhabitats should be paramount.

Management of disturbance and grazing pressure must be assessed on a case-by-case basis. The response of spring flora and fauna to grazing relief, through fencing or stock removal, requires ongoing monitoring, particularly at sites where stock have been removed and *Phragmites* is present. In some cases, it would be appropriate to maintain a grazing regime on spring wetlands. Building a gate on any fence provides the necessary flexibility for future management.

1.5.4 Invasive species

In a survey of Queensland springs, Fensham and Fairfax (2003) recorded 23 exotic plant species. Eleven of these were grasses, and the greatest threat is posed by those that are sown as 'ponded pastures' to provide fodder for domestic stock. These water-tolerant, vigorous exotic grasses have the capacity to take over entire spring wetlands, forming monospecific stands at the expense of native spring species. Three perennial ponded pasture species have been recorded in GAB spring wetlands: para grass *Urochloa mutica* is known from 12 springs, while single populations of hymenachne *Hymenachne amplexicaulis* and alamein grass *Echinochloa polystachya* have been recorded. These grasses may be dispersed via overland flow or wetland birds, and represent a serious threat to the natural values of spring wetlands in the areas where they occur. Date palms *Phoenix dactylifera* have proliferated at a number of spring complexes in Queensland and South Australia, most notably the large infestation at Dalhousie Springs in the Dalhousie supergroup in South Australia. There are also examples where woody exotics have become established in the broader non-wetland environment around springs. Examples include rubber vine *Cryptostegia grandiflora* at Lagoon Springs at Corinda and parkinsonia *Parkinsonia aculeata* and prickly acacia *Acacia nilotica* at Edgbaston, both in the Barcaldine supergroup. Generally these infestations, while worthy of eradication, do not directly affect the values of the spring.

Introduced aquatic fauna such as mosquito fish *Gambusia holbrooki* are present in many larger springs and may pose a serious threat to native fauna through predation and competition (Wager and Unmack, 2000). Cane toads *Rhinella marinus* are found in many of the springs in the eastern part of the GAB in Queensland and eat endemic invertebrates and under high population densities, such as those that occur with the hatching of a clutch of toadlets, may have a deleterious effect on invertebrate populations (Clifford et al., 2013). At Pelican Creek springs the critically endangered red-finned blue-eye *Scaturiginichthys vermeilipinnis* is facing extinction as a result of gambusia invading its habitat, as discussed in detail in section 3.6.2.3.

Management issues and recovery actions need to be assessed on a case-by-case basis, as detailed for each supergroup in the sections below.

2 Methods

2.1 Project aims

The aims of this project were to:

1) Assess the location and status of all springs in the LEBSA study area in Queensland (see Introduction for overview of geographical scope of LEBSA project)
2) Examine the hydrogeology of these springs in relation to potential developments in these areas
3) Record the history and cultural values of springs
4) Assess their contemporary biological values
5) Assess the nature and severity of threats to springs and their dependent species and communities; and
6) Determine any signs of recovery with bore capping and potential for habitat restoration

2.2 Hydrogeological methods

The interpretation of the hydrogeology of the springs is usually underpinned by the existing mapping of the geology in the region of the springs. Detailed interpretations of spring clusters were developed from a digital elevation model, surface mapping of solid geology, fault structure mapping and the stratigraphy provided by bore logs (Table 1).

The potentiometric surface of the relevant aquifers was interpreted from the modelled GIS surfaces extrapolated from groundwater measurements and in some cases surfaces were determined for the purposes of this report from individual bores where a more local measure was required. In these cases the standing water level was translated to the elevations of the DEM. For example a bore with a standing water level of -2m (i.e. 2m below the ground surface), and a surveyed elevation of 243m, with a DEM elevation of 241m was assigned a standing water level of 239m. This allows for consistent comparison between bores and springs because the DEM is the only source of uniform elevations across the study area. In many instances it was necessary to utilise information from bores that were not directly aligned with our stratigraphy lines. The springs we represent on our stratigraphic diagrams may also be displaced from our stratigraphic line. We made no attempt to adjust stratigraphy for potential elevation differences between bores and springs and the stratigraphic profile they inform. However, where the elevation of a bore or spring is substantially different from the point on a stratigraphy that it represents, we have represented this difference by positioning the actual elevation of the bore (above or below the ground surface) on the stratigraphic profile. The standing water level of a projected bore is transposed directly to the stratigraphic line as the potentiometric head. However, the values of standing water levels provided in the figure captions come directly from the location of the bore itself. Where potentiometric head has been inferred from a pressure measurement we converted using pounds per square inches divided by 1.42, which equals head in metres.

All elevations were derived from a digital elevation model (Table 1) to ensure consistency. An analysis was conducted comparing the elevations from the Digital Elevation Model with the Queensland state survey data (Appendix A) within a large area of Queensland encompassing springs. This analysis suggests an absolute accuracy whereby 13.8% of locations have elevations accurate within 2m, and 35.0% of locations accurate to within 3m. The same assessment for relative accuracy (i.e. accuracy of the difference in elevations between locations) is much improved with 75.9% of locations having elevations accurate to within 2m and 86.2% within 3m. This discrepancy is exaggerated where topography is rugged and tree cover is high. Springs and bores tend to be positioned in open flat areas and it is suggested that in these locations accuracy will be within 2m.

The possibility that some springs have a groundwater source within a localised aquifer was tested using the following method:

1) A recharge catchment was inferred from upslope areas and surface drainage within the same geological unit where a spring or group of springs is located

2) The recharge volume over this catchment was determined from mean annual rainfall

3) The discharge of the springs was compared with recharge over the inferred catchment.

Table 1. Data sources for interpretation of spring hydrogeology

Product	Source

Geological basins	http://www.ga.gov.au/metadata-gateway/metadata/record/gcat_c3fac1d5-48c1-624e-e044-00144fdd4fa6/Australian+Geological+Provinces%2C+2013.01+edition
Solid geology	http://data.gov.au/dataset/hydrogeology-of-the-great-artesian-basin-boundaries-of-the-hydrogeological-units/resource/9f96d59d-9839-4cde-929a-911f4302da64
Fault structures	http://www.ga.gov.au/metadata-gateway/metadata/record/gcat_d9838342-57d3-09d4-e044-00144fdd4fa6/Great+Artesian+Basin+major+geological+structural+elements
Potentionometric surface (Ronlow Beds, Hutton Sandstone, Hooray Sandstone)	Analysis_Galilee_hydrogeological_investigations. V.2 (supplied by Geosciences Australia)
Great Artesian Basin	Habermehl and Lau (1997)
Geological maps (1:250 000 series)	Julia Creek (Vine et al., 1961); Millungera (Grimes and McLaren, 1972); Boulia (Casey et al., 1967); (Vine and Doutch, 1972); Tambo (Exon et al., 1969); Galilee (Vine et al., 1972a); Jericho (Vine et al., 1972b)
Digital Elevation Model	1 second SRTM Derived Hydrological Digital Elevation Model (DEM-H) version 1.0. Available from the Geosciences Australia at: http://www.ga.gov.au/metadata-gateway/metadata/record/gcat_a05f7893-0050-7506-e044-00144fdd4fa6/1+second+SRTM+Derived+Hydrological+Digital+Elevation+Model+%28DEM-H%29+version+1.0

2.3 Historical records

Firstly, we conducted a systematic analysis of historical records of springs. We examined several sets of historical maps, including original pastoral run surveys (drafted between 1860 and 1890) and historical sheet maps (1880-1940), as well as more recent topographic maps (1964-2008). We reviewed historical literature relevant to the spring areas, including explorer journals, newspaper articles accessed through the National Library of Australia Trove website (http://trove.nla.gov.au/), reports of government geologists and land/water inspectors, official government reports and books. People with long-term knowledge of the springs districts and/or specific groups of springs were interviewed.

2.4 Spring surveys

This historical analysis formed the basis of a comprehensive on-ground survey of springs in the Barcaldine, Flinders River and Springvale supergroups, as well as the Galilee and Tertiary springs. Once a spring had been located in the historical record, we used a combination of mapping software (ArcGIS 10.1) and aerial imagery (mostly that available on Google Earth) to interpret the spring's location in the landscape and obtain an approximate coordinate. During field survey, the combination of our assigned coordinates and the local knowledge of landholders were usually sufficient to locate the springs. Springs can often be detected through a series of visual cues including soil dampness (indicating the spring is potentially active), mounding, scalded terrain (due to carbonate deposits) and sunken depressions. Evidence of both Aboriginal (stone flakes and cores, hearths, grindstones) and European (e.g. old fences or yards, ruins of buildings, wells, bottles, tin) occupation in an otherwise waterless area may also indicate the presence of a now-inactive spring (Fensham et al., In press).

At all sites, the landscape position and surrounding vegetation were described and photos taken. Each vent in a spring group was marked with a hand-held GPS and its activity status recorded. For active springs, soak and wetland area (defined as >50% cover of wetland vegetation), excavation damage (wells, pipes, bores, direct excavation) and impacts of stock and feral animals were recorded. All plant species present in the spring wetland were recorded, and the wetland was surveyed for molluscs, fish and invertebrates. Unidentified and significant plant species were vouchered and these collections have been lodged at the Queensland Herbarium. For rare and threatened species (Silcock et al., 2014), detailed assessments of habitat, population size, extent and threats were made (Keith, 2000). Where springs had free water, pH and conductivity measurements were taken. Alkalinity was also measured at some springs.

2.5 Springs database and spring reports

The data generated through this project has been incorporated into a database using Microsoft Access. The intention is to develop a single database that can store data on springs and is compatible across research groups working in both Queensland and South Australia. The spring database includes 12 tables storing data derived from a combination of extensive field survey, historical evidence and interpretation, and water chemistry from laboratory analysis. Some data is also derived from currently existing datasets (e.g. surface geology maps, digital elevation model). Derived data is explicitly flagged in the metadata (**Figure. Histogram presenting the percentage of locations according to the categories of the difference in elevation between the ground control points and the Digital Elevation Model for an area of central Queensland. The values on the x axis represent the upper limit of each category.**

Appendix B). The 12 tables are linked using primary keys described in Figure 4. A description of each table is provided (

Table **2**) and individual fields are clearly defined in the metadata (**Figure. Histogram presenting the percentage of locations according to the categories of the difference in elevation between the ground control points and the Digital Elevation Model for an area of central Queensland. The values on the x axis represent the upper limit of each category.**

Appendix B). The database must represent relationships between the entities being assessed. For example there can be multiple spring vents in individual spring wetlands and the data tables in the database allow for data related to both separate vents and the separate wetlands.

There can also be data relating to individual wetlands that is collected from multiple survey visits and the database also allows for these relationships where necessary (Figure 4). While most data is included in the database, photographs and additional reports (including historical information) (see Appendix C for an example) are contained in directories that are identified through the Site Details table. The photographs are further organised within Imatch (3.6) software although photographs can be searched for and viewed without this software.

Table 2. Descriptions of the 12 tables in the database

Table Name	Description
A. Site Details	Physical information about a spring vent that is not likely to change through time (e.g. location, geological setting)
B. Spring	The spring wetland area, connectivity and flow at each date of visit (visit number)
C. Condition	Disturbance level from excavation, feral and domestic stock as well as morphology of the vent at each date of visit

Table Name	Description
D. Observers	One or more observers present on a visit date
E. Photos	Photographs of springs including a date, description, GPS coordinate and locality
F. Flora Record	Record of each plant species recorded on different dates, as well as other attributes of this specific population (e.g. isolated population)
F. Flora Taxa	Taxon name for each plant species including its ID number in Herbrecs (QLD Herbarium database) and its status (e.g. endemic, EPBC listed, invasive)
G. Fauna Record	Record of each species of animal recorded at different dates. Abundance, and other attributes of this specific population (e.g. Isolated population)
G. Fauna Taxa	Taxon name for each animal species including an ID number and its status (e.g. endemic, EPBC listed, invasive)
H. Water	Record of pH, temperature, conductivity, alkalinity, at a specified distance from the vent at different visit dates. Other specific attribute of the recording.
I. Chemistry	Chemistry data from laboratory analysis from samples at specified distances from the vent
K. GDE-ATLAS	GDE Atlas attributes allowing the inclusion of the spring database into the GDE Atlas
K. Conservation Ranking	Conservation status of each spring according to EPBC criteria

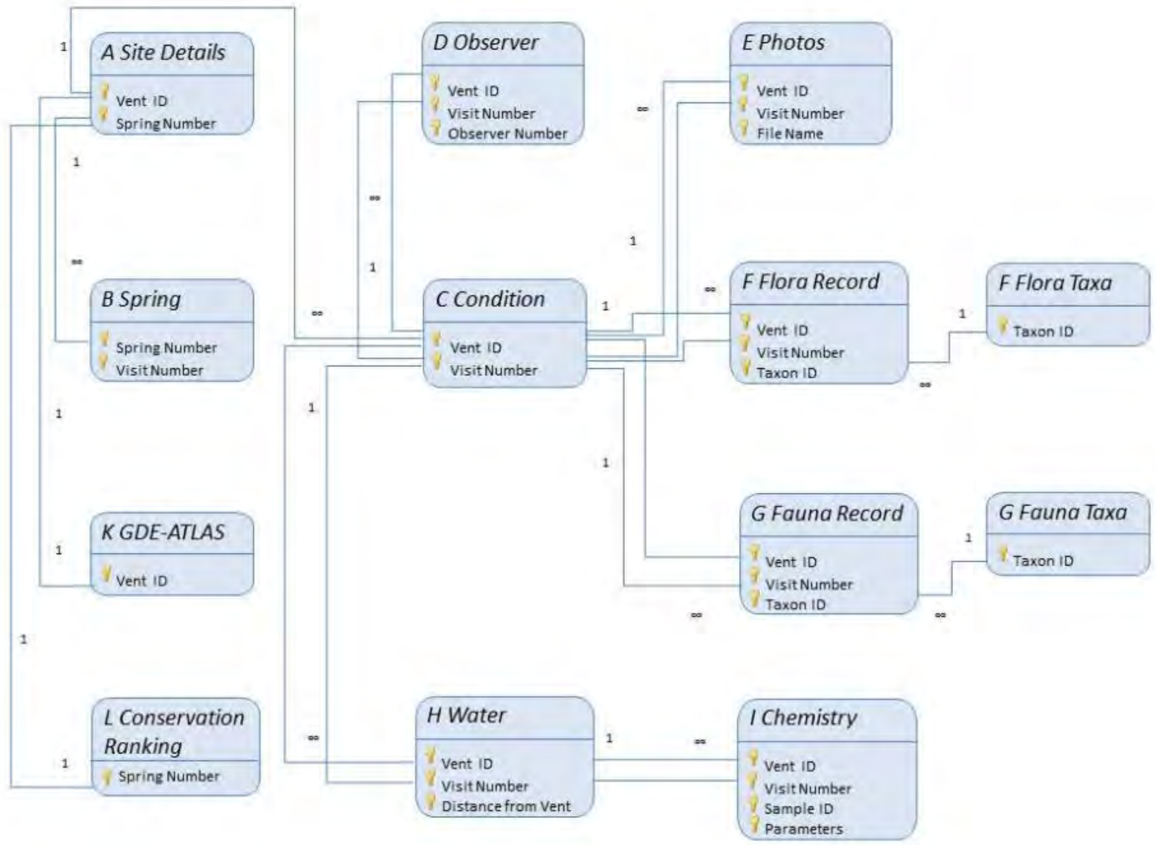

Figure 4. Relationships of the tables in the LEBSA database. The primary keys under each table name define the attributes that are necessary for a record to be entered in that table. The links are defined by the primary keys that they relate to and the relationship type (one-to-one or one-to-many). One-to-one relationships links a single record of a table to a single other record of another table. One-to-many relationships link multiple

record of a table to a single one of another table (i.e. multiple record of the spring 'Condition' for a single vent at different date).

2.6 Data extent

The locality of the vast majority of the discharge springs in the target areas has been identified (Table 3). Determining the actual locality of all outcrop springs is an exceedingly difficult task because there is leakage at a range of scales and permanence (depending on seasonal conditions) from outcropping sandstone. The botanical inventories are complete for a large number of springs, but subsequent visits will lead to further refinement. The sampling of invertebrates is much less complete, but is limited by the availability of an adequate taxonomy to identify species and endemism.

Table 3. Summary of the extent (percent available) of existing data represented by this report and previous reports for active spring complexes in the Queensland and New South Wales sections of the Great Artesian Basin

Supergroup Name	Type	Region	Plant census	Invertebrate census	Water chemistry	Source Aquifer	Historical report
Arid Tertiary	Outcrop	Arid Tertiary	92	34	84	100	100
Barcaldine	Discharge	GAB	88	100	88	100	100
Barcaldine	Outcrop	GAB	84	80	76	100	100
Bourke	Discharge	GAB	50	100	80	0	100
Doongmabulla	Discharge	GAB	100	100	100	100	100
Eulo	Discharge	GAB	82	95	69	0	100
Flinders River	Discharge	GAB	89	67	78	100	100
Flinders River	Outcrop	GAB	54	21	54	100	75
Galilee-Permian	Discharge	Galilee-Permian	100	100	100	100	100
Galilee-Permian	Outcrop	Galilee-Permian	100	100	100	100	100
Galilee-Triassic	Outcrop	Galilee-Triassic	100	50	100	100	100
Mitchell/Staaten	Discharge	GAB	100	0	100	0	0
Mitchell/Staaten	Outcrop	GAB	100	50	100	100	0
Mulligan	Discharge	GAB	75	100	92	0	100
Springsure	Discharge	GAB	100	91	55	100	100
Springsure	Outcrop	GAB	70	60	43	55	80
Springvale	Discharge	GAB	86	57	57	100	100

3 Barcaldine Supergroup

3.1 Overview

Springs comprising the Barcaldine supergroup occur over a 330 x 100 km area (Figure 5) and include 287 active spring wetlands, and 50 inactive springs. Thirteen percent of the outcrop springs and 15% of the discharge springs are inactive (

Table 4). The springs are concentrated in two lines: a western line of predominantly discharge springs and an eastern line comprising outcrop springs (Figure 5). There are also non-GAB springs emanating from local Tertiary sandstone aquifers to the west, east and south of the supergroup, and covered in Section 9. The springs at Doongmabulla/Labona have previously been included in this supergroup and may be appropriately included in this group in subsequent collations, but are treated separately in this report because of ambiguity about their source aquifer and potential impacts from proposed coal mining developments.

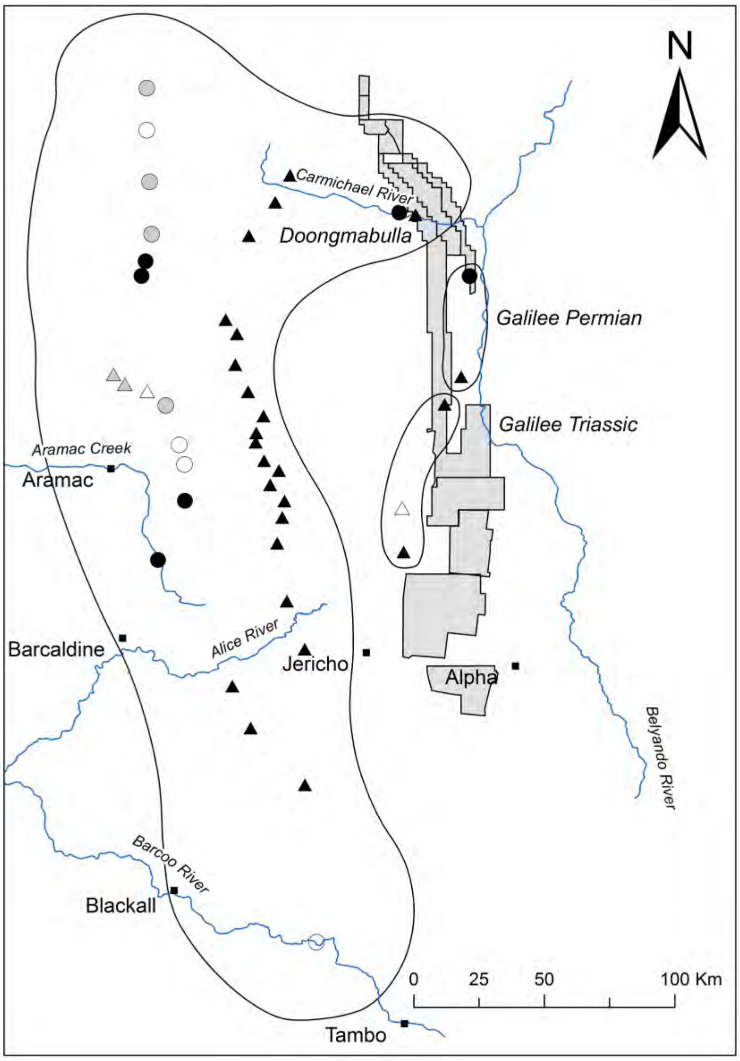

Figure 5. Spring complexes within the Barcaldine supergroup with the Doongmabulla, Galilee Permian and Galilee Triassic spring groups identified. Spring complexes showing 100% active springs (solid), partially (1%-99%) active (grey) and 100% inactive (open symbols). Outcrop springs (triangles) are distinguished from discharge springs (circles). The leases for the proposed coal mining developments in the Galilee Basin are shown (grey polygons).

Table 4. Summary of the status of the springs in the Barcaldine supergroup (excluding Doongmabulla) at the complex, wetland and vent scale.

	Complex			Spring		Vent	
	Active	Partially active	Inactive	Active	Inactive	Active	Inactive
Outcrop	21	3	1	71	11	78	11
Discharge	4	4	4	216	39	218	39

The outcrop springs within the Barcaldine supergroup occur towards the eastern margin of the Eromanga Basin where the sediments comprising aquifer units are outcropping (Figure 6). The springs typically occur in relatively flat terrain where there is outcropping sandstone. Most of these springs have been excavated and for some the water level is below the rim of the excavated sandstone (Figure 7).

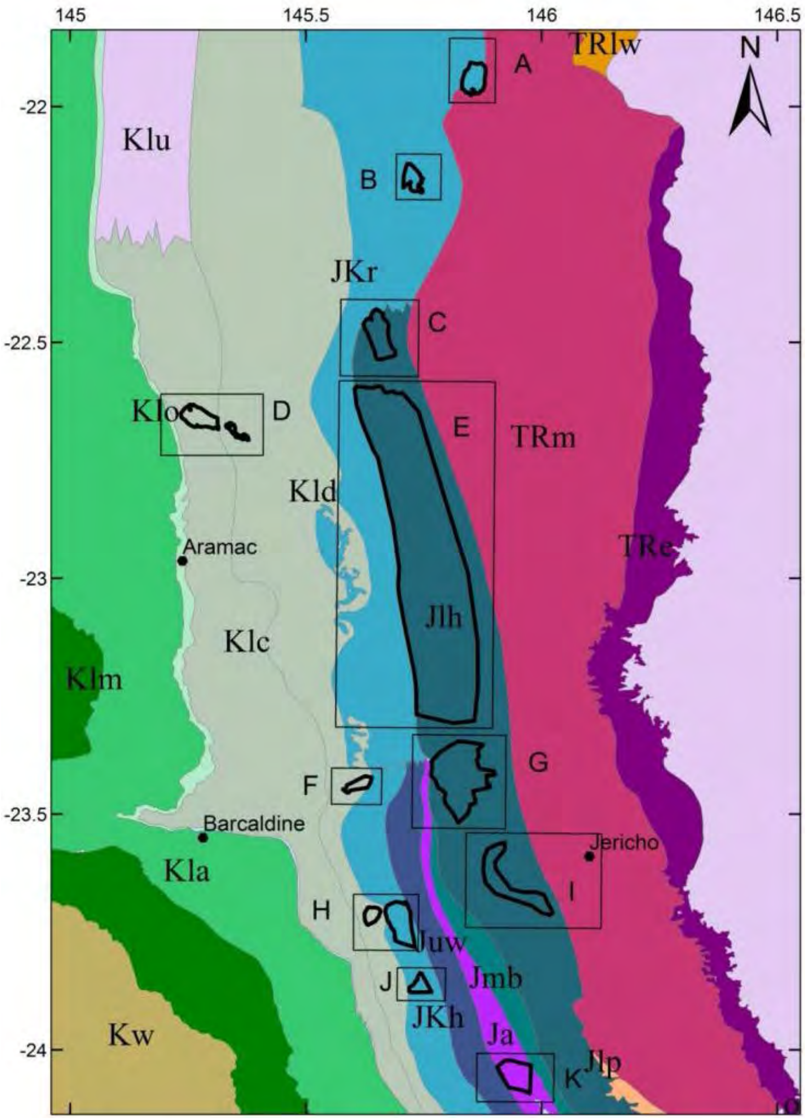

Figure 6. Outcrop springs (labelled polygons) in the eastern Barcaldine supergroup with the consolidated sedimentary geology of the Great Artesian Basin (i.e. Cainozoic units) removed.
Tre: Clematis Sandstone; Trlw: Warrang Sandstone; Trm: Moolayember Formation; Jlp: Precipice Sandstone; Jlh: Hutton Sandstone; Jkr: Ronlow Beds; Jmb: Birkhead Formation; Ja, Adori Sandstone, Juw, Westbourne Formation; Jkh, Hooray Sandstone; Kld, Doncaster Member, Klc, Coreena Member; Klo: Toolebuc Formation; Kla: Allaru Mudstone; Klo: Mockunda Formation; Kw: Winton Formation (Data source: Hydrogeology of the Great Artesian Basin-boundaries of the hydrogeological units, GeoSciences Australia, 2014, catalogue no. 72665).

Figure 7. Box Flat Spring is typical of the springs in the eastern Barcaldine supergroup, occurring in flat terrain with sandstone outcropping and having been excavated.

The discharge springs extend in a north-south line. In the middle section this line of springs is associated with the floodplains of the tributaries of Aramac Creek, and in the northern section by the floodplain of Thunderbolt Creek. These sections are intersected by a residual plateau (Figure 8). In the far south almost 200 km from the other discharge springs in this supergroup are the Northampton Hotel springs to the east-south-east of Blackall.

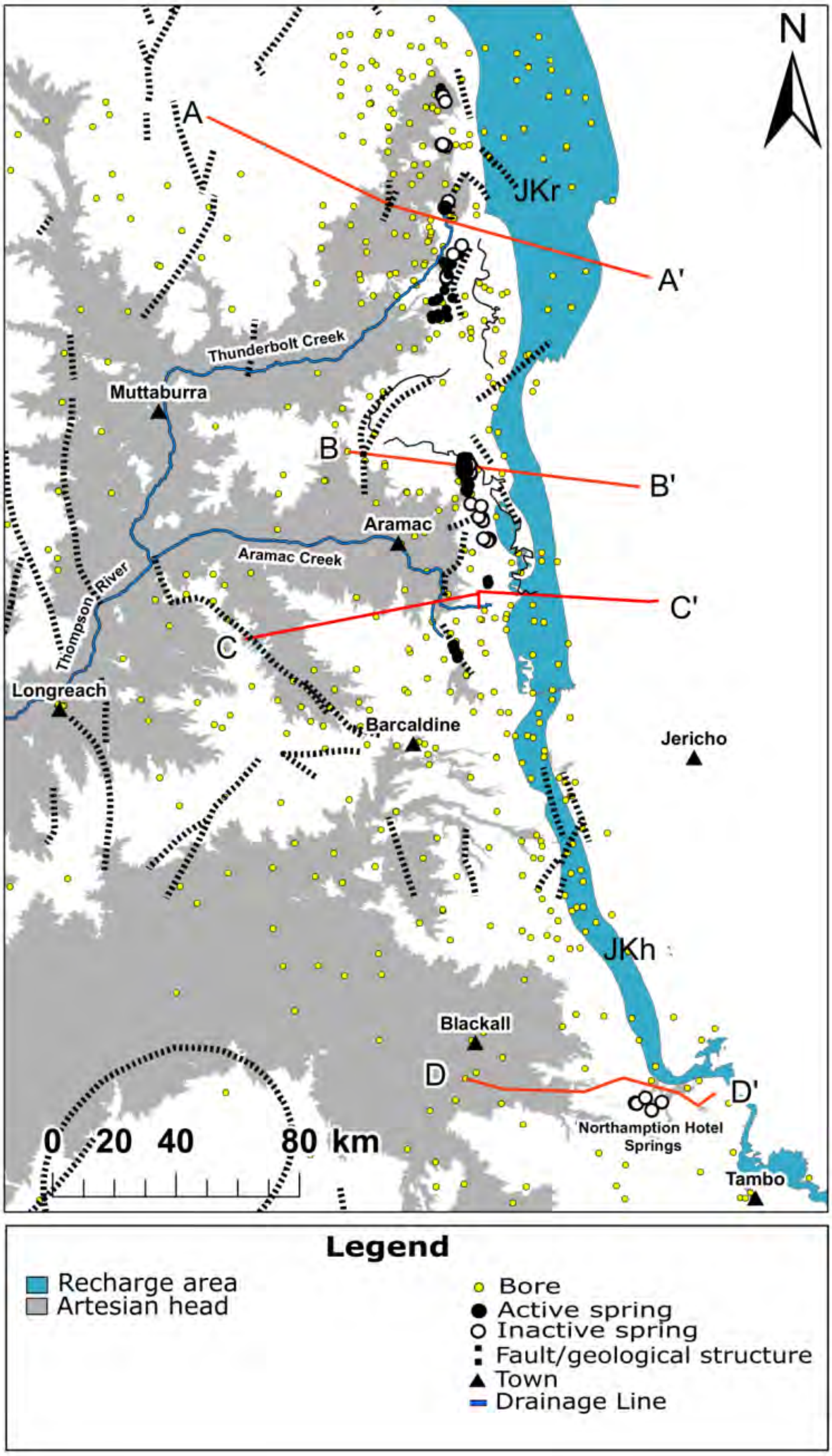

Figure 8. The Barcaldine supergroup discharge springs. The outcropping Ronlow Beds (Jkr)/Hooray sandstone (Jkh) that provide the water source for the springs is identified in blue. Bores are identified in yellow. Stratigraphies presented below are identified.

3.2 Hydrogeology

3.2.1 Regional geology

The stratigraphic relations between the sedimentary units in the vicinity of the Barcaldine supergroup outcrop springs is presented in Figure 2c. The base of this sequence is formed by the water-bearing Hutton Sandstone which is overlain by the Injune Creek group of sediments (including interbedded units mostly forming non-porous aquicludes and aquitards). These are overlain by the Hooray Sandstone, often identified as Ronlow Beds forming an equivalent in this region. The Hooray Sandstone is the most important aquifer for groundwater exploitation throughout the GAB. The Hooray Sandstone is overlain by generally fine-grained sediments of the Wallumbilla Formation including the Doncaster and Coreena Members. These units can include water-bearing facies but generally act as an aquitard in this region.

In practice, the sandstone units in this area represent transitional facies with a gradual eastward reduction in the amount of argillaceous sediment accompanied by a thinning of the Hooray Sandstone and Injune Creek Group (Burger and Senior, 1979) such that the Ronlow Beds are dominantly equivalent to the Hutton Sandstone (Figure 6).

3.2.2 Hydrology of the springs

3.2.2.1 Barcaldine outcrop springs

These springs mostly overlie the Hutton Sandstone, but there are some springs overlying the Hooray Sandstone, Ronlow Beds, Adori Sandstone, Doncaster Member and Coreena Member (Figure 6).

The Doncaster and Coreena Members are generally fine-grained and are not usually considered aquifer-bearing units, but some springs overlying these units (group D; Figure 6) are included here because they have a similar character to the other Barcaldine supergroup outcrop springs and are assumed to have a similar mechanism of discharge (see below). If our interpretation is correct the source of these springs is from permeable beds within the Doncaster and Coreena Members.

The observations of The Vagabond, who travelled to “The Springs” 13 miles west of Jericho in 1885 when the railway line was under construction, verifies that many of the ‘springs’ were actually holes dug through to the shallow rocky watertable, as described in his article ‘A winter tour in Queensland’, published in *The Australasian Supplement*,:

> *This is called The Springs because any railway navvy armed with a crowbar can here successfully imitate Moses's feat at Horeb, and striking the reef of solid limestone rock which runs across the plain water will gush therefrom* (19 September 1885, p.1).

A contemporaneous reporter from The Maitland Mercury and Hunter River General Advertiser referred to springs in the general vicinity;

> *In the same desert country at Green Tree there are fine springs. Then west of Green Tree you come on the native wells. Then there are the mud springs at Coreena station…*(May 22 1890, p.6)

It is probable that the ‘native wells’ included some of the springs in this group, and this suggests that some of the excavations were initiated by Aboriginal people.

There are very few springs in this area that have not been excavated, the Yellow Water Springs being the prime example (Figure 9). The ‘weeping rock’ discharge of this spring reveals the likely appearance of the other springs before excavation.

Figure 9. The Yellow Water Spring, one of the few springs in the eastern Barcaldine supergroup that has not been excavated. This spring provides a rare insight into the original character of these springs.

The potentiometric surface in these sandstone units is mostly below ground level (Table 5) suggesting either a deep source or local recharge source and a gravity-fed discharge. A potential deep aquifer source is the Clematis Sandstone, but this is unlikely given the potentiometric surface in this aquifer is insufficient to generate discharge for these springs. Furthermore there is no evidence of either fracturing or faulting through the confining sediments of the Moolayember Formation, which is about 200m thick through this area (Vine et al., 1972b).

The evidence suggests that these springs are fed by gravity from local recharge. They all occur in geological units that are sufficiently porous to contain and transmit groundwater, with the exception of group D on Figure 6 which occurs in sediments that are generally fine-grained. The terrain is generally flat but a detailed examination of the elevation indicates that they all occur in areas where there is outcrop at higher elevation which could provide recharge (Figure 10).

Likely recharge areas for each cluster of these springs have been inferred from the position of the spring and breaks in slope of the surrounding topography. Assuming that these areas receive 500mm of rainfall per annum and using the discharge rates inferred from field inspection (Table 5), the proportion of recharge required to supply this discharge can be calculated. The proportion of recharge required is less than 0.016% in all cases except the Maryvale Springs where the estimate of the proportion of recharge water required to provide discharge to the spring is 1.18%

Table 5. Spring clusters as identified on Figure 6 with source geology, mean elevation, assumed recharge area, assumed recharge volumes (assuming 500mm rainfall per year), discharge and the proportion of assumed recharge required to supply discharge to the springs. The modelled head was supplied by Geosciences Australia (Table 1).

Cluster	Name	Geology	Average modelled potentiometric head (m)	Elevation of lowest spring	Presumed recharge area (km2)	Recharge ML/yr	Discharge ML/yr	Discharge/ recharge (%)
A	Scott, Kyong	Ronlow Beds (JKr)	-46.01	327	29.77	14883.6	1.242	0.008
B	Marion	Ronlow Beds (JKr)	-115.94	395	18.10	9052.2	0.001	0.000
C	Black Swamp, Yellow waterhole	Hutton Sandstone (Jlh)	-27.56	289	46.03	23015.8	1.382	0.006
D	Budgerry West	Coreena Member (Klc)	NA	267	28.18	14091.0	37.752	0.268
D	Budgerry East	Doncaster Member (Kld)	NA	281	5.31	2656.6	14.763	0.556
E	Barcaldine Core Spring	Hutton Sandstone (Jlh)	-50.68	294	1053.38	526691.0	10.289	0.002
F	Valley Downs	Doncaster Member (Kld)	NA	325	11.80	5898.4	0.906	0.015
G	Heart	Hutton Sandstone (Jlh)	-15.45	326	145.35	72673.6	3.719	0.005
H	North Delta West	Doncaster Member (Kld)	NA	292	10.27	5137.5	0.738	0.014
H	North Delta East	Hooray Sandstone (JKh)	-2.67	305	44.02	22010.0	3.110	0.014
I	Jericho	Hutton Sandstone (Jlh)	-11.05	336	68.17	34082.7	0.622	0.002
J	Alls Well	Hooray Sandstone (JKh)	1.39	323	11.91	5952.6	0.001	0.000

Cluster	Name	Geology	Average modelled potentiometric head (m)	Elevation of lowest spring	Presumed recharge area (km2)	Recharge ML/yr	Discharge ML/yr	Discharge/ recharge (%)
K	Maryvale	Adori Sandstone (Ja)	NA	386	38.80	19398.4	229.211	1.182

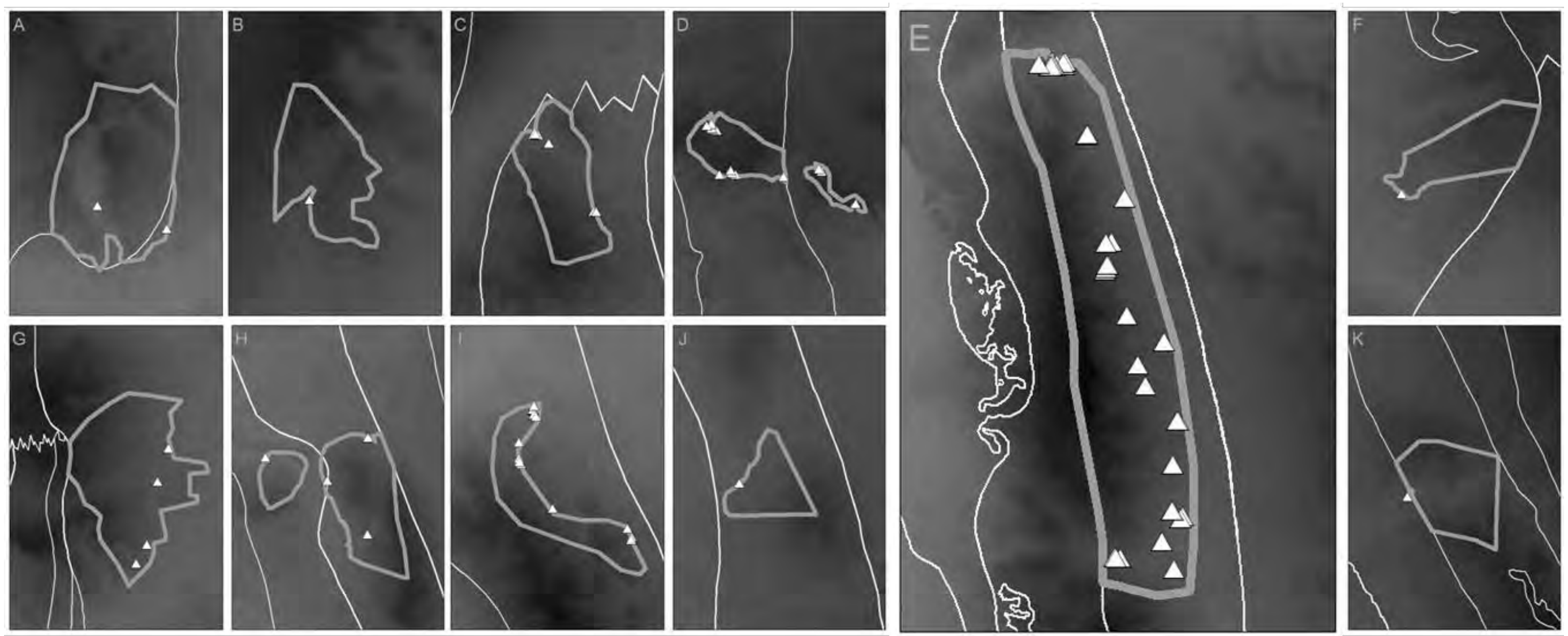

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Figure 10. Individual spring clusters identified on Figure 6 with geological boundaries represented as narrow white lines, estimated recharge areas grey lines, and springs identified as white triangles. The digital terrain model is represented as dark (high elevation) to light (low elevation), and is scaled appropriately to demonstrate the extent of upslope terrain for each spring cluster.

There is little evidence that these springs have diminished in flow during European settlement, and this would be in keeping with a local groundwater source rather than a regional aquifer. The exceptions are the springs at Sandy Creek (site 342) which were described by Griffiths:

> *The Sandy Creek springs are close to the west boundary and about 3 miles south of the NW corner. The water issues from the desert formation and fills pools about a mile in extent running north into Sandy Creek. The water suits stock but is not considered good for human consumption. During the 1897 drought (Nov) 9 to 10 000 sheep with 70% of lambs were regularly watered here, taking about 24 000 gallons per day.*

In 1999, the main spring at Sandy Creek was active, excavated and dammed, with free water covering 250m^2 but was not flowing the creek (Figure 11). Clearly these springs have diminished in flow, which is atypical for outcrop springs fed by gravity. The modelled surface of the Ronlow Beds aquifer (Hooray Sandstone equivalent) is 26m below the ground surface. The groundwater surface decline as a result of regional drawdown impacts is substantially less in this region. This suggests the decline in this spring is the result of interception of local groundwater sources, probably by the bore adjacent to the spring (Figure 11).

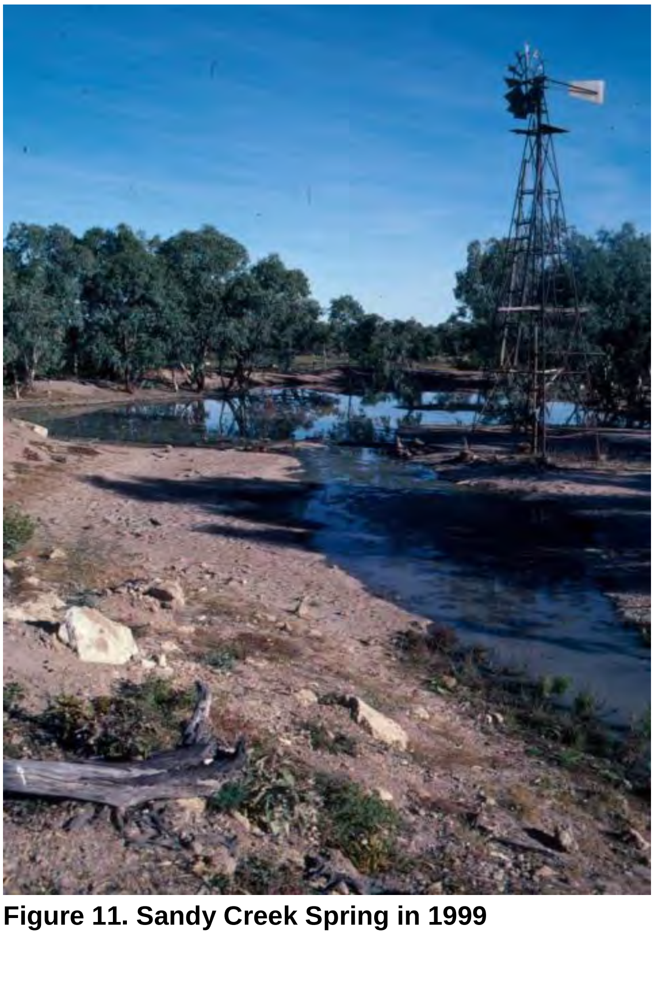


Figure 11. Sandy Creek Spring in 1999

3.2.2.2 Barcaldine discharge springs

These springs (with the exception of the Northhampton Hotel Springs) almost certainly emanate from the Ronlow Beds/Hooray Sandstone where erosion has thinned or bisected the overlying Wallumbilla Formation. The springs occur along the margin of where the potentiometric surface in the Hooray

Sandstone becomes artesian (Figure 8) and an intersection of the springs with a modelled surface of potentiometric head suggests pressure relative to ground surface in the vicinity of –24.5 m and +7.8 m.

Stratigraphic sections bisecting this line of springs suggest that they occur where there is a coincidence of a relatively thin confining layer and artesian pressure. To the east of this line there is insufficient aquifer pressure to provide artesian flow, and west of this line the aquitard may be too thick for a flow path to form. Where the springs occur the Wallumbilla formation is generally between 40 and 100m m deep (Figure 12, Figure 13, Figure 14, Figure 15), but it may be considerably reduced where current streams enhance erosion. The Wallumbilla Formation may include permeable beds sufficient to transmit discharge from the underlying sandstone over such distances.

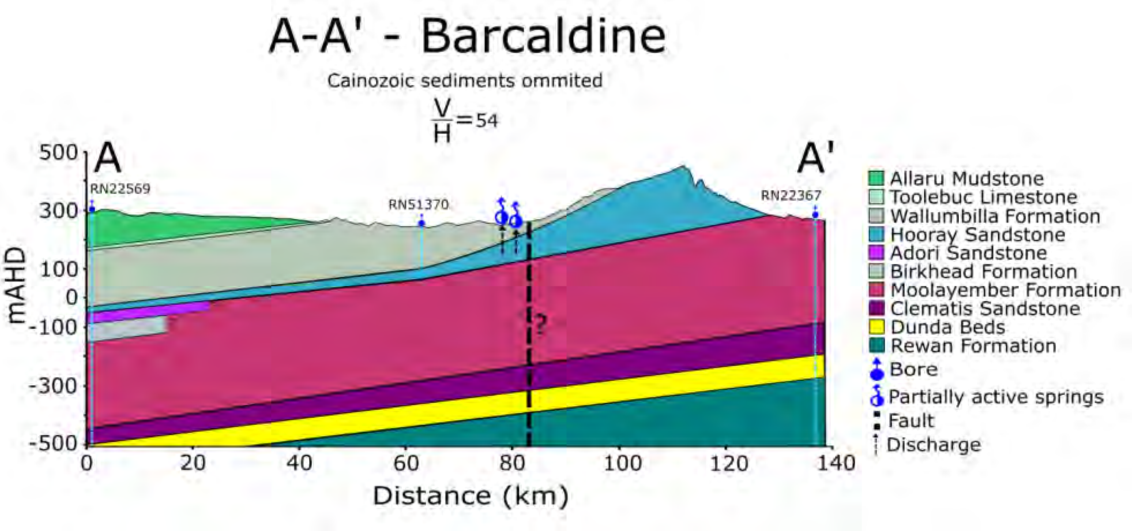


Figure 12. Stratigraphy at Corinda (see Figure 8). Figure 11 indicates the position of the Barcaldine discharge springs and position of a fault structure that may provide a weakness in the Wallumbilla Formation permitting discharge.

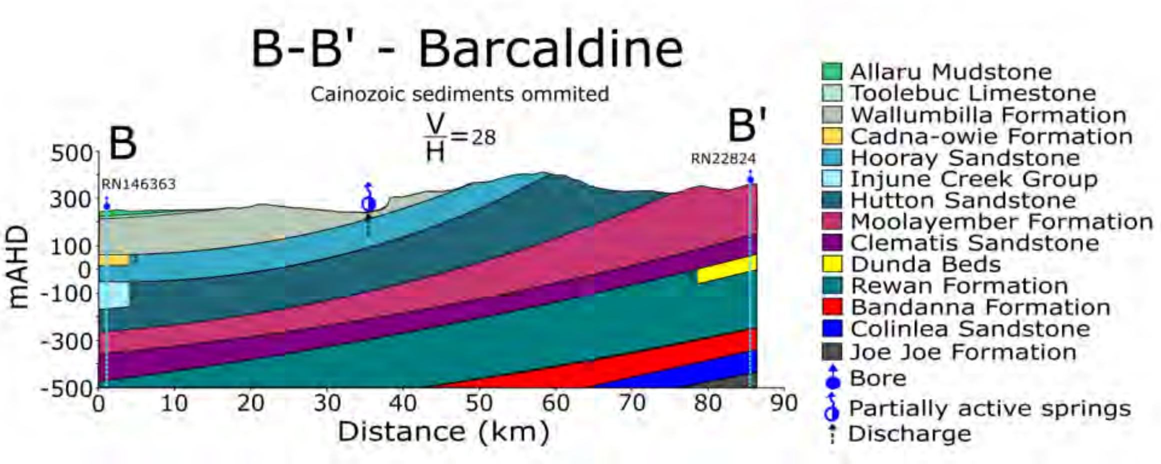


Figure 13. Stratigraphy at Edgbaston (see Figure 8) indicating the position of the Barcaldine discharge springs where the Wallumbilla Formation has been thinned by Pelican Creek.

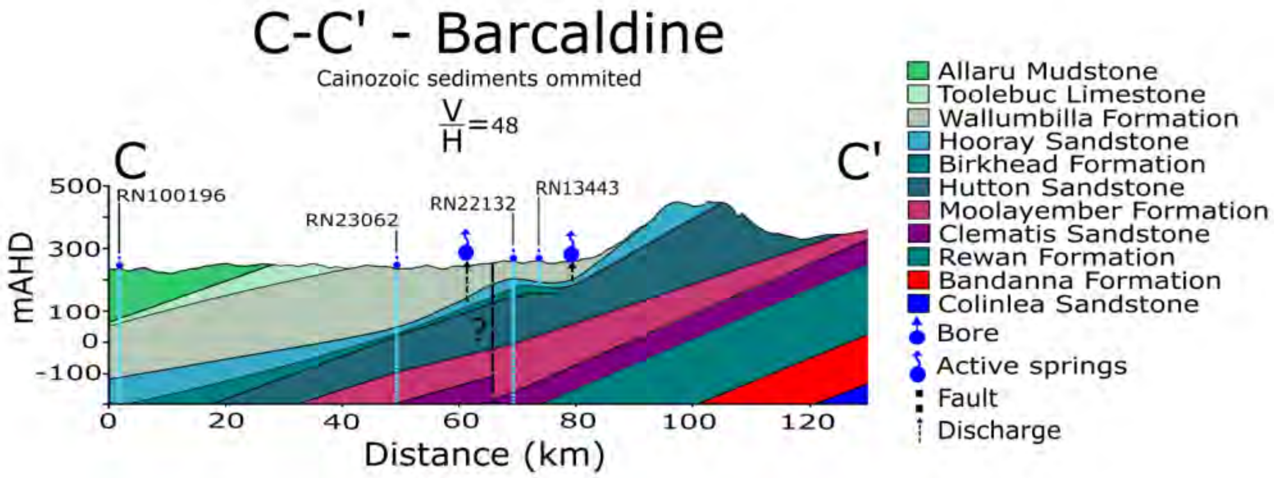


Figure 14. Stratigraphy at Coreena (see Figure 8) indicating the position of the Barcaldine discharge springs. The Coreena Springs in the west may be associated with a fault structure that may provide a weakness in the Wallumbilla Formation permitting discharge, and the Jersey Springs in the east where the Wallumbilla Formation has been thinned by erosion associated with Sandy Creek.

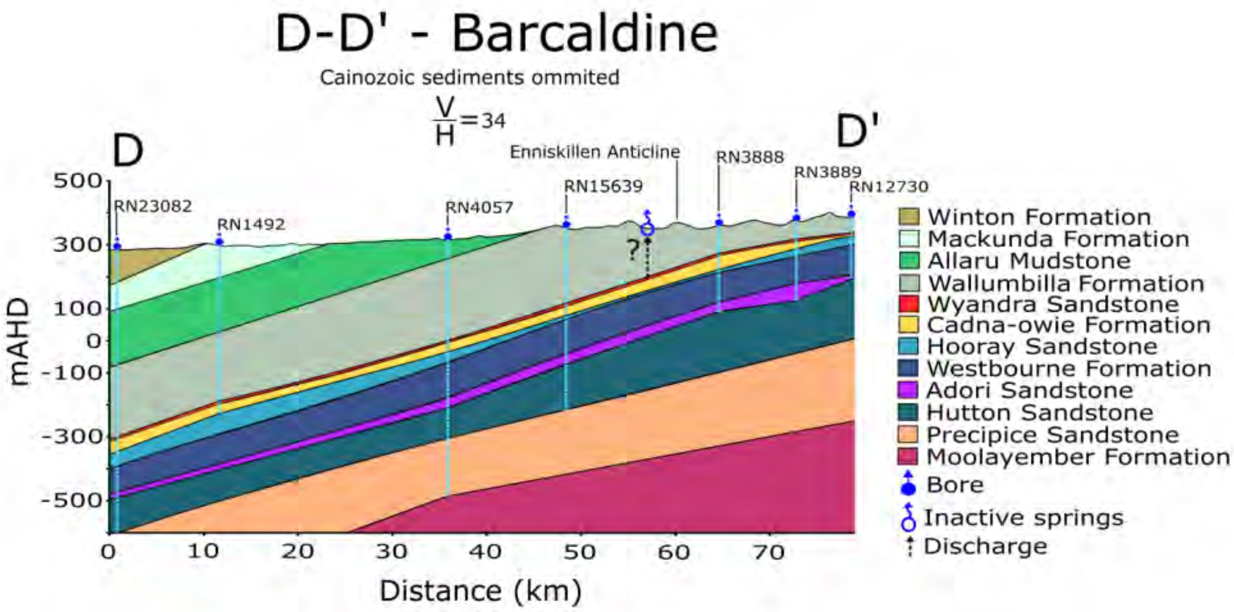


Figure 15. Stratigraphy at Northampton Hotel (see Figure 8) indicating the position of the Barcaldine discharge springs. There is no evidence of thinning or faulting in the Wallumbilla Formation that would allow discharge.

There is also evidence of fault structures in some locations, such as at Corinda and Coreena (Figure 12, Figure 14) that may be allowing discharge through fractures in the aquitard.

The source of the outlying Northampton Hotel Springs in the far south of the Barcaldine supergroup is difficult to explain. These currently inactive springs were never very substantial, described by Griffiths in 1898-9 as supplying a waterhole 'sufficient for the local stock'. The aquitard formed by the Walumbilla Formation is approximately 150m thick (Figure 15), and while the Mt Enniskillen anticline trends northeast through the springs it is not apparent for a stratigraphy prepared from nearby bores (Figure 15). The source of these springs is either through permeable beds in the Walumbilla Formation or from a local aquifer within the Walumbilla Formation. The extinction of the springs in coincidence with extensive extraction through bores into the main aquifer in the Hooray Sandstone lend weight toward the former interpretation.

The discharge springs, particularly those in the Pelican Creek area, are associated with calcium carbonate precipitated from the groundwater as travertine deposits. Calcium carbonate is generally held in solution where pH is lowered, usually by carbonic acid derived from a source of carbon-dioxide. The interpretation presented here suggests that these springs have their source in the outcropping Ronlow Beds 30 km to the east at an elevation about 40m above the springs. This suggests intermediate residence times for the groundwater, but this is sufficient to accumulate calcium carbonate for the formation of the travertine around spring discharge areas.

Around Pelican Creek there are large areas of travertine that are not associated with current springs indicating considerable dynamism in spring locations over long time frames. Fossilised spring-dependent snails occur in the travertine. There is some evidence that travertine accumulations can block spring discharge resulting in emergence at new locations. An area in upper Pelican Creek known locally as the Bald Ring may be an example of a travertine shield with springs emerging from its expanding edge (Figure 16).

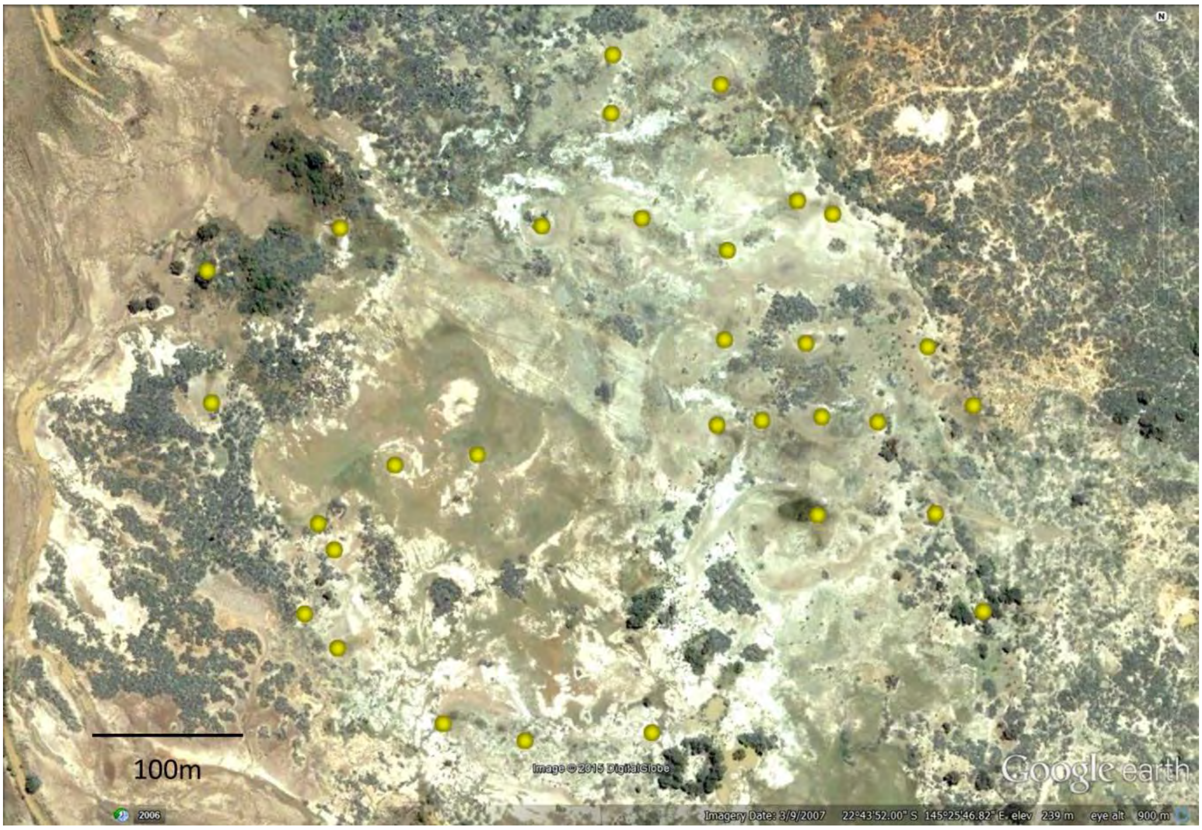


Figure 16. The Bald Ring at Edgbaston appears to be a travertine shield with springs (yellow circles) emerging around its margin; satellite image captured 2007.

There are also Pleistocene megafauna deposits adjacent to Pelican Creek which probably represent a spring-fed swamp that is no longer active. Many springs in the region have become inactive presumably because of depression cones in the potentiometric surface around groundwater bores.

Springs occur along Pelican Creek and its flood-out lakes on Edgbaston. The highest of these springs is not far from the break of slope at the base of the retreating scarp. In this location erosion is presumably reducing the thickness of the aquitard to the point where springs can emerge. The springs of the western Barcaldine Supergroup seem to be dynamic, with new springs emerging as erosion allows release of groundwater through the aquitard and closure of springs as they become cemented by travertine deposition. Despite this dynamism the concentration of endemic species (particularly in the headwaters of Pelican Creek) suggests considerable antiquity for the springs in their general geomorphological setting.

3.3 Historical record

Sixteen spring groups are marked on the historical survey plans, and 13 on the 4 mile series (Table 6; Figure 17; Figure 18). The majority of springs are not marked on historical maps**.**

Table 6. Springs marked on historical maps and plans in the Barcaldine supergroup

Map/plan inspected	Springs marked
M57.106, Tributaries of Aramac Creek (1876)	Friendly Springs
M57.102, Survey of Cornish Creek (& its) tributaries (1866)	Two-Mile, Winter, Lagoon
M57.104, Survey of Runs, Mitchell District (c.1870s)	Kyong springs
M57.105, Survey of Runs, Mitchell District (c.1870s)	Boxflat spring, F-Nut spring (Gracevale)
Survey Run Plan, Mitchell District M.57.106 (1876)	Jersey Springs, Elton South, some springs in Pelican Creek complex, Valley Downs
Survey plan M.57.138 (circa 1870s)	The Lake Springs, Bloodwood, Hollywood, 10 Mile, Boxflat
4 mile series (1919-1929)	Boss's Creek, Big (Corinda), Two-Mile, Winter, Lagoon, Thunderbolt Creek (Corinda/The Springs), Friendly, Valley Downs, House (Texas), 14 Mile, Clines, Grace, F-Nut

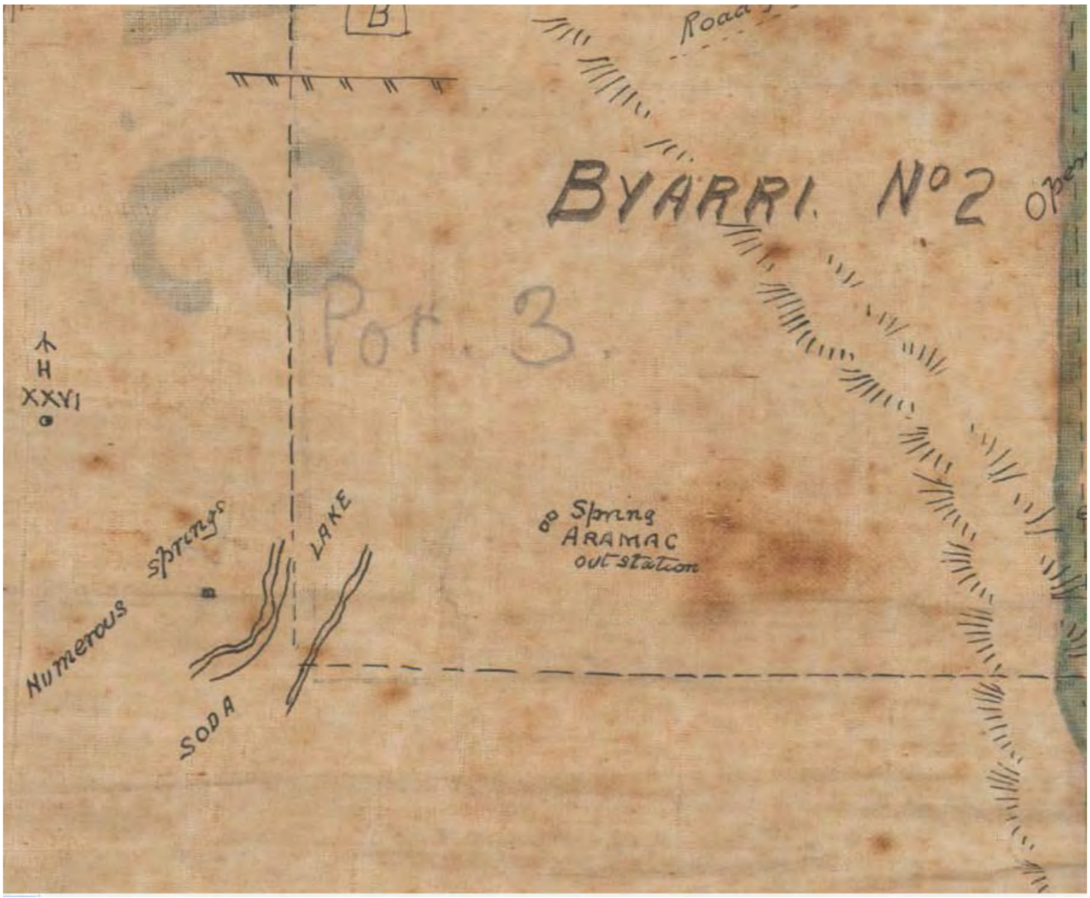


Figure 17. Survey plan M.57.138 (c.1870s), showing springs west of Lake Mueller; Aramac Outstation appears to be on present-day Myross at Big Moon Spring (this is corroborated by an early newspaper article about 'the moon springs')

Figure 18. Example of 4 mile map: 4 mile series 1, sheet 11C (1929), showing unnamed springs on Corinda.

In 1895, J. Alfred Griffiths was employed by the Water Supply Department of the Queensland Government to conduct a survey of artesian waters. He visited many springs across the GAB between 1896 and 1898, riding up to 30 miles a day on horseback, except on Sundays. His work encompassed many springs in the north-western portion of the Barcaldine supergroup, as well as some south-eastern outliers near the town of Blackall. Griffiths' unpublished reports are held in the John Oxley Library and contain descriptions of the springs based on his field notes and discussions with property managers, including location, size, temperature, flow rate, 'improvements' to the spring and the number of stock able to be watered (Fairfax and Fensham, 2002). He also sketched maps showing the location of the springs he visited (Figure 19).

Figure 19. Portion of Griffiths' sketch map from 1897, showing Aberfeldie Springs east of old Aberfoyle homestead. The boxed well on the most northerly spring is marked, as are the mud springs to the south-east.

Ten years later, Geologist Dr V.J. Danes travelled on horseback between Aramac and Pentland and described springs belonging to five groups, from Pelican Creek north to Fleetwood. In a report published in the Queensland Geographical Journal he wrote:

> *'The existence of water-bearing sandstone stratum, bringing permanent springs to the surface wherever it is cut by the same…is a very important factor, the springs being a sure refuge for the stock also in a period of heavy, continuous drought, when other superficial supplies fail…The springs in the Lake Mueller basin, on the western foot of the range, near old Barcoorah, and probably also some occurring further north along the same foot region, and the springs at Doongmabulla, seem to be products of one more or less continuous and identical water-bearing horizon…'* (Danes 1909:98).

The field observations of Griffiths and, to a lesser extent, Danes, which predate the extinction of many springs due to aquifer draw-down, were extremely valuable in locating now-inactive springs during this project. Springs in the Barcaldine supergroup are also mentioned in newspaper articles dating from the 1880s, although these tend to provide only passing mention of the springs, or very short descriptions. A notable exception is an article appearing in *The Capricornian* on 7 November 1885, which considers the occurrence and hydrogeology of the 'Aramac springs' in detail, although few individual springs are mentioned. These articles are included in the relevant individual spring reports, and are also used to explore the cultural history of the springs in the Section 3.4.

3.4 Cultural history

3.4.1 Aboriginal history

The area encompassed by the Barcaldine supergroup was home to three groups of Aboriginal people: the Iningai in the west, the Yagalingu (Jagalingou) in the east and the Bidjara on the south-eastern fringe. Apart from a smattering of permanent waterholes on Aramac and Torrens Creek and the Barcoo River, the springs are the only source of permanent water in the area bounded by the supergroup (Silcock, 2009). They would have been vital sources of water in dry times, as well as providing stop-over points for people travelling between the Desert Uplands and the grasslands to the west. One report, in *The Capricornian* (Saturday 17 January 1925, p.58), states that Coreena means 'big water' in the local Aboriginal language. While an apt name given the proximity of springs to the homestead, there is no verification of Coreena's etymology and it would be the only Aboriginal name to have survived in the Barcaldine supergroup. There are stone tool scatters, mostly flakes but occasional axes and grindstones, on the claypans and scalds surrounding most discharge springs (Figure 20).

Stone flakes and tools are in relatively high densities in the vicinity of Atherton Spring on Aberfoyle, McKenzie's Spring on Lake Huffer and the Northampton Hotel springs east of Blackall, although the density at the latter would also be related to the proximity to the almost-permanent Swan Hill waterhole on the Barcoo River. Grindstones or base plate fragments were found at Big (Mongooburra) Spring and Old Jericho springs on Corinda/The Springs, Kennedy's Spring on Sumana and Two Tree Spring on Myross, and an axe near Big Moon spring on Myross in the Pelican Creek spring group. Fragments of hearths are common on the lower slopes of shrubby dunes and small claypans around the intermittently-filled Lake Huffer, and the springs particularly the large Smokey Spring would have sustained people when the lake was dry.

Mysteriously, artefacts are in very low densities at other springs, including the large Pelican Creek group in waterless country north of Aramac. Extensive searching around the springs and scalds on Edgbaston has revealed only very occasional stone flakes. A branch of local folklore suggests that these springs were considered haunted or 'bad water' and the area was avoided by Aboriginal people (Michael Wills, pers. comm., April 2009), but this is impossible to verify.

Figure 20. Typical scalded area in vicinity of Barcaldine supergroup discharge springs with abundant stone flake (left) and grindstone (right).

An extensive collection of paintings including many images at the base of cliffs representing the ‘circle of life’ have been documented not far from the Gracevale outcrop springs north of Jericho (Cooper 2013), hinting at the ceremonial significance of springs in the area. Stone flakes and tools are also scattered around the majority of outcrop springs, including grindstones at Little Spring on Ightham west of Jericho and Top Spring on Kismet. Silcrete flakes were recorded in particularly high densities around Sandalwood Spring on Minnamoora and in the vicinity of the North Delta springs east of Barcaldine. Some of these outcrop springs have the appearance of being wells or small soaks (Figure 21). As discussed in the Hydrogeology section above, it seems that some outcrop springs may have been small sandstone soaks, which were kept scooped out and maintained by Aboriginal people and later excavated and/or milled by early pastoral settlers.

Figure 21. Attention spring on Springton west of Jericho in 2014. These outcrop springs may naturally exist as small soaks, which were excavated and maintained as water sources over millennia by Aboriginal people.

We will never know the true significance of the Barcaldine supergroup springs for Aboriginal people. While early explorers passed peaceably through the area, permanent pastoral settlement focused around reliable water sources inevitably brought conflict. The district has a shrouded but chilling frontier history. The dispossession of Aboriginal people was swift, violent and deliberately concealed (Bottoms, 2013), leaving only the archaeological record and anecdotal accounts to hint at a complex, sophisticated cosmology dating back tens of thousands of years.

In a petition to the Colonial Secretary in 1866, a group of prominent squatters reported a ‘very troublesome and hostile spirit of the Native Blacks of the Barcoo, Alice and Thompson [sic] Rivers’, and requested Native Police be sent to the area (Cooper, 2013), p.11). Native Police Barracks operated at various locations on these rivers between 1869 and 1879, including at Bowen Downs north of Aramac (Richards, 2008). A massacre is recorded at Grey Rock east of Aramac, where at least 13 Aboriginal men hiding in a cave were shot in retaliation for the murder of a white man, but we will never know the full extent of violence on the Queensland frontier (Bottoms 2013). By 1880, just three decades after the arrival of Europeans, Aboriginal people had mostly disappeared from the area, either through direct violence or disease, while a small number were assimilated into station life as stockmen, domestic hands and trackers in bush searches. During the first decades of the twentieth century, those remaining were removed to missions, mostly to Barambah, later renamed Cherbourg (Blake, 2001; Cooper, 2013).

3.4.2 European history

Major Thomas Mitchell was the first European explorer to pass through the area encompassing the Barcaldine supergroup in 1846, followed by Edmund Kennedy (1847), Augustus Gregory (1858), Frederick Walker (1861), William Landsborough and Nat Buchanan (1862). None mentioned the springs, despite Walker passing close to the discharge springs north of Aramac. The distinction between ‘the explorers’ and pioneer pastoralists is blurry, with stations being taken up even as the search for Burke and Wills was ongoing. The leader of one of the search parties, William

Landsborough, along with Nat Buchanan, applied for the lease over Bowen Downs run in 1862, shortly after returning from his journey. In the same year, James T Allan, Ernest C Davies and Jemmy Wilkinson travelled through the area as prospective pastoralists. As a result of this journey, Allan claimed vast runs in the Tambo district, including Mt Enniskillen in 1863. Barcaldine Downs and Nive Downs were taken up in the same year (Godwin & L'Oste-Brown 2012).

As with elsewhere in inland Australia, pastoral settlement was dictated by the availability of water. Pioneering squatters concentrated their runs and grazing activities on permanent waterholes along major rivers and the sparse network of artesian springs. By the end of the 1870s, most watered runs had been taken up, forcing new landholders to choose land with limited access to surface water (Cooper 2013). Early homesteads and outstations were built near springs, including old Mt Enniskillen (Figure 22). Springvale, Aramac Outstations (Big Moon Spring, Myross and Friendly Springs, Ravenswood), The Lake, Old Lake Huffer (Figure 22), Aberfeldie, Old Barcoorah and North Delta. Some of these remain beside springs, while others have been relocated since the advent of bores. There was a shepherd's hut at Five Mile springs on Ballygar (Figure 22), camp sites at other now-extinct springs including Camp Spring on Corinda and a shearing shed at the Black Swamp springs on the overflow of Lake Gallilee.

Figure 22. Rusty buckets and old bits of tin and wire and fireplaces lying on travertine pavements amongst tea-tree thickets are the only reminders of past human endeavour once nourished by springs at Five Mile Springs, Ballygar, which ceased to flow in the early 1950s (top), while the ruins of Old Lake Huffer homestead remain above an active spring (bottom left); the spring and bore described by J. Alfred Griffiths at the old Mt Enniskillen homestead are now long-dry (bottom right).

The springs were highly valued as water for stock, especially during dry times. A correspondent travelling by rail to Barcaldine in 1888 marvelled at the 'mud springs': 'pure clean water bubbles to the surface, and rushes away in rivulets…The springs were of inestimable value during the drought, and suffered no diminution during the dry time (*The Western Champion*, September 4 1888). A report in *The Northern Miner* from 1915, when the country was in the midst of a 'harrowing' drought noted that 'Lake Dunn, a generally well supplied hole, is dry and the Tamblyns, Dicksons and others are depending upon springs' (11 May 1915, p.6). The nature and permanence of springs were considered when determining rents for pastoral properties, along with waterholes and, later, bores. The number of animals watered at now inactive or much-diminished springs, as described by J. Alfred Griffiths in the late 1890s, seems astonishing to the contemporary visitor.

The value of the springs is reflected in the often extensive works that were carried out to improve access for stock. Some mounded springs, including Atherton and Camp, had drains cut in them. The Barcoo Correspondent to the *Morning Bulletin* on 2 January 1889 wrote of the Coreena Springs:

> *A number of mud springs (some of which are brackish and consequently useless) exist upon the property. Several of these have been opened up, and the water conveyed to strongly-erected sheep, cattle, and horse troughing. I had time to see one line of troughing-the fifth-which had been erected about a mile from the homestead. It was 280 feet in length, was most substantially built, could water 20,000 sheep at a time, and cost £200* (p.5).

Over three-quarters of outcrop springs in the Barcaldine group have been excavated and contained, often by concrete tanks, and now pump from below ground level. It is possible that these springs were always small soaks and had to be excavated to provide reliable and accessible water for stock. Some such as Little and Heart Springs on Ightham north-east of Jericho may only exist due to excavation. Figure 23 shows examples of outcrop springs which may not rise to the surface or only exist as small soaks without excavation.

Figure 23. Little Spring, Ightham, an excavated hole on a lancewood slope (top left); a spring-fed excavated pool dug in sandstone near Lake Dunn (top right), and Bloodwood Spring, Garfield (bottom), an excavated 4 x 4m square hole where water is pumped from 1m below surface.

The location and permanence of springs were important in planning road and rail routes before bores were widely sunk and reliable motor vehicles reduced the need for horse changes and stop-overs between major towns. Prolific and peripatetic correspondent John Stanley James, writing under the *nom de plume* ‘The Vagabond’, travelled to ‘The Springs’ 13 miles west of Jericho (on present-day Ightham) in 1885 and described an improbably idyllic existence at a camp of railway-builders:

> *I have a pleasant drive with Mr. Gwynneth to "The Springs," a new railway camp 13 miles from Jericho. This is called The Springs because any railway navvy armed with a crowbar can here successfully imitate Moses's feat at Horeb, and striking the reef of solid limestone rock which runs across the plain water will gush therefrom…To the lover of the picturesque and the student of humanity The Springs is a very charming place. An upland down fringed by and dotted with trees. Overhead a sky flecked with fleecy clouds as white as the driven snow. A dry, pure atmosphere expanding the lungs. The camp, peeping through the bush, as yet too new to have left ugly traces of man's conquest over nature in the shape of cairns of broken bottles and battered tin-cans. And there is no publichouse or bad grog here. Neither is there store or school. A few boarding tents accommodate bachelor navvies who do not care about cooking their own tucker. But the children ran about happy, free from care as regards primer, or slate, or copy-book… The life of a navvy here is one to be envied by toilers in the cities. He does not work too hard, he earns good money, he feeds at Mrs. B.'s as well as a Saxon prince in the olden days, and has more cleanliness; he can save a pile, and then he can go into Jericho, and most probably (after the manner of his kind) have a " hellfire" time till his money is gone...’* (Figure 24).

Figure 24. Spring-fed idyll, where any navvy armed with a crowbar can bring forth water from the ground in the style of Moses: one of the springs on the plain at Ightham, once the site of a thriving railway camp (left), vividly described by John Stanley James aka ‘The Vagabond’ (The Vagabond, 1885)(right, photo: www.abc.net.au)

There were hotels and/or Cobb & Co change stations at Maryvale Springs, Northampton Hotel springs, Box Flat and Friendly Springs (Figure 25). Further north, the ‘tea-tree belt’ containing numerous springs extending from Corinda to Adelong was an important landmark for travellers coming from the east. These springs were the goal of parties travelling from Bowen to Bowen Downs, and were the first water reached after the unreliable ‘Wattle Soak’ to the north-east. An old-timer, ‘C.F.B.’, recounted in *The Longreach Leader:*

> *A few miles from this hole [the 10-Mile Waterhole on Corinda], they hit the point aimed at from the other side of the divide – a patch of black ti-tree scrub which runs through Corinda, Lake Huffer, Adelong and old Aramac station round behind Coreena. All along*

this black ti-tree belt were good springs really marking the actual western feathering out of the watershed in this vicinity.'

Our friends then followed down Thunderbolt Creek to Reedy Creek thence to the junction of Reedy with Cornish Creek to their destination, Bowen Downs…Going back along their route, one is struck with the grand bushmanship of the men who opened this road, picking their way through ridges which spelt death to starving stock, picking out watering places which if missed would have meant miles of dry country on each side. The ti-tree country on Corinda juts out in an easterly direction with miles of country on either side when they picked it ('A Saga of the Old Station Hand', 8 December 1948, p.58).

Ten-Mile springs were also used as a stop-over for carriers on the road between Aramac and Jericho, with *The Western Champion* reporting, in an article on road conditions between Alpha and Tambo and Blackall that 'The Divisional Board party have cleared out the Ten-mile Springs, and are putting pumps and troughing in order at the dams' (10 March 1892, p.6).

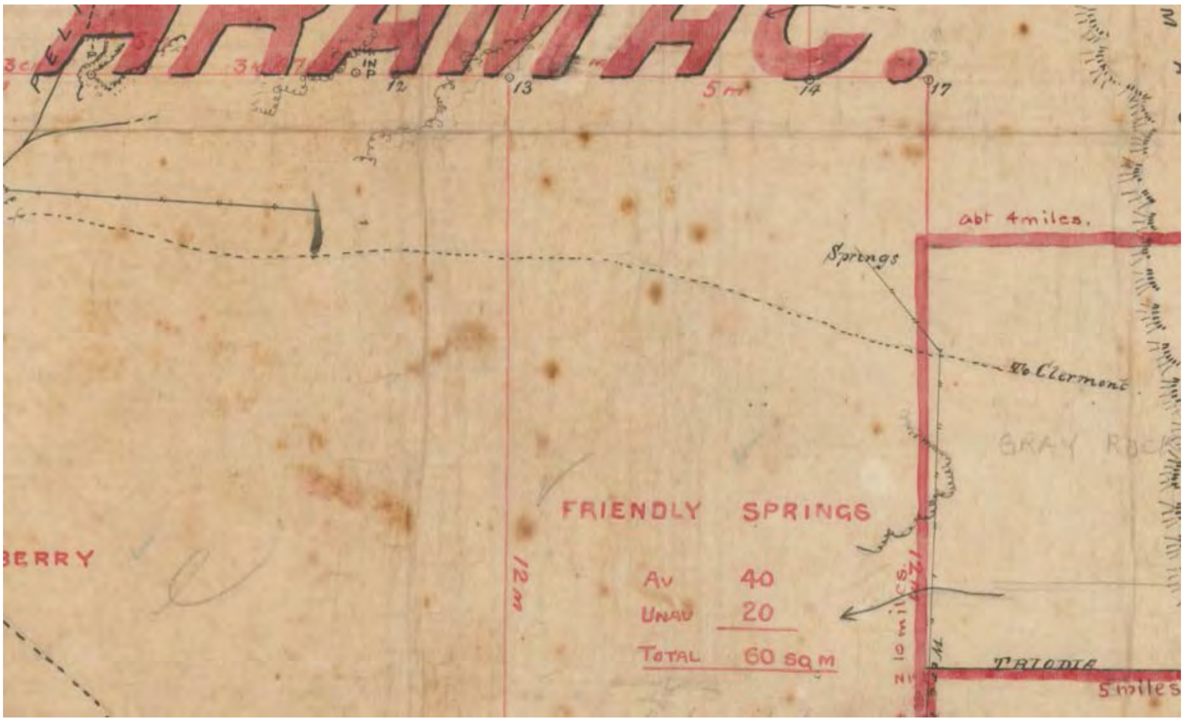


Figure 25. Survey Plan Mitchell District M.57.106 (1876). Friendly Springs are marked on the Aramac-Clermont Road.

Springs were also of interest to recreational travellers and day-trippers, as demonstrated in newspaper accounts of travellers passing the 'famous' or 'celebrated' springs, as well as the plethora of short stories, mostly sent in by children from stations, in old newspapers which feature visits to springs. 'The Moon Springs' or the 'Moonstones', part of the Pelican Creek springs on present-day Myross, were apparently the most visited in the Barcaldine supergroup. A group of locals celebrated Separation Day of 1887 (commemorating the 1859 separation of Queensland from New South Wales) with an excursion to these springs, 25 miles north of Aramac. The *Western Champion's* Special Correspondent enthused:

The trip was very enjoyable; not only were the 'moons' worth the seeing (they are really a wonderful freak of nature and worth journeying double the distance to see) but the shooting also was excellent. Joe Martin took the belated travellers in and hospitably

> *entertained them. The party returned to town in quite good spirits, slightly burnt, and a bit sore.* (20 December 1887, p.4)

The following year, the *Morning Bulletin's* Barcoo Correspondent wrote of the curious 'Moonstones', and expressed a desire to see them more fully studied:

> *It is probably not generally known that there are some wonderful springs some 25 miles from Aramac, in the desert country, known us the Moonstones. These springs are surrounded by a remarkably fine white sand. Anyone bathing in the springs cannot sink in the water below the middle owing to the buoyant nature of the water. It appears to be similar in nature to the Barcaldine bore water, being wonderfully soft, very slightly mineralised, and clear as crystal. It would be interesting if Mr. Geologist Jack would visit the locality, or even your Mr. Smith* (17 February 1888, p.5).

J.A. Porter reminisced in the *Longreach Leader* (1947, p.21) about a trip from Boongoondoo to Aramac, inadvertently providing the first reference to the endangered red-finned blue-eye (*Scaturiginichthys vermeilipinnis*), as these reminiscences probably predate the arrival of the now-ubiquitous gambusia (*Gambusia holbrooki*):

> *I remember the Moon Springs well. In fact it was Jack who first showed them to me, once when we were riding from Clare. From Boongoondoo to Aramac we took a different road. I wonder if he still remembers that trip. We stayed the night with old Joe Martin and his good wife. Joe was for many years employed on Aramac Station, and lived on its eastern boundary. After we had enjoyed a tremendous feed of curried eggs, old Joe took us to a spring-fed pool near the house, and, after equipping us both with small rods, and lines fitted with tiny hooks, told us to throw back all the fish we caught. That was the only time I ever really shone as a fisherman. We caught them in dozens, as fast as we could pull them out, but none of them was more than three or four inches long.*

The springs also generated folklore and stories, as strange natural features inevitably do. 'Battler', a correspondent to the *Morning Bulletin* (Rockhampton), reported a curious story about the springs in an article entitled 'On the Track'

> *It is many years since John Rule and Dyson Lacey took up Aramac Station. Coreena, which is on Aramac Creek, was taken up by them shortly afterwards…John Rule I knew very well; he had some quaint, and to put it mildly, some remarkable tales to tell of life in the early days in the west…Mr. Rule used to tell one tale about when he was hungry in the bush. He would strip and get into one of the numerous hot springs in the district. He would have a stick across the top of the spring to hold on by, and in a few minutes he would feel something nibbling his toes. He would put his hand down and catch a crayfish, and this went on until he filled his quart pot. He would then come out of the water and cook them. He stood the tale very well until he used to bring them out of the water cooked* (16 Dec 1924, p.12).

The flow of springs was also used as an indicator of drought-breaking rains, and in the newspapers of the early 20th century it is common to find articles speculating about the link between spring flow and impending drought or rain. In a series of articles in the late 1890s, Government Meteorologist Mr O. Wragge even expounded his theory that volcanic eruptions influence spring flow in Australia.

While the springs were depended upon by residents, travellers and their stock, and appreciated as outback curios, it was the clues they provided to the existence of a vast supply of underground water that proved most tantalising for the new pastoralists. In this way, springs played a wider role in the discovery, development and scientific understanding of the GAB. Soon after the first shallow bore was drilled on Wee Wattah Spring in western New South Wales in 1879 and the first successful deep bore was sunk at Thurulgoona Station south of Cunnamulla in 1886 (Powell, 2012), newspapers were enthusiastically reporting on the groundwater resources around Aramac. While the mud springs had been 'cleaned out' and troughed for many years, and shallow bores put down since the 1880s, it was the discovery of underground water some distance from bores which understandably caused the greatest excitement.

A correspondent to the *Morning Bulletin* in 1890 (31 December, p.6) enthused about the discovery of artesian water away from the springs on Coreena:

> *The magnificent discovery of artesian water on Coreena run has caused much jubilation, and first reports are fully borne out by subsequent ones. The great flow was struck upon a part of the run where it will be peculiarly serviceable.*

A decade later, a 'Special Commissioner' to *The Capricornian* reported in breathless terms about the groundwater supplies of the Aramac district:

> *The country comprising Aramac Station and its environment may be considered to be imperially endowed with artesian water. Six bores have been put down at various parts of the run, averaging 700 ft. in depth. Each of these bores gives out something like 1,000,000 gallons of water daily. On the eastern side of the run there can be seen numerous natural springs giving a never failing supply of the purest water…There is no district, so far explored for the purpose in Central Queensland, which has such an abundant supply of artesian water at such a shallow depth as that round about Aramac. In view of the wonderful subterranean sheets of water known to exist here, it is only reasonable to predict a rapid development of this portion of the country when the present large leaseholds are submitted in small holdings. Irrigation could be carried on to any extent and rendered easy by the utilisation of the natural watercourses which pervade the country in many places.* (15 October 1898, p.28)

Sinking of bores increased rapidly following severe stock losses in the Federation Drought (1898-2902) and it was a condition of pastoral leases that by 1918 artesian bores must have been sunk. Bore drilling remained an expensive and imprecise operation, and it was not until the 1950s that the combination of favourable seasons, high wool prices, improved technology and government subsidies gave pastoralists the opportunity to invest extensively in bores (Noble et al., 1998).
By 1960, 18 000 bores had been drilled across the GAB, resulting in a drastic loss of pressure in the aquifer. Total recorded discharge from free-flowing artesian bores in the Basin was >2000 Mega Litres per day from 1700 bores in 1916, but by 1998 <1000 ML/day was discharging from 3400 bores (GABCC 2000).

Spring flows in the discharge areas of the GAB declined similarly. Existing data indicate that some 40% of discharge spring groups have become completely inactive since pastoral settlement, while some springs within another 14% of groups are inactive (Fairfax and Fensham, 2002; Fensham et al., 2004). In the Barcaldine supergroup, 7 of 30 discharge spring groups are completely inactive, while two more (Aberfeldie and Jersey) are much-reduced in flow. Some springs in the Thunderbolt Creek group on Corinda/The Springs also appear to have declined in flow since the 1890s, especially Old Jericho, Thunderbolt and Lagoon Springs. Friendly and Five-Mile springs apparently stopped flowing in the 1950s, coinciding with many bores being sunk in the area (Frank Manwaring, pers.comm.). Outcrop springs have mostly been unaffected, with the notable exception of three groups centred along an escarpment west of Edgbaston: Sandy Creek, Budgerry and Old Barcoorah (Table 6).

Table 7. Historical descriptions of J. Alfred Griffiths (1897-8) of springs in Barcaldine supergroup with major declines. All are discharge springs with the exception of Sandy Creek, Budgerry, Barcoorah and Marion, which appear to be outcrop springs.

Spring group	Summary of historical description	Current Status
Sandy Creek	Several spring-fed pools for 1 mile along creek, watering about 16 000 sheep in drought	Dammed, free water covering 250m^2
Budgerry	At the foot of a scarp and running a creek for half a mile	Inactive
Old Barcoorah	Springs partially opened and drained, the largest opening yielding 4400 gpd. The whole group fills ¼ mile of waterholes in the creek & the greatest flow noted at the head of the waterhole was 6370 gpd but this is exclusive of great loss by soakage	Inactive
Marion	Filled small waterholes in creek; bore sunk on one in 1891	Inactive
Atherton	Main spring an oval mound 20 yards long x 2 feet high, covered with reeds at the top, form which a small stream issues and flows down the slope into a logged drinking place the overflow spreading in shallow lagoons for some hundred yards around. Flow estimated at 9,260 gallons daily. Another spring of similar character flowing 2000 gpd + two small springs sufficient to supply a small camp.	All inactive
Aberfeldie	Most northerly spring boxed with no measureable flow + line of water springs for ¼ mile forming pools around base of tea-trees + a couple of mud springs with small trickles	Main spring active; others inactive
Big (Corinda)	Not visited by Griffiths, but its name suggests considerable flow.	Inactive
Two-Mile (Hideaway)	Keeps about ¼ mile of rock pools filled.	Inactive
Five-Mile (Corinda)	A strip of land about 30 chains x 5 chains is fenced in. The whole strip was formerly boggy but now the water flows from two or three defined spots at the east end, resting(?) amongst the roots of the rushes. Flow = 18,300 g.p.d, water lost in the sand of Thunderbolt Creek about ¼ mile west. In winter the water gets a mile further down the creek.	Inactive
Camp	Peat mound 11 feet high and about 30 yards across; drains cut in 1897; flow initially strong but mound sank to 2ft and in six months had dwindled to a trickle of 3600 gpd; supplied horses and camps.	Inactive
Two-Mile (Corinda)	Large oval peat mound about 6ft high covering about 40 x 100 yards. Shallow drains lead east and they flow about 3 chains west of the mound (towards the creek); measured 3840 gallons per day.	Wetland 100m diameter
Winter	Large unimproved peat mound 200 x 400 yards in extent. In summer the evaporation equals the exudation, but in winter pools are formed all round supplied by the flows.	300 x 180m wetland
Lagoon	No streams run out but a lagoon 150 x 20 yards is permanently supplied.	Active but no discernible flow
Thunderbolt	…peat mound about 5 feet high and about 180 x 30 yards in extent. The creek water spreads all round in pockets there being here no defined channel. The water rises to the top & flows in a gutter down the slope of the mound; flow about 10,000 g.pd.	Active, but no discernible flow
Old Jericho	Same size as Thunderbolt but no drain cut.	Active, but no discernible flow
Five-Mile (Ballygar)	Group of springs yield about 10,000 gpd	All inactive
Friendly	Estimated to yield 100,000 gpd	All inactive
Jersey Springs	Estimated to yield 100,000 gpd.	Active but flow much-reduced
Northampton Hotel	…about 7 artesian mud springs between the Northampton Hotel on the Barcoo and the Enniskillen Homestead…about ½ mile east of the Hotel. Keep a supply in a waterhole sufficient for the local stock. The most northerly one is on Cattle Creek near the homestead and has been improved by Bore No. 1.	All inactive

While the springs continued to be utilised by pastoralists, the seemingly inexhaustible supplies obtained from bores meant that they played an increasingly peripheral role. Bores were celebrated in both folklore and the annals of the colonial scientific literature. The miracle of groundwater was easier to appreciate in the form of clear gushing fountains as opposed to muddy, wobbling quagmires. Springs, once the life blood of early settlement, faded into obscurity, a mere footnote in the in historical development of one of the world's largest artesian basins.

By 1944, little more than half a century after the drilling of the first bores in the district, J.K. Little wrote elegiacally about the Moon Springs, in the final lines of a lengthy article titled 'Vagrant Western Memories', published in The Longreach Leader:

> *'A feature of the desert country, which seems to be forgotten, was a couple of marvellous circular springs near a nest of mud springs just on the desert edge of Aramac Station country. Moon Springs we called them and a peculiar fine sand churned up to ground level, as far as the top water came. You could not grip that peculiar sand, however tight you grasped it under water, it would escape from the hand bar a faint smear. Passing through Aramac some seven years ago, I could neither contact anyone who knew those springs and bar one old identity, who still ran a store, named Kingston, not one of the folk was known to me in the long ago.*
>
> *That was a good reminder that the "March of Time" obliterates a heap of past history; that, in many ways was interesting. For my own, past years have not deteriorated my great regard for the west and those who carried on and still carry on'* (13 December 1944, p.14)

In some respects mirroring the global resurgence of spring pilgrimages, well-dressings and health spas, the Barcaldine springs have re-entered the public and scientific consciousness over the past two decades. This is mostly as a result of biological surveys, which have revealed an astounding diversity of specialised and strange life forms. Edgbaston Station was purchased by Bush Heritage Australia in 2009 and is now managed to conserve the springs and their dependent organisms.

3.5 Biological values

3.5.1 Outcrop springs

Most Barcaldine outcrop springs are small and dominated by generalist wetland species, mostly grasses, sedges and annual forbs, both native and exotic. River red gums (*Eucalyptus camaldulensis*), the characteristic tree of inland wetlands and Australia's most widely-distributed eucalypt, occur around most springs. No endemic species have been recorded from outcrop springs in the Barcaldine supergroup, although some support geographically isolated populations of plants otherwise restricted to wetter areas. Four springs in The Lake group support *Myriophyllum implicatum*, representing a disjunct population of this aquatic species, while *Fimbristylis* sp. (Lake Buchanan V.J.Neldner+ 3362) is only known from one spring in this group and the shores of ephemeral Lakes Buchanan and Constant 100 km to the north.

More than three-quarters of outcrop springs have been excavated and/or contained in the Barcaldine group, destroying their spring wetlands (Figure 26) and making it difficult to judge whether they would have contained endemic species prior to modification. However the fact that even relatively unmodified outcrop springs do not contain specialised species suggest it is unlikely that any endemic species have been lost. Rather, the more neutral water chemistry and greater temporal fluctuations of outcrop springs compared to discharge springs seem to have limited the evolution of specialised endemics (Fensham et al., 2011).

Figure 26. Outcrop spring on The Lake: one of the few of the Barcaldine outcrop springs that has not been excavated.

3.5.2 Discharge springs

The Barcaldine supergroup stands out even amongst the exceptional endemism of GAB discharge springs (see Section 1). Nine spring groups contain endemic species, with Pelican Creek containing by far the highest concentration of endemic species in the GAB and indeed inland Australia (38 spring endemic species, including 24 that occur nowhere else). Coreena and Thunderbolt Creek have four endemic species each. Smoky, Coreena and Thunderbolt Creek each contain an endemic snail that is restricted to these springs (Table 8).

3.5.2.1 Plants

Four plant species are endemic to the Barcaldine supergroup: *Eriocaulon aloefolium, Eriocaulon giganteum*, *Eryngium fontanum* and *Peplidium* sp. (Edgbaston R.J. Fensham 3341) (Figure 27). The two *Eriocaulon* species are each restricted to a single population on Edgbaston in the Pelican Creek spring group. Both are perennial tussock-forming herbs, the former with fleshy aloevera-like leaves to 10cm long, the latter growing to 40cm high (see (Davies et al., 2007) for full morphological descriptions). *E. aloefolium* occurs across 0.005km^2 over two adjacent spring wetlands. In 2010, 1274 clumps were counted; this had almost doubled to 2588 in June 2013 but plants were smaller, suggesting a recent recruitment event (Paul Foreman, unpublished data). It is selectively dug up by pigs at certain times, however seems to recover well from this disturbance. The spring containing *Eriocaulon giganteum* lies on the ephemeral Lake Mueller and is surrounded by *Melaleuca bracteata.* Its area of occupancy is <0.001 ha, with 263 individuals counted in 2013, down from 480 in 2010, apparently due to flooding mortality amongst smaller plants in lower lying areas (Paul Foreman, unpublished data).

Table 8: Occurrence of spring endemics by spring complex, Barcaldine supergroup.

	Archers	Coreena	Thunderbolt Creek	Pelican Creek	Smoky	Kennedy	Old Lake Huffer	McKenzie's	Total springs, Barcaldine (all GAB)
Plants									
Chloris sp. (Edgbaston R.J. Fensham 5694)				4					
Eriocaulon aloefolium	-	-	-	2	-	-	-	-	2 (2)
Eriocaulon carsonii	-	-	2	70	-	-	-	-	89 (140)
Eriocaulon gigantium	-	-	-	1	-	-	-	-	1 (1)
Eryngium fontanum	-	1	-	54	-	-	-	-	60 (60)
Hydrocotyle dipleura	1	-	-	51	1	1	1	-	65 (75)
Isotoma sp. (Myross R.J. Fensham 3883)	-	-	-	12	-	-	-	-	15 (16)
Myriophyllum artesium	1	1	9	61	1		-	-	89 (130)
Peplidium sp. (Edgbaston R.J. Fensham 3341)	-	-	-	25	-	-	-	-	25 (25)
Sporobolus pamelae	1	1	-	108	-	1	-	1	126 (130)
Fish									
Scaturiginichthys vermeilipinnis	-	-	-	3	-	-	-	-	3 (3)
Chlamydogobius micropterus	-	-	-	29	-	-	-	-	29 (30)
Molluscs							-		
Gabbia davisi	-	-	-	-	1	-	-	-	1 (1)
G. fontana	-	-	-	13	-	-	-	-	13 (13)
G. pallidula	-	-			-	-	-	-	
Glyptophysa n.sp.	-	-	-	11	-	-	-	-	11 (11)
Gyraulus edgbastonensis	-	-	-	16	-	-	-	-	16 (16)
Jardinella colmani	-	-	2	-	-	-	-	-	2 (2)
Jardinella coreena	-	1	-	-	-	-	-	-	1 (1)
J. aff. accum smooth	-	-	-	4	-	-	-	-	4 (4)
J. edgbastonensis	-	-	-	38	-	-	-	-	38 (38)
J. aff. edgbastonensis	-	-	-	15	-	-	-	-	15 (15)
J. corrugata	-	-	-	17	-	-	-	-	17 (17)
J. accuminata	-	-	-	12	-	-	-	-	12 (12)
J. jesswiseae	-	-	-	31	-	-	-	-	31 (31)
J. pallida	-	-	-	18	-	-	-	-	18 (18)
J. Myross A aff pallida	-	-	-	5	-	-	-	-	5 (5)
J. Myross B tall keeled	-	-	-	5	-	-	-	-	5 (5)
J. Myross C aff accum ribbed	-	-	-	1	-	-	-	-	1 (1)
J. Myross D (fat) aff corrugata	-	-	-	13	-	-	-	-	13 (13)
J. zeidlerorum	-	-	-	10	-	-	-	-	10 (10)
Edgbastonia alanwillsi	-	-		16	-	-	-	-	16 (16)
Other invertebrates									
Dugesia artesiana (flatworm)	-	-	-	2	-	-	-	-	2 (2)
TOTAL ENDEMIC SPECIES	3	4	4	31	3	2	1	1	

Figure 27. Plant species endemic to the Barcladine supergroup (clockwise from top left: *Eriocaulon aloefolium, Eriocaulon giganteum, Peplidium* sp. (Edgbaston R.J. Fensham 3341), *Eryngium fontanum*)

Peplidium sp. (Edgbaston R.J. Fensham 3341), a slender prostrate forb with round leaves and dark-pink flowers, is also restricted to the Pelican Creek springs where it is known from 25 springs, mostly north and east of the Edgbaston homestead. It can be locally abundant within its extremely restricted range, with a conservative population estimate of 2500 plants. *Eryngium fontanum* is a distinctive upright perennial herb with a circular cluster of fleshy leaves at its base, a solid fleshy taproot and flowering stems 40-80 cm long producing elongated blue flowerheads. It occurs at Doongmabulla (four adjacent spring wetlands), Pelican Creek (recorded from 54 spring wetlands) and Coreena (one small population of 20 plants), and the total number of individuals is probably <6000 plants.

A further three species are known only from the Barcaldine and Eulo supergroups, and in all cases Barcaldine represents their stronghold. *Isotoma* sp. (Myross R.J. Fensham 3883), a tiny mat-forming aquatic to <3cm high with white flowers, is mostly restricted to the Barcaldine supergroup, but also occurs in one spring at Yowah Creek west of Eulo.

It has been recorded in 12 spring wetlands at Pelican Creek and three at Moses Springs on Doongmabulla. Its mat-forming habit and inconspicuous nature when not flowering render it very difficult to estimate population size, but a conservation estimate would be 200 plants per population * 15 springs = 3000 plants in total.

The robust perennial grass *Sporobolus pamelae* only occurs at four spring wetlands west of Eulo outside the Barcaldine supergroup. It is a characteristic and often dominant grass in >80 spring wetlands at Pelican Creek and 15 at Doongmabulla, with scattered tussocks at four other springs. *Hydrocotyle dipleura*, a distinctive ground-hugging forb forming small carpets across patches on permanent groundwater soakage areas, occurs at four spring groups at Eulo and six at Barcaldine, where it has been recorded from 65 individual springs. Most (51) of these populations are at Pelican Creek. The tall perennial grass *Chloris* sp. (Edgbaston R.J. Fensham 5694) is extensive around the damp edges of springs at Doongmabulla and is patchily common over small areas at Edgbaston. It is often heavily grazed by macropods and has been recommended for listing as Endangered (Silcock et al., 2014). *Utricularia fenshamii* is almost an endemic known from Barcaldine supergroup discharge springs and also the Eulo Bourke and Mitchell-Staaten supergroups. However, it is also known from a swamp near Wee Waa in New South Wales (Jobson, 2013). The Barcaldine supergroup contains more than half the known populations of *Eriocaulon carsonii* and *Myriophyllum artesium*

Some springs also contain disjunct populations of some plant species, notably belah (*Casuarina cristata*) at Smoky Spring on Lake Huffer; *Cenchrus purpurascens* and *Utricularia caerulea* at Edgbaston and Doongmabulla; *Leersia hexandra* at Thunderbolt Spring on Corinda; and black tea-tree (*Melaleuca bracteata*) and bore-drain sedge (*Cyperus laevigatus*), both of which characterise many springs. *Baumea rubiginosa, Isachne globsa, Ischaemum australe* and *Sacciolepis indica* at Doongmabulla also represent isolated inland occurrences of primarily higher-rainfall mesic species.

3.5.2.2 Fish

Fish species known from the Barcaldine group comprise endemic spring species, riverine vagrants that access springs opportunistically and the widespread invasive species gambusia, *Gambusia holbrooki*. Two of the three fish species endemic to Great Artesian Basin springs in Queensland occur in – and only in – the Barcaldine group (Figure 28); the red-finned blue-eye, *Scaturiginichthys vermeilipinnis,* and the Edgbaston goby, *Chlamydogobius squamigenus*)(Figure 28). Both species are listed as endangered under Queensland legislation (NCA 1992) and critically endangered by the IUCN (2015). Under federal legislation (EPBC 1999), the blue-eye is endangered and the goby vulnerable.

Figure 28. Endemic fish from the Barcladine supergroup: red-finned blue-eye (top) and Edgbaston goby (bottom) (photos: Adam Kerezsy).

Red-finned blue-eye was discovered in 1990 by Australian fish ecologist Peter Unmack at Edgbaston Station north-east of Aramac. The species is the only member of its family (Pseudomugilidae) from Australia's interior, and is rarely larger than three centimetres long. The springs at Edgbaston remain the only habitats where red-finned blue-eye have been found, however the spring complex is also inhabited by gambusia and observations from 2009 have demonstrated that gambusia colonisation leads to extirpation of the endemic species at individual spring scale (Kerezsy and Fensham, 2013).

Edgbaston was purchased by the not-for-profit conservation group Bush Heritage Australia in 2008 and a recovery project was initiated in 2009 to ameliorate red-finned blue-eye decline. Techniques that have been used to-date at Edgbaston Reserve have included application of the piscicide rotenone (to control gambusia), relocation of red-finned blue-eye to springs that are gambusia-free and the installation of barriers around these springs to reduce the chance of subsequent gambusia colonisation (Kerezsy and Fensham, 2013). A captive breeding project was also initiated in 2014 by Bush Heritage Australia, although initial results indicate that maintaining and breeding the species in captivity is difficult (A. Kerezsy, pers. comm.). Similar results were reported in the 1990s by fish hobbyists, and no captive populations have endured from these attempts (Fairfax et al., 2007).

Red-finned blue-eye occurred in four springs at the commencement of the recovery project. They currently occur in eight, although six are relocated populations established between 2009 and 2014 (Kerezsy and Fensham, 2013; Kerezsy, 2015).The continuing decline of naturally-occurring populations of the species as well as the unpredictable success or failure of relocated populations suggest that the future of the species remains precarious and that on-going management is crucial to maintaining populations in the short to medium term (Kerezsy and Fensham, 2013).

The Edgbaston goby is a benthic species that grows to a maximum length of five to six centimetres (Allen et al., 2002). There are related species at Elizabeth Springs in the Diamantina catchment in western Queensland (*Chlamydogobius micropterus*), at Dalhousie Springs in northern South Australia (*Chlamydogobius dalhousiensis*), in the Finke River in the Northern Territory (*Chlamydogobius japalpa*) and in the southern Lake Eyre Basin (*Chlamydogobius eremius*). Speciation within the genus is likely to be a result of isolation and Australia's drying climate over a long time period: as permanent water in the arid zone became more scarce, the small gobies were probably forced to retreat to spring complexes (at Edgbaston, Elizabeth Springs and Dalhousie) and isolated riverine water sources in the Finke and southern Lake Eyre regions.

Though not generally considered as imperilled as red-finned blue-eye, populations of Edgbaston goby have remained low: the species was found in eight springs at Edgbaston in 1994 (Wager, 1999), at nine in 2009 (Kerezsy, 2009) and nine in 2014 (Kerezsy, 2014c). In addition, Edgbaston goby is also present in at least one spring on Myross (a property adjoining Edgbaston) and in its outflow in Pelican Creek, and a population was recently found in a bore drain on Ravenswood, some 30 kilometres to the south-west (Kerezsy, 2014b). A population recorded from a bore drain at Crossmoor Station can be considered extinct as this bore has been capped.

Although Edgbaston goby has a wider distribution than red-finned blue-eye and can demonstrably co-habit with gambusia and survive in non-spring environments, evidence from Edgbaston suggests that increasing gambusia abundance may have a deleterious impact on the species (Kerezsy, 2014b). In the first instance, management of the species would benefit from additional survey of all permanent waters in the Aramac/Muttaburra/Longreach areas in order to accurately establish the distribution of the species. However, a recovery project similar to that in place for red-finned blue-eye is also worthy of consideration, particularly as populations of Edgbaston goby are often small (<50 individuals).

Riverine fish species present in catchments of the Lake Eyre Basin migrate to and colonise new areas following flooding: it is not surprising that these species occasionally access springs (Kerezsy et al., 2013). In the Barcaldine group, spangled perch, *Leiopotherapon unicolor*, glassfish, *Ambassis* sp., desert rainbowfish, *Melanotaenia splendida tatei* and hardyhead, *Craterocephalus* *stercusmuscarum* have been observed either opportunistically or as part of routine sampling (P. Unmack, S. Brooks, R. Fairfax, R. Fensham, A. Kerezsy pers. obs.).

These observations suggest that any small-bodied riverine fish species may access spring environments when conditions are favourable, however due to the shallowness of the springs, the high temperatures some springs reach in summer and the clarity of the water, these species can correctly be considered vagrants. Although hardyhead (*Craterocephalus stercusmuscarum*) from Big Moon Spring on Myross were once considered a possible separate spring species (Wager and Unmack, 2000), recent observations suggest that the fish is more widespread in the Aramac Creek catchment (D. Sternberg pers. com.), and genetically it is closely related to other populations elsewhere in the Lake Eyre Basin (Unmack and Dowling, 2010).

3.5.2.3 Invertebrates

The Barcaldine supergroup is home to the highest proportion of endemic invertebrate taxa in GAB springs nationally, many of which are restricted to particular regions. The invertebrate fauna can be broadly divided based on the way they use the habitat: transient and widely dispersing species (e.g. dragonflies) are common across numerous spring groups with little regional specialisation, whilst obligate aquatic groups such as molluscs tend to be endemic to a particular complex. Endemic taxa are particularly valuable and of primary conservation concern as they occupy very narrow ranges (i.e. most have a full range <50km radius) and rely solely on a particular set of springs. Current levels of endemism within the supergroup are likely to be an underestimate as numerous taxa found in Barcaldine that are represented in other areas (e.g. the amphipod genus *Austrochiltonia*, the shrimp species *Caridina thermophila*, flatworms *Dugesia artesiana*) have been ear-marked as potential endemics yet to be confirmed (Ponder et al., 2010).

Of confirmed endemic taxa the Barcaldine supergroup is particularly rich in molluscs: at least 15 species of gastropods are endemic to the supergroup. These comprise ten described and several undescribed species of *Jardinella* (Hydrobiidae), three species of spring endemic *Gabbia* (Bithyniidae) and two endemic Planorbidae (Ponder et al., 2010). Pelican Creek contains the highest concentration of endemics with nine species, while Smoky, Coreena and the Thunderbolt Creek springs (Winter and Thunderbolt Springs) are home to one endemic snail each. The species of Edgbaston are highly variable in shape and size, ranging from the tiny (<3mm) sand-coloured *Jardinella pallida* to the largest and most distinctive undescribed species of *Glyptophysa*, with a surprising amount of morphological variability arising in this local radiation of the Hydrobiidae.

Endemic gastropods rarely occupy all springs within a complex, which is likely the product of the interplay between limits on dispersal and environmental limits created by the variability of the spring environment. Snails are only able to move to new springs if there is a wetted area for them to traverse (e.g. connected spring tails), and most colonisation events are likely to be the product of transport on floodwaters or incidental transport on large mammals or birds. Most species within the Edgbaston complex are unable to survive more than two hours out of water, and most perish within six hours of being exposed to the highest natural levels of salinity (>6ppm) or extreme temperatures (>45°C), including *Jardinella acuminata*, *Jardinella jesswisea*, *Glyptophysa* n.sp. and *Gyraulus edgbastonensis* (Renee Rossini, unpub. data). This restricts many species to those springs that remain stable throughout daily and seasonal fluctuations, and to the permanent and deepest parts of those springs. More tolerant species (e.g. *Gabbia fontana, Jardinella corrugata*) can persevere up to 24 hours out of water and extreme salinities and are often found at spring edges or in shallow edges or tails.

Though spatially restricted to permanent and stable areas, many species are numerically common. Population estimates for two species based on their habitat associations predict that, in a large spring (E509) there could be up to 5,000 individuals of the large *Glyptophysa* n. sp. and between 13,000 and 26,000 individuals of *Jardinella corrugata* (Renee Rossini, unpublished data). It is likely that these numbers fluctuate markedly between seasons as extensive mortality occurs following winter when the spring tails begin to dry due to increase evaporation, leaving hundreds of individuals trapped and exposed to extreme conditions.

3.5.2.4 Groundwater scald plants

Sodic and salty groundwater scalds (Figure 29) are often associated with discharge springs, and these areas have a specialised non-aquatic flora (Figure 30;

Table 9). Two species are endemic to this habitat and occur only on Edgbaston Reserve: *Gunniopsis* sp. (R.J. Fensham 5094) is known from three populations within a 2 km^2 area, totalling 80 plants, while the recently-described *Pluchea alata* (Bean, 2013b) can be locally common over small areas of scalded habitat adjacent to springs. The Near Threatened *Sporobolus partimpatens* is known from groundwater scalds within the Barcaldine, Bourke, Springsure, Eulo and Mulligan River supergroups, while undescribed *Calocephalus*, *Sclerolaena* and *Dissocarpos* species are restricted to groundwater scalds in the Aramac-Barcaldine area. *Trianthema* sp. (Coorabulka R.W. Purdie 1404) occurs on groundwater scalds throughout the GAB. *Eremophea spinosa* and the recently-described *Sphaeromorphaea major* (Bean, 2013a) are restricted to groundwater scalds in the Barcaldine supergroup in inland Queensland, but occur in other habitats elsewhere.

Figure 29. Scalded area in the vicinity of discharge springs provide habitat for endemic plant species.

Figure 30. Endemic plant species associated with scalded areas around discharge springs (clockwise from top left): *Gunniopsis* sp. (Edgbaston R.J. Fensham 5094); undescribed dioecious *Sclerolaena*; *Trianthema* sp. (Coorabulka R.W. Purdie 1404) and undescribed *Calocephalus* sp. (Edgbaston J.Silcock JLS800)

Table 9. Plants species endemic to GAB groundwater scalds, Barcaldine supergroup

Spring or complex	Scald endemics
Archer’s	*Calocephalus* sp. (Edgbaston J.Silcock JLS800), *Sclerolaena “dioecia”, Sporobolus partimpatens,Trianthema* sp. (Coorabulka R.W. Purdie 1404)
Edgbaston/Myross	*Gunniopsis* sp. (Edgbaston R.J. Fensham 5694), *Pluchea alata, Calocephalus* sp. (Edgbaston J.Silcock JLS800), *Trianthema* sp. (Coorabulka R.W. Purdie 1404), *Dissocarpos* sp. (Doongmabulla E.J. Thompson+GAL21), *Sclerolaena “dioecia”, Sporobolus partimpatens, Dactyloctenium buchananensis,*
Smokey	*Calocephalus* sp. (Edgbaston J.Silcock JLS800), *Sporobolus partimpatens, Trianthema* sp. (Coorabulka R.W. Purdie 1404)
Coreena (including Maranda)	*Calocephalus* sp. (Edgbaston J.Silcock JLS800), *Trianthema* sp. (Coorabulka R.W. Purdie 1404), *Dissocarpos* sp. (Doongmabulla E.J. Thompson+GAL21), *Sclerolaena “dioecia”, Sporobolus partimpatens, Dactyloctenium buchananensis*
Thunderbolt Creek (Corinda/Lake Huffer)	*Calocephalus* sp. (Edgbaston J.Silcock JLS800), *Dactyloctenium buchananensis, Eremophea spinosa, Sclerolaena “dioecia”, Sporobolus partimpatens, Trianthema* sp. (Coorabulka R.W. Purdie 1404)
Old Lake Huffer	*Eremophea spinosa, Sclerolaena “dioecia”, Trianthema* sp. (Coorabulka R.W. Purdie 1404)

3.6 Key threats and management

3.6.1 Aquifer drawdown

There has been extensive loss of discharge springs in the Barcaldine supergroup (Figure 8) as a result of aquifer drawdown (Figure 31).

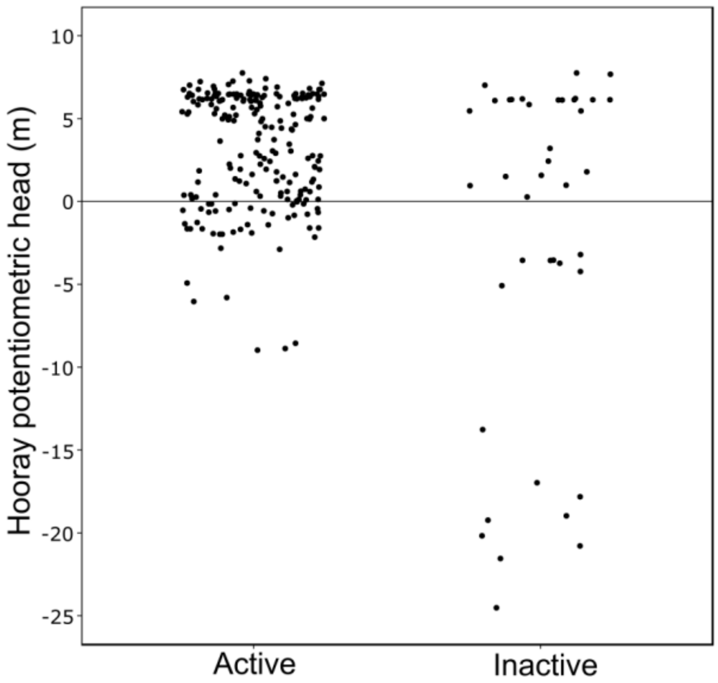


Figure 31. Range in the modelled current potentiometric head of the Hooray aquifer for active and inactive discharge springs in the Barcaldine Supergroup. Inactive springs exhibiting positive head may reflect conduits for discharge that have become closed or inaccuracies in the modelled potentiometric head. Active springs below the zero line presumably reflect inaccuracies in the modelled potentiometric head.

Given the rate of spring extinction and the high concentration of endemics in the discharge springs of the Barcaldine supergroup, it seems likely that local extinctions have occurred. From Griffiths' descriptions, it seems likely that Aberfeldie, Atherton, Five-Mile (Corinda) and Camp (Corinda) once contained spring endemics (Figure 32).

The draining and subsequent extinction of the peat mounds described by Griffiths at Atherton, Camp, Winter and Thunderbolt Springs, even where the springs remain active, essentially represents the loss of an ecosystem type in this region. In October 1897 he described Atherton Spring as 'an oval mound about 20 yards long and 2 feet high, covered with reeds at the top, from which a small stream issues and flows down the slope into a logged drinking place the overflow spreading in shallow lagoons for some hundred yards around'. There is no sign of the oval mound covered with reeds as described by Griffiths or the logged drinking place, however it is easy to imagine the spring overflow spreading into shallow lagoons around the spring in the past.

His description of Camp Spring on Thunderbolt Creek on Corinda illustrates the fate of these peat springs:

> *In the beginning of 1897 this was a peat mound 11 feet high and about 30 yards across, all with springs). In May '97 drains were cut to the centre and at first a strong flow of water was got, but mound sank, until in November it was only a trickle (1.1 in an V = 3,600 g.pd.) and the mound was only 2 feet high.*


Figure 32. Atherton Spring, described by Griffiths as a peat mound (left); possible location of Griffiths' Camp Spring, although peat mound or evidence of camp no longer evident (right).

There remain a couple of active low peaty mounds on Coreena south of the house, and some peaty vents at Two-Mile spring on Corinda (Figure 33); *Myriophyllum artesium* was recorded at the latter.

Figure 33. Peaty vent, Two-Mile spring, Corinda.

3.6.2 Invasive species

3.6.2.1 Exotic plants

A stand of para grass (*Urochloa mutica*) at a spring on Edgbaston in the Pelican Creek complex has been eradicated by manual removal over an 18 month period, while date palms at Dalhousie Springs have been effectively eradicated over recent years. These examples of successful eradication suggest that removal of isolated weed populations from spring wetlands is a valuable management exercise.

Dense infestations of rubber vine (*Cryptostegia grandiflora*) occur in the black tea-tree (M*elaleuca bracteata*) forest surrounding the Thunderbolt Creek springs on Corinda (Lagoon, Winter, Two-Mile), and will be time-consuming and expensive but potentaily possible to control. Prickly acacia (*Acacia nilotica)* and Parkinsonia (*Parkinsonia aculeata*) are still abundant around some springs on Edgbaston amongst the Pelican Creek Springs. Control is progressing over recent years at Edgbaston, but requires strategic follow-up for long-term success. None of these infestations specifically threaten values associated with the spring wetlands themselves but compromise the ‘naturalness’ of the landscape setting. An exception is rubber vine where it can festoon trees surrounding the spring and substantially increased shading over the spring. Burning to control rubber vine at this site would open up the canopy which may benefit the *Eriocaulon carsonii* population within the spring.

3.6.2.2 Grazing and rooting

Ongoing pig control, through trapping, baiting and shooting, is critical, particularly for conservation of *Eriocaulon* species, which are selectively rooted up by pigs. *Eriocaulon carsonii* was found only in three patches near the central vent of Thunderbolt Spring, under a *Melaleuca bracteata* forest, covering <1m^2 (probably about 1000 individuals). Its existence in the spring is imperilled by ongoing rooting of pigs, with a mob of about 30 seen near the spring in June 2013. *Eriocaulon aloefolium* is also targeted by pigs and although it seems to recover well from this disturbance, it is inherently vulnerable due to occurring in a single population.

Macropod grazing pressure at Edgbaston can be extremely high at times but does not seem to be detrimental to the plant communities and may help to maintain the shallow free water that provides prime invertebrate and fish habitat.

3.6.2.3 Gambusia

Gambusia (*Gambusia holbrooki*), from the south-eastern United States, were liberated on all suitable continents in the early twentieth century for mosquito control as a response to malaria and have since become the most widespread freshwater fish in the world (Pyke, 2008). Gambusia are present in the Cooper Creek catchment in Queensland (Arthington et al., 2005) and these populations have colonised the Barcaldine spring group. Gambusia is a small fish, five to six centimetres long, with broad dietary and environmental tolerances. As such, and unfortunately, they are able to persist in the shallow spring environments and it is thought that, as live-bearers, they out-compete egg-laying fishes like the red-finned blue-eye (Kerezsy and Fensham, 2013). Gambusia are widespread throughout the spring complex at Pelican Creek, and were found in 39 springs in 2014 (Kerezsy, 2014c).

Gambusia has progressively colonised the springs that contain red-finned blue-eyes, and the extinction of the native fish inevitably follows colonisation by the feral fish (Kerezsy and Fensham, 2013). Only one large natural population of the red-finned blue-eye survives in a spring without gambusia. This spring is high in the catchment and relatively resistant from invasion because it has not been connected to other springs and waterways during big floods. Recovery efforts have included earthworks to restrict overland flow between the last natural population and potential sources of colonisation by gambusia; removal of gambusia from springs that may be further isolated by artificial barriers; using the selective piscicide rotenone to eradicate gambusia from springs; establishment of red-finned blue-eye populations in springs in landscape settings that may be immune from gambusia colonisation; and establishment of artificial wetlands and populations of red-finned blue-eyes using bore discharge (Figure 34). These recovery efforts are coordinated by the landholder at Edgbaston, Bush Heritage Australia, and should be supported. The rescue from otherwise imminent extinction of the red-finned blue-eye is achievable with strategic and innovative responses and will be successful with ongoing management that adapts to successes, failures and emerging circumstances.

Figure 34. Developing artificial wetland at Edgbaston house that could provide habitat for the Critically Endangered spring endemic the red-finned blue-eye. The location is sufficiently isolated from flood waters to avoid colonisation by gambusia. The silt-fence barrier provides an extra layer of protection.

The presence of gambusia in the great majority of open bore drains in the vicinity of the Barcaldine group (Kerezsy, 2014a) is an additional concern. These populations pose an extra threat to recovery projects as they constitute a potentially endless supply of colonising alien species. Accurately establishing the distribution of gambusia in all permanent waters in the area may be useful in this regard, and particularly if drains are found where native species persist and/or gambusia are absent.

Although gambusia are known to impact populations of endemic fish, it is likely that they also impact other spring fauna. Gambusia should therefore be considered the most important biological threat to the ecological integrity of native spring species and communities in the Barcaldine supergroup.

3.6.3 Significant species

Monitoring of the rarest endemics *Eriocaulon aloefolium*, *Eriocaulon giganticum*, *Gunniopsis* sp. (Edgbaston R.J. Fensham 5694) and *Chloris* sp. (Edgbaston R.J. Fensham 5694) should be conducted to determine trends in population sizes and identify potential threatening processes. In particular, the impact of pigs on *Eriocaulon aloefolium* needs to be regularly assessed with a view to fencing if necessary.

3.6.4 Impacts of proposed coal and coal-seam gas developments

The Barcaldine supergroup springs (with the notable exception of the Doongmabulla springs which have been treated separately in this report) are relatively immune from impacts of proposed coal mining developments in the Galilee Basin. All of the springs in the Barcaldine supergroup are relatively remote from the proposed developments in the Galilee Basin and are hydrologically isolated by aquitards. There is a possibility that there is some hydrological connectivity through the Rewan Formation, but the Moolayember is a thick mostly fine-grained sedimentary unit that probably provides an effective barrier between the Galilee and Eromanga Basin where the Barcaldine supergroup is situated.

4 Flinders River Supergroup

4.1 Overview

The outcrop springs of the Flinders River supergroup are typically within the gullies of the Gregory Range (Figure 35) and have been partially surveyed and approximately tallied using likely images from remote sensing (Table 10). These springs have a very different character to the springs of the plains as the water drains out of the rocks under gravity rather than welling upwards under artesian pressure. Some of these springs are large and provide the perennial source for major streams such as the Norman, Clara and Yappar Rivers flowing westward from the ranges and the Gilbert River flowing northward. Only some of these springs have been visited and most are difficult to access. This project has concentrated on compiling information for the 'discharge springs' within the Great Artesian Basin that occur on flat country away from the ranges. Unlike outcrop springs, discharge springs have suffered severely diminished flows (Figure 35) due to reduced aquifer pressure brought about by extensive sinking of bores. Only 20% of the discharge spring wetlands remain active.

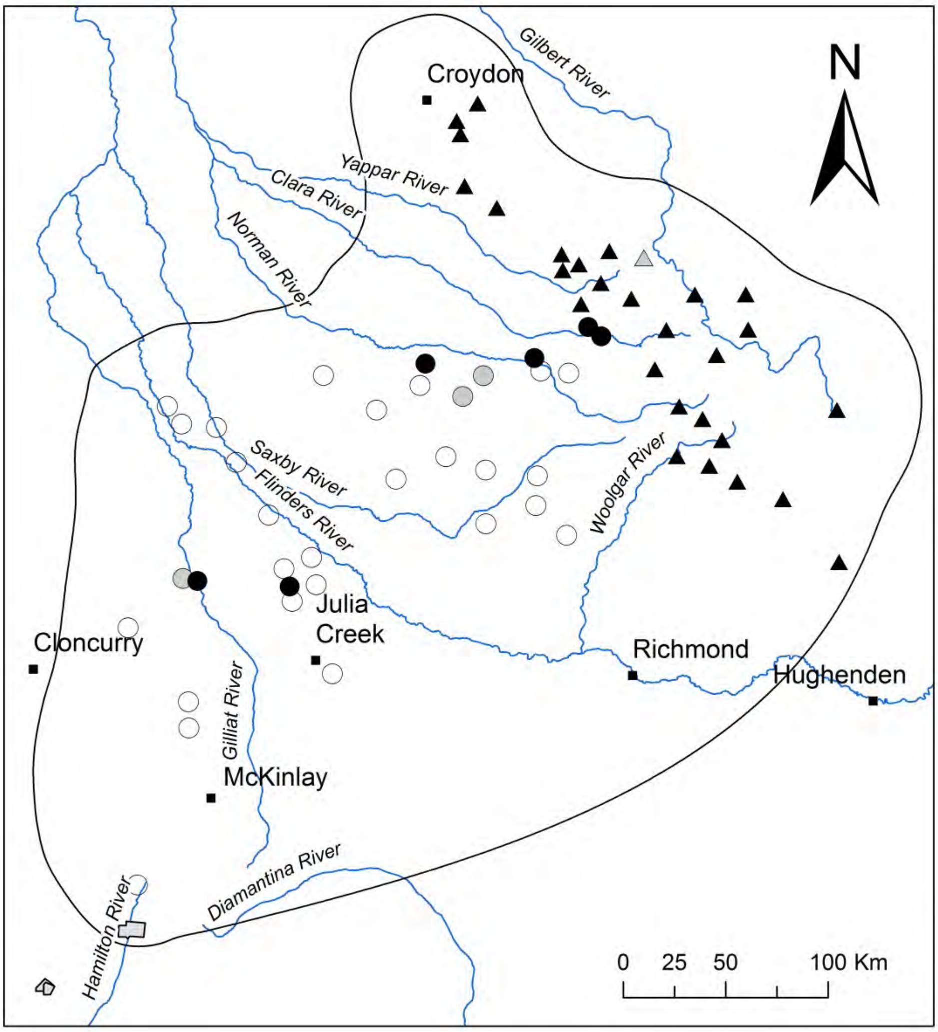


Figure 35. Spring complexes within the Flinders River supergroup. Spring complexes with 100% active springs (solid), partially (1%-99%) active (grey) and 100% inactive (open symbols) are identified. Outcrop springs (triangles) are distinguished from discharge springs (circles). The Cannington Mine is shaded grey in the lower left.

Table 10. Summary of the status of the springs in the Flinders River supergroup at the complex, wetland and vent scale.

	Complex			Wetland		Vent	
	Active	Partially active	Inactive	Active	Inactive	Active	Inactive
Outcrop	27	1	0	91	1	91	1
Discharge	6	3	26	29	118	29	121

4.2 Hydrogeology

4.2.1 Regional geology

The Flinders River supergroup spans the Euroka Arch, a basement structure partially separating the Carpentaria Basin from the Eromanga Basin. Granite provides the basement in the northern Eromanga Basin in the southwest of the supergroup and is exposed in a very limited area by the Kevin Downs Fault. The basement of the Carpentaria Basin in the vicinity of the springs is metamorphosed sediments and these Precambrian schists outcrop in the vicinity of springs at Mt Fort Bowen, Mt Brown and Mt Little. The Gilbert River Formation forms the lower unit of the Mesozoic sedimentary sequence and is the main water-bearing aquifer for the springs in this supergroup. Some stratigraphic sequences in bores describe Hooray Sandstone, Cadna-owie Formation and Wyandra Sandstone, but these units are synonymous with facies within the Gilbert River. This sandstone is overlain by a sequence of Cretaceous units, the Wilgunyah Formation, the Toolebuc Member and the Allaru Member that act as aquitards. The Gilbert River Formation outcrops extensively in the eastern part of the Supergroup and there are many large outcrop springs, many of which are isolated in rugged ranges, providing baseflow for major streams including the Woolgar, Norman, Clara and Yappar Rivers.

In addition to the isolated outcrops of granite and metamorphic rocks in the western edges there are important structures relating to springs. A large network of springs is aligned in the vicinity of the Woodstock Structure, a pronounced section of the Euroka Arch. Another structure clearly associated with springs is the north-south trending St Elmo Structure. Tectonic activity that created these structures during the Paleozoic has reactivated to result in minor faulting.

4.2.2 Hydrology of the springs

The springs associated with the outcropping Gilbert River Formation in the eastern region of the supergroup are probably gravity-fed springs fed from higher elevation sandstone. The Gregory Range to the east of these areas is represented by a tableland of Tertiary sands overlying the sandstone. These provide recharge intake beds that store water before it percolates through the sandstone. In the south and centre of the region these springs emanate from stratigraphic weaknesses associated with side-gullies from the main streams (Figure 36). In the northern areas to the south-east of Croydon large springs are associated with the footslopes of the outcropping sandstone but not necessarily in association with gullies.

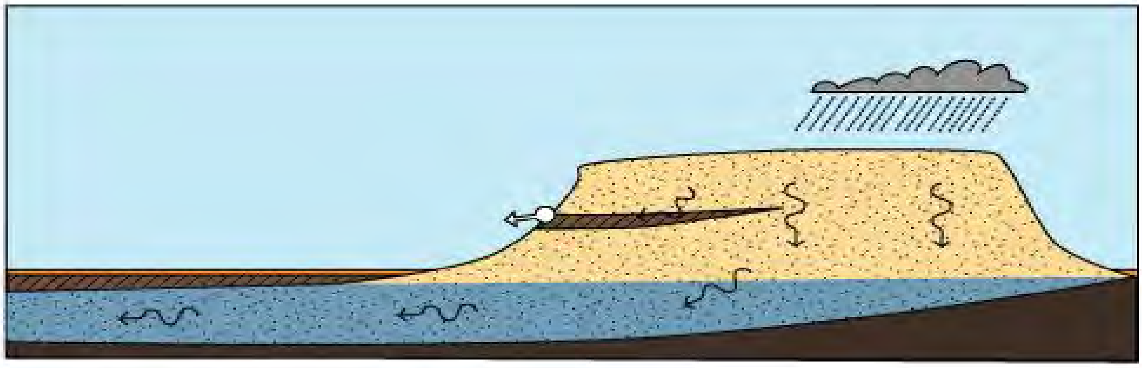


Figure 36. Conceptual diagram representing the outcrop springs in the outcropping Gilbert River Formation. The brown wedge may represent a confining layer in the sandstone or a fracture aligned with the stratigraphy.

The discharge springs associated with the Woodstock Structure (Pelham, East Creek and nearby properties) are not aligned in a linear arrangement suggesting that they may be associated with polygonal fault structures (Stratigraphy A, Figure 37). The springs on Bunda Bunda, Saxby Downs and nearby properties to the south may also be associated with polygonal faulting (Stratigraphy C, Figure 37). There is no obvious evidence of faulting in the stratigraphy represented by bore logs for either of these spring clusters (Figure 38, Figure 40).

These faults may be only relatively weak but the substantial artesian pressures in this region (probably up to 80m head), some of the highest in the GAB, were sufficient to result in surface discharge through springs. This artesian head has diminished after more than a century of discharge through large bores throughout the region, and the network of springs currently includes active springs, inactive springs and springs that were previously permanent, but are now only ephemeral. These ephemeral springs often occur in local sinkholes (Figure 40), but do not have obvious vents suggesting that their current groundwater source is diffuse discharge from the regolith. Presumably the groundwater source from the Wyandra Sandstone Member/Hooray Sandstone/Gilbert River Formation is supplementing local aquifers in the overlying Cainozoic deposits.

When these surface aquifers are diminished during long dry periods discharge through faults in the underlying aquitard soaks up into the regolith and the groundwater does not discharge at the surface. When the surface aquifer in the regolith is replenished by rainfall, groundwater diffuses to the surface in the hollows of former permanent springs. When aquifer pressure was higher before groundwater exploitation through bores, some of these now ephemeral springs would have been permanent, while others were probably always ephemeral.

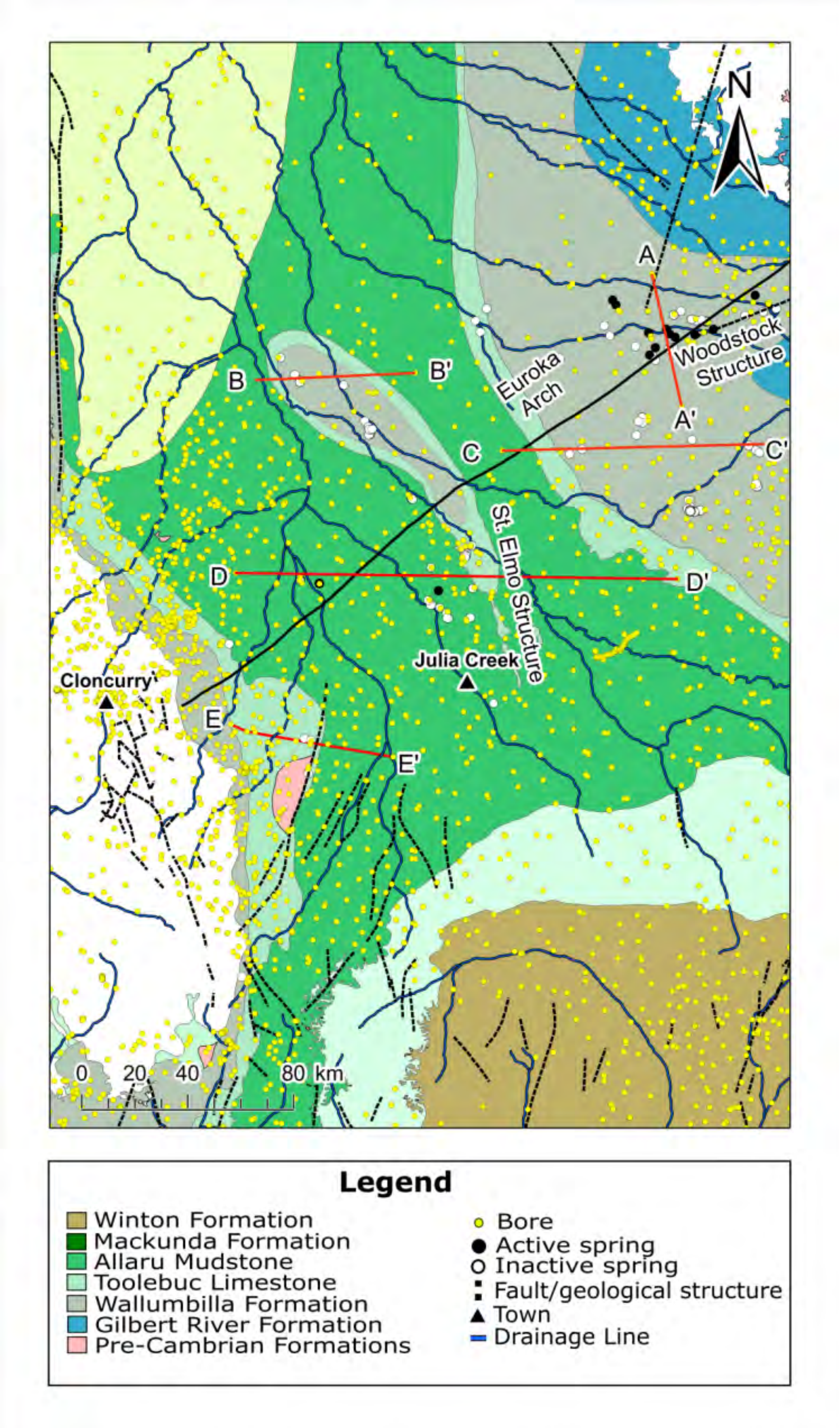


Figure 37. Discharge springs in the Flinders River supergroup and the associated surface geology with some important structural features identified. The position of the stratigraphic lines represented below is indicated.

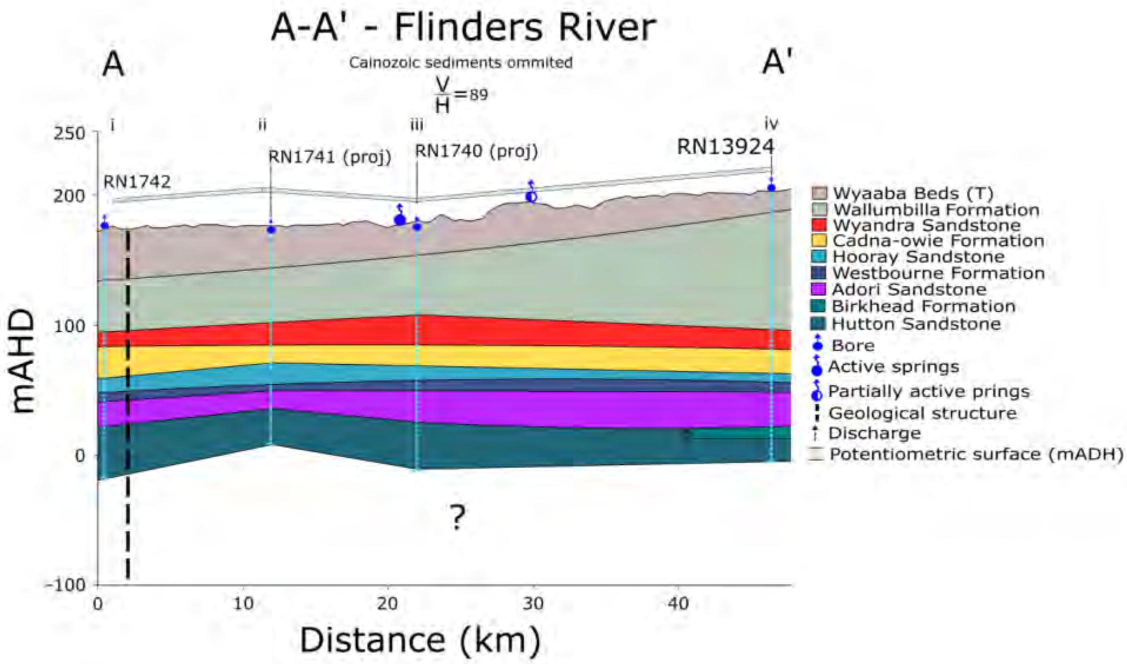


Figure 38. Stratigraphy through Flinders River discharge springs (see A-A'; Figure 37 for location). Where bores are projected onto the stratigraphic line the difference in elevation is indicated by the position of the bore symbol in relation to the ground surface. The range in the potentiometric head over time is represented by the limits of the grey bar and the roman numerals indicate the location of the bores that inform the head. i: RN92941, min. date 1998: SWL 19.12, max.date 2001: SWL 22.16; ii: RN92941, min. date 1995: SWL 30.4, max.date 2002: SWL 33.6; iii: RN92411, min. date 1995: SWL 30.4, max.date 2002: SWL 33.6; RN69661, min. date 1992: SWL 32, max.date 1999: SWL 35.4; iv: RN13924, min. date 1989: SWL 15, max.date 2011: SWL 18.6.

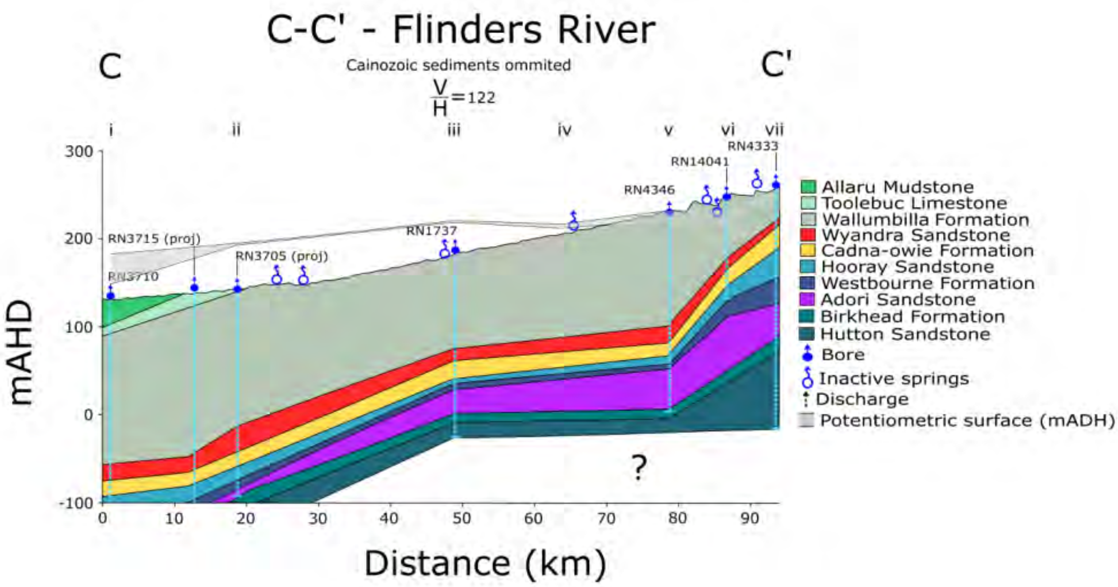


Figure 39. Stratigraphy through Flinders River discharge springs (see C-C'; Figure 34 for location). Where bores are projected onto the stratigraphic line the difference in elevation is indicated by the position of the bore symbol in relation to the ground surface. The range in the potentiometric head over time is represented by the limits of the grey bar and the roman numerals indicate the location of the bores that inform the head. i: RN3710, min. date 1968: SWL 16.9, max.date 1902: SWL 51; ii: RN93497, min. date 1998: SWL 47.62, max.date 2002: SWL 50.68; iii: RN93366, min. date 1996: SWL 33.78, max.date 1999: SWL 36.57; iv: RN14155, min. date 1991: SWL 9.6, max.date 2011: SWL 15.41; v: RN4346, min. date 1971: SWL -5.39, max.date 1915: SWL 4.18; vi: RN14041, min. date 1968: SWL -14.3, max.date 2011: SWL - 25.6; vii: RN4333, min. date 1901: SWL -9.14, max.date 1912: SWL -5.79.

Figure 40. Savannah Run 1 Spring. These sinkhole shaped features no longer flow permanently. Some of them such as the Savannah Run Springs on Bunda Bunda are used as cattle watering points and are supplemented by bore water.

When the regolith includes fine-grained dispersive silt, springs can form mud mounds. Mud-springs can be flat or mounded but form where the groundwater has mixed with fine sediment to form a slurry emanating from the spring vent. The slurry may not flow to the surface for long periods and dry surface layers can form a 'skin' over the soupy interior material. Occasionally the groundwater-mud slurry spews to the surface in a burst of activity. At Cooradine there are mud springs that have had a relatively temporary existence, appearing in a location, exhibiting a fit of activity and then drying up and deflating leaving a sunken hollow (Figure 41). This cycle can occur within the space of a decade (Patrick Hick pers. comm.). Many of the mud springs in the Julia Creek area have become inactive.

There are also springs associated with outcropping basement rocks. The best examples of these are at Mt Fort Bowen, Mt Brown and Mt Little. There is little evidence of the sediments rising toward the surface as they onlap to the metamorphic cones (Figure 42). It seems that the contact between the sediments and basement blocks is sufficient to provide an effective conduit for groundwater discharge. However, many of these springs have become extinct despite positive artesian pressure in this area (Figure 42). One of the springs in the vicinity of Mt Brown was a rare example of a hot spring within the GAB, and the temperature was estimated at 49°C (Palmer 1884). The source of the heat was probably a result of the natural geothermal gradient with depth. There are also minor springs associated with outcropping granite in the vicinity of Kevin Downs but these springs are now extinct.

Figure 41. Active mud spring at Cooradine in 2012 (above) and an inactive deflation hollow (below) formed by a collapsed mud spring.

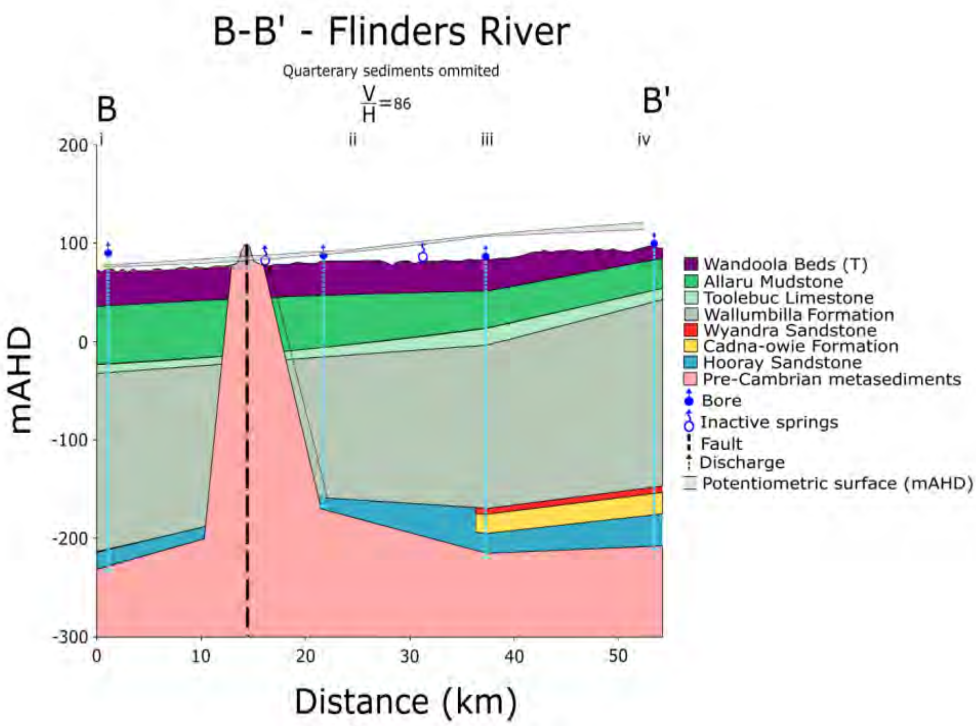


Figure 42. Stratigraphy through Flinders River discharge springs (see B-B'; Figure 34 for location). Where bores are projected onto the stratigraphic line the difference in elevation is indicated by the position of the bore symbol in relation to the ground surface. The range in the potentiometric head over time is represented by the limits of the grey bar and the roman numerals indicate the location of the bores that inform the head. i: RN1949, min. date 1969: SWL -2.29, max.date 1947: SWL -0.61; ii: RN31843, min. date 1973: SWL 6.3, max.date 1988: SWL 8.4; iii: RN14615, min. date 1973: SWL 21.13, max.date 2000: SWL 22.5; iv: RN15425, min. date 2005: SWL 22.4, max.date 2011: SWL 30.7.

Other springs are associated with faulting associated with the western side of the St Elmo Structure. In this stratigraphy generated from bore logs the potential displacement of these fault structures is as much as 100m (Figure 43). Many of the bores are inactive despite positive, but greatly diminished artesian pressure (Figure 43).

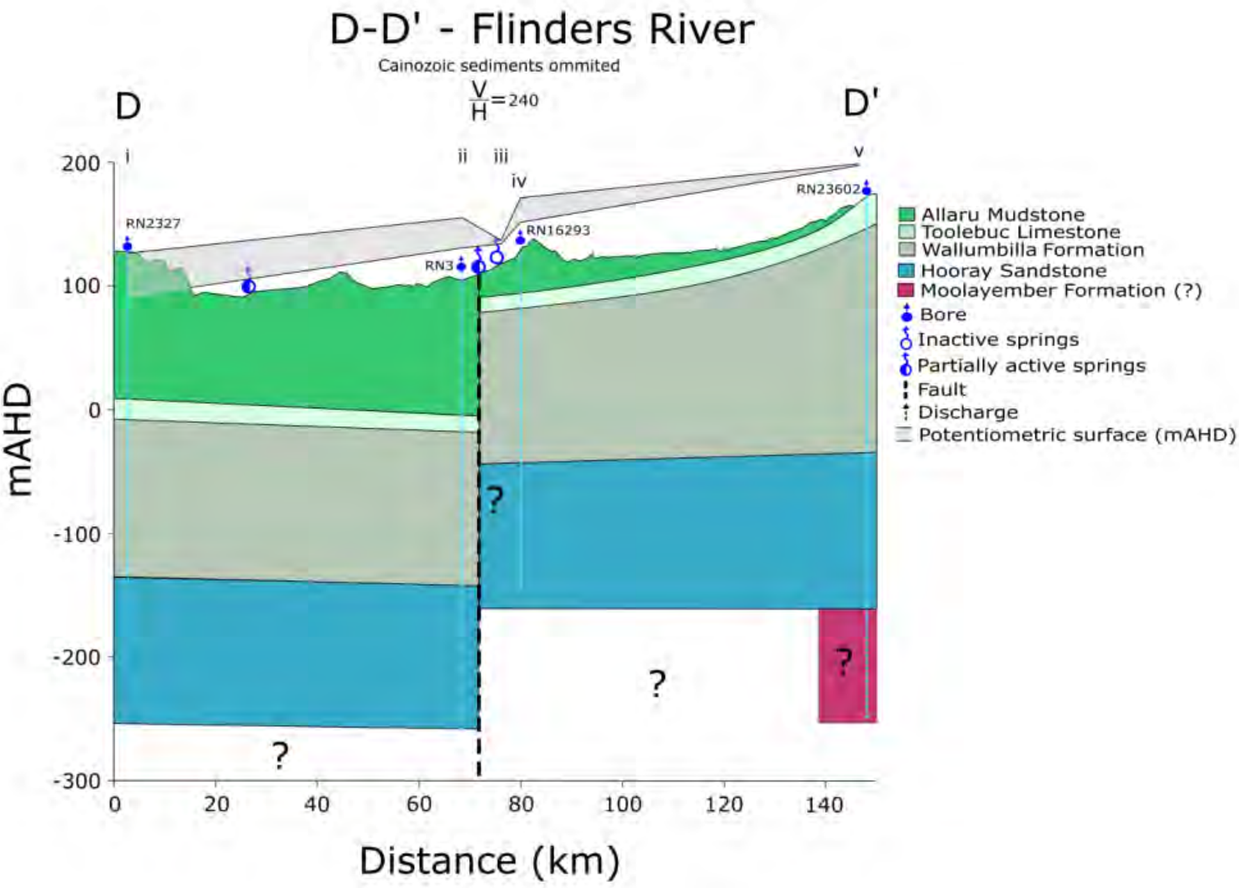


Figure 43. Stratigraphy through Flinders River discharge springs (see D-D'; Figure 34 for location). Where bores are projected onto the stratigraphic line the difference in elevation is indicated by the position of the bore symbol in relation to the ground surface. The range in the potentiometric head over time is represented by the limits of the grey bar and the roman numerals indicate the location of the bores that inform the head. i: RN2327, min. date 1970 : SWL - 36.58, max.date: 1967: SWL -1.83; ii: RN3, min. date 1989 : SWL 17.7, max.date: 1922: SWL 42.67; iii: RN93868, min. date 2002 : SWL 15.82, max.date: 2002: SWL 19.02; iv: RN9166, min. date 1943 : SWL 16.9, max.date: 1943: SWL 36.62; v: RN93412, min. date 1997 : SWL 9.1, max.date: 1998: SWL 9.9.

Two inactive springs, Box Creek and Leilavale (yet to be located on the ground) straddle the Kevin Downs Fault, where there is currently insufficient potentiometric head for artesian discharge (Figure 44).

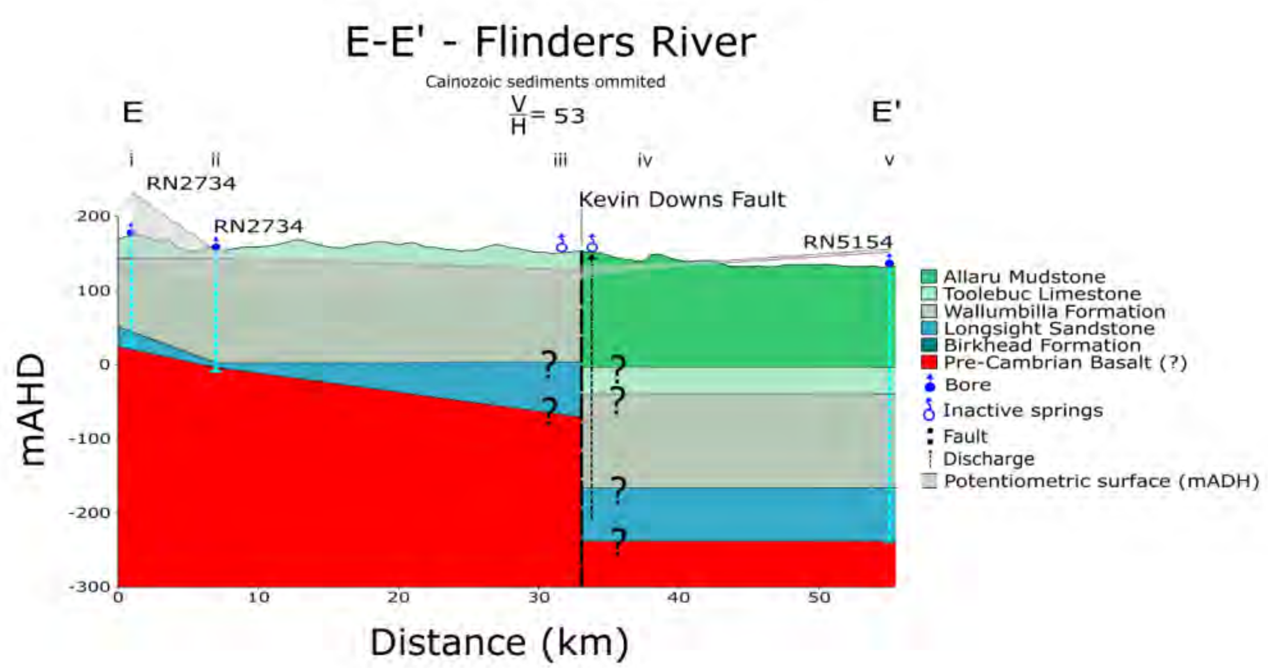


Figure 44. Stratigraphy through Flinders River discharge springs (see E-E'; Figure 37 for location). Where bores are projected onto the stratigraphic line the difference in elevation is indicated by the position of the bore symbol in relation to the ground surface. The range in the potentiometric head over time is represented by the limits of the grey bar and the roman numerals indicate the location of the bores that inform the head. i: RN2755, min. date 1955: SWL -12.2 , max.date 1896 : SWL 57; ii: RN2731, min. date 1967: SWL -42.67 , max.date 1915 : SWL -0.09; iii: RN2463, min. date 1937: SWL –36.58 , max.date 1937 : SWL -18.29; iv: RN2450, min. date 1967 : SWL -7.32, max.date 1937: SWL -2.74; v: RN14339, min. date 1993: SWL 18 , max.date 2011 : SWL 22.6.

4.3 Historical record

In the early 1860s, four separate relief expeditions were launched, ostensibly in search of the lost explorers Burke and Wills but with a keen eye on assessing the pastoral potential of the country traversed. Three of these expeditions passed through the area covered by the Flinders River supergroup.

Frederick Walker (Figure 45) and his party were travelling north-west in late 1861 towards Burke & Wills' most northerly camp. After crossing the watershed ranges north of Hughenden on 30 October, Walker's Aboriginal guide Rodney found a 'beautiful spring-waterhole' on the Stawell River, where the party camped for the night. Just before dark, they shot at least 12 local Aboriginal people who were aggressively displaying their resentment at the explorers' incursion on their spring. After leaving the Stawell, Walker's party became increasingly afflicted by soft ground, heat and lack of water. On 5 November, some 20 km east of Mill Mill springs on present-day Solway Downs, the party tried digging for water but the place 'gave every symptom, but nothing beyond mud'. On 8 November the party hit a creek and tried again to dig for water. The flow was too slow, so they 'went half a mile further down and there found a spring which, being dug out, made a capital waterhole'. This seems have been on Boorabin Creek, although no springs are known from this creek today.

The following day, Walker hit Cockatoo Creek and the springs along it, probably Cockatoo and Five Springs (currently on Pelham), writing:

> *'So great was the heat and so heavy the ground, that the horses were much distressed, and it was a great comfort to find some bulrushes, good springs of water, and grass, at*

the end of 10 miles. Our course has been, on average, 32° N. of W., and we had crossed over to a large creek still running W.N.W.'

Figure 45. Early visitors to the Flinders River springs, from left: Frederick Walker, William Landsborough and Jackey, and Edward Palmer, eulogised as 'pioneer, poet and legislator'. Both Walker and Landsborough were leading search parties in search of Burke and Wills

William Landsborough (Figure 45) led his relief expedition southwards, from the Gulf of Carpentaria to the Warrego River. Towards the end of February 1862, while travelling up the Flinders River, his party came upon the Fort Bowen springs:

'Left camp at 8.47 a.m. and reached the base of Fort Bowen in four and a half miles at 10.25…At the base we found springs surrounded by reeds and clumps of tea-trees. Plains surround Fort Bowen on all sides.'

Two days later, some 20 miles to the south-east, they came across more springs at the base of Mounts Little and Browne:

'At 11.40 came south-east and by east towards Mount Little for four and a half miles, and reached a watercourse full of water from the east. At 12.15, having come one and a half miles further in the same direction, we halted till 12.30 for Jackey, who had gone to waterholes surrounded by springs and clumps of tea-trees for the purpose of shooting ducks.'

The party continued with no further observations of springs, despite passing close to the Lara and Manfred Downs springs in the following days. At the end of the day's travel Landsborough wrote, somewhat quixotically, that he 'never saw finer-looking herbage than that along our path today. If it always rained when the grass required moisture this would be one of the best places, if not altogether the best, in Australia'.

'Big John' McKinlay, leader of the South Australian Burke Relief Expedition, passed close to springs on the western edge of the Flinders River group between 24 and 30 April 1862, including Leilavale, Box Creek, Fort Constantine, Dalgonally and Fullarton Bore, but was travelling quickly north by this stage and did not document any springs.

The springs received more detailed attention from pioneer pastoralist and politician Edward Palmer (Figure 45), who established Canobie Station in the 1860s. Palmer was a keen naturalist, historian, anthropologist and poet, finding time to pen a history of Northern Australia, compose poems such as 'The Gidya Tree' and publish papers in various journals. One of these, published in 1884 in the Proceedings of the Royal Society of Queensland, was titled 'Hot springs and mud eruptions on the lower Flinders River'. This paper describes the clusters of mud and water springs from north of Julia Creek to Fort Bowen:

On the Lower Flinders [the springs] occur in separate clusters, each consisting of innumerable small eruptions, surrounding one or two large central or main springs, within a radius of a mile or so, and all more or less in a state of activity, that is, they emit streams of thin mud or water intermittently… Fresh ground keeps continually breaking up, or is forced up, while old cones are sometimes falling in, forming hollows half- full of reddish water, strong as lye, and quite undrinkable. None of the springs are isolated, but confined to the vicinity of one or other of the half-dozen groups which compose the collection on the Lower Flinders. The direction of these groups is in a north and south course from each other, with the Flinders River dividing them, and they are comprised within a line or distance of eighty miles. A thoroughly scientific description of these numerous and wonderful displays of natural forces would prove very interesting and instructive. The vegetation surrounding them is peculiar, and somewhat distinct from that of the plains. The locality of any of the groups of mineral springs is indicated by the presence of gigantic tea-trees surrounding them, and many of the mounds present a pleasing green appearance, from being covered with a sward of Fimbristylis in such masses, fallen or recumbent, as to form a safe carpet, yielding and soft, but dense enough to support cattle going in to feed on the various grasses found there. In ancient days the same springs have proved a trap for too confiding animals, as is proved by the fact of some bones having been ejected in the mud from one of them; the bones are coloured, but in a good state of preservation… The overflow from some of the mineral springs deposits a white incrustation (pp.19-23).

He considers the springs of Fort Bowen and Mount Browne in the greatest detail, writing that:

…at both of these small mountains numbers of springs and mounds of erupted mud, coated with a whitish crust of soda, lie scattered about, with stumps of large tea-tree and reeds, and pools of discoloured water throughout; while at Mount Browne occur two hot springs on the south side, with a temperature of 120° Farenheit at the surface. The water stands in a large basin on a mound raised many feet above the level of the plain, and covered with gigantic tea-trees (Melaleuca leucadendron), amongst the matted roots of which the hot water steams in clear, shining, crystal pools. The basin, or cavity, is fathomless, while the roots and branches lying in it are coated with a soft, green vegetable matter, with air bubbles attached, small bubbles of carbonic acid innumerable, which are continually rising to the surface. The water is too hot to bear the hand in for any length of time, but when cooled is good for use, and always bright and clear, and free from any taste, while that in the adjoining cold springs is extremely disagreeable. No change has been observed in the hot springs in level or temperature since 1865, when a cattle station was settled there by Mr. James Gibson. The ground round all these springs is treacherous, is hollow, shakes to the tread, and feels like a huge blister, merely covered with a skin of soil, held together by roots and rushes, over which one can walk.

At times the pressure from below forces the thin crust upwards, and a flow of thin brown liquid mud spreads about, sometimes in great quantities. In one of the springs at Mount Browne flakes of granite are forced up, and lie on the surface. It seems as if a connection existed down by the side of the mountain to subterranean regions, whence the hot water flows, and is kept at one constant level and temperature. Most of the mud springs have formed large mounds, or cones, by constant overflow, and the water now stands on the top, while the surrounding parts are spongy, and liable to break through when stock comes near them at others lagoons are formed, and kept at a uniform level by the flow of water…

…A collection of plants made at a dry time of the year from one or two of the springs near Fort Bowen afforded [modern names and comments included in brackets]:

1. *Melaleuca leucadendron, Linn. The large tea-tree. Also a smaller species of melaleuca [Melaleuca bracteata], with hard thin bark, and of a dwarfed or stunted growth.*

2. *Chenolea (or Bassia) diacantha, F. v. M. [Sclerolaena diacantha] A prickly "roley-poley," found in bare places in large bunches, with terrible spines half an inch long and very sharp.*

3. *Pennisetum compressum [Cenchrus purpurascens], Rich Brn. A grass, three feet high, found all through the springs with a large terminal reddish flower.*

4. *Pluchea sp. [Pluchea rubelliflora] Herb, eighteen inches high, in quantities round the springs.*

5. *Typha angustifolia, [Typha domingnesis] Linn. The common rushes, with cylindrical brown tops.*

6. *Teucrium integrifolium, F. v. M. Herb, one foot high, with small white flower, leaves opposite, lanceolate. Very plentiful.*

7. *Trianthema crystalline Vahl. [confirmed as Trianthema sp. Coorabulka R.W.Purdie 1404 from specimen at Melbourne Herbarium] Herb, with short, fleshy leaves and reddish stems; grows in bare places round springs.*

8. *Portulaca filifolia, F. v. M. Herb, erect, eighteen inches high, branching, bright yellow flowers. Plant very brittle.*

9. *Fimbristylis sp. [probably Cyperus laevigatus] Rush, growing densely over soft springs, forming a compact mass.*

10. *Eragrostis sp. [possibly Eragrostis fenshamii] A grass about two feet six inches high.*

11. *Schoenus sp. [confirmed as Schoenus falcatus] Grass, two feet high, in large, strong bunches, growing over the hot springs and through the water.*

12. *Phragmites Roxburghii, [Phragmites australis] Kunth (pp. 22-3)*

Palmer's specimens from the springs are lodged at the Australian National Herbarium in Melbourne. Some are widespread generalist species, but *Cenchrus purpurascens, Trianthema* sp. (Coorabulka R.W. Purdie 1404), *Cyperus laevigatus* and *Eragrostis fenshamii* are all spring endemics. In a lengthy letter to the editor of The Queenslander, published on 10 June 1882, Palmer provided some additional descriptions of the Fort Bowen and Mt Browne springs, and also noted springs to the east and north-west, which are today known as Crocodile springs and Box Hole Mud springs (both extinct):

> *Next to the Fort Bowen springs are two large collections of the same, one to the eastward about ten miles [Crocodile], and another to the northward by west a similar distance [Box Hole Mud], and within about two miles from the river, keeping the same distance away as the others. These last have a good flow of water, that keeps a large lagoon constantly full to the surface in any season.*

Further south, Palmer also recorded that 'Above [i.e. upstream following the Flinders River] Dalgonally Station, on Julia Creek, some very extensive mounds are an indication of the force of the pressure from below, while an open spring between it and the Flinders has numerous small fish in it' (1884, p.22). He also mentions mud springs on Manfred Downs, and provides a sketch map of the location of springs on the lower Flinders (Figure 46).

Only Cudgie Cudgie and Waddy springs are named, but the other springs mapped are today known as Gilliat Bore, Fullarton Bore/Dalgonally, 20 Mile, Alva Downs, Sunny Plains, Manfred Downs Station, Washpool, Reedy, Mt Fort Bowen and Boxhole mud springs. He also mapped a spring just south of Taldora, which was not visited during this project. Palmer had provided more detail on the southern springs in his 1882 Letter to the Editor:

> *Following down the western, or left, side, the first large collection of springs is found on Julia Creek, upwards of thirty miles away from the* [Flinders] *river, where there are large mounds formed of mud thrown up, with water oozing out on every side. Some are 20ft. high, and the ground is bare of grass all round for some yards distant; and not much water collected in their neighbourhood unless where a creek occurs near, when it will generally be found full to the surface. One remarkable spring is situated below these, and nearer the river by eight or ten miles, away from flood water, and in the middle of the open plain, no creek or channel connecting with it. Here a large mound rises, on the top of which is a basin of clear water where the cattle come in to drink from the plains surrounding; and in this water are numerous small fish up to 6in. long—inclining one to think that they could only have arrived there by some subterranean passage.*

This 'large collection' of mud springs are the 20 Mile/Sunny Plains group (all now inactive), and probably also refers to Bauhinia Spring two miles to the north, while the 'remarkable' tall mound with fish 8-10 miles closer to the river probably relates to the now-vanished Station Springs at Manfred Downs.

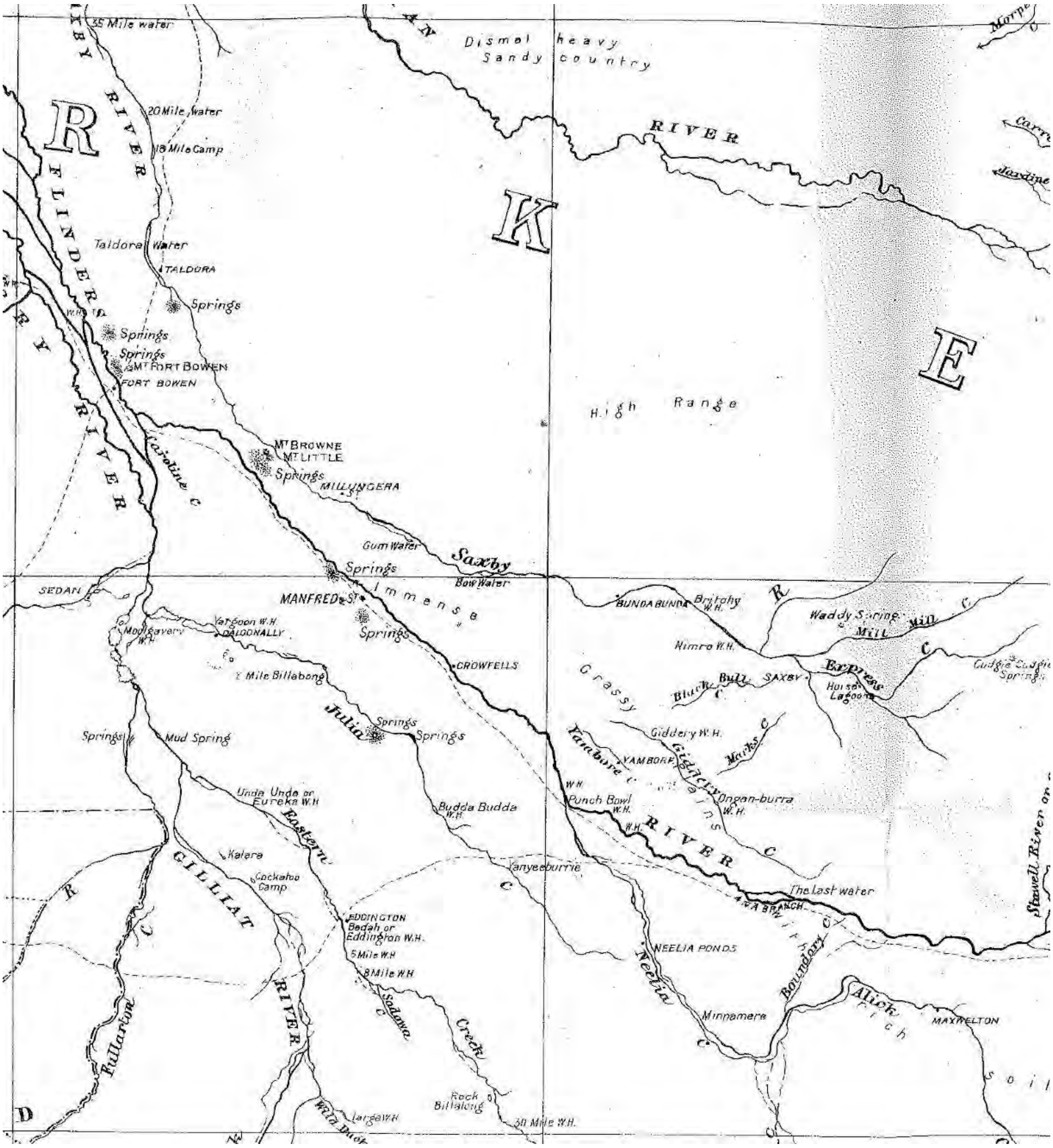


Figure 46. Section of Palmer's 1884 map titled 'Position of Springs on the Lower Flinders River' (Palmer, 1884a)

The 1896 record of J. Alfred Griffiths is almost comprehensive for the Flinders River discharge springs. He describes 90% of the spring groups, and only misses one large spring (Bauhinia). His notes provide the only records of many springs and while he did not consider some notes particularly important at the time, as shown by his rather perfunctory mention of Box Creek and Leilavale Springs, these records have been invaluable in locating now-extinct and forgotten springs. They also shed light on the former character of some now much-diminished and/or modified springs. Given the detail contained in Griffith's notes, and the high rate of spring extinction in this group, these records are presented in detail in Table 11, along with a summary of the current status of each spring. Property names refer to current boundaries rather than the original larger runs.

Table 11 Springs described by J. Alfred Griffiths in Flinders River Supergroup, 1896, and their current status

Spring and property	JAG description summary, 1896	Current status
Black, Pelham	'…large peat mound, fenced and piled with troughing but not at present used. The pool in the top is 5–6 yards across, with 10 foot of clear warm water, the fluid sand below that being over 40 feet deep. There are water gum trees on the top. The overflow fills several pools on the plain and runs a gully about 200 yards to the south east. Output…50000gpd.'	Active: large peaty mound 10 x 50 x 2.8 m high; outflow is mostly to the south where drains and holes have been excavated.
Native Dog, Pelham	'…a large Pandanus mound of about 2 acres, the pools on top of which supply 200 cattle with say over 2000gpd. There are no drains or improvements. The water is good and cold.'	Active: peaty mound 40 m diameter x 2.5m high; surrounded by moat which is directed into drain.
Plain spring, East Creek	'…large peaty mound about 20 feet high covered with tea tree, currajong and pandanus trees is fenced in. The peat has been opened in two places at the exit, about two yards wide…The bottom is below 40 feet and the runny sand is dark and shelly. The temperature is above 110 Fahrenheit. The jet rises about a foot above the pool. The overflow estimated at 100000gpd is run into large troughs (10 foot by 3 foot) and the surplus fills a sandy creek for 1.5 miles. Water of good quality, like rain.'	Inactive: water at 3m depth in a flume pipe; peaty substrate supports *Eucalyptus camaldulensis* forest with a dense understorey
Sandy Camp, Pelham	'… several springs spread over a half mile with cool pools on top which do not overflow'	Inactive: 'blow-outs' may be old mud-springs, and hold rainwater longer than they would without groundwater influence.
George's, Pelham	'…flat spring covering a few perches, surrounded by sandstone ridges which enclose a pool 200 by 30 yards [180m by 30m], in which is maintained several inches of water by the soakage from the grass and peat of the unimproved spring. It would supply 2000 to 3000 cattle, possibly 40000gpd.'	Active: pool at head of the spring 15 x 15 m, with narrow tail extending for about 100 m; peaty.
Wombat, Pelham	'…covers about 1000 yards [920m] of sandy flat and is at present unfenced. Formerly troughing was fixed but at present there is only a swampy hole, which supplies about 200 cattle, say 2000gpd.'	Active: open pool 20m by 30m with a peaty substrate
Five Springs, Pelham	'…single peaty mounds from 3 to 10 feet high without distinct craters, the water being collected by a drain heading to a small pool. There is a tailing yard and 300 cattle can be watered here, the flow will be over 5000gpd.'	Inactive: recently developed as two large dams
Currajong, East Creek	'…about the same extent as Plain Spring and is similarly fenced and improved. An opening to the north runs into troughs and one to the south into a creek hole about 20 yards long. One thousand cattle can be supplied. The water is colder than Plain Spring and not of such good quality. Estimated output of 50000 gpd.'	Active: two vents on peat mound 2.5m high with a paperbark forest covering about 60 x 40 m
Dead Dog, Pelham	'… 2 fenced springs, which open in the sides of a gully and run the creek about 1.5 miles northwards towards the Norman River. It waters 500 cattle and probably runs over 10000gpd.'	Inactive: no feature matching Griffith's directions, and they can only be assigned to a general location
Cockatoo, Pelham	'…peaty mounds with Pandanus trees and also springs depressed in clay holes. There are no improvements but 300 cattle can drink from the clay pools, and over 5000gpd probably exudes.'	Active?: bore sunk in spring, and outflow runs the creek for >300m; possible to imagine the spring-fed hollows Griffiths described; old silt scoop is a testament to the loss of the spring mound.

Spring and property	JAG description summary, 1896	Current status
S, Pelham	'…similar [to Sandy Camp] but smaller group is located about 5 miles east north east from Pelham Springs.'	Inactive: hollows found in this location are probably extinct springs.
In-Between Springs, East Creek	'A large group of springs…extending in area from 100-150 acres in the fork of Pelham and East creeks and on the south side of Pelham creek. The springs are both muddy and peaty. Some pools occur and in the unimproved condition about 500 cattle are supplied, but no streams issue capable of filling holes in the creeks. Amongst the trees are Pandanus palms. The outflow probably exceeds 10000gpd.'	Probably inactive; difficult to align with features on the ground.
Detached Line, East Creek	'A line of detached mud and water springs extend along the road on the block Pelham Number 1 from the Currajong spring westward for about 10 miles towards the Block Pelham Number 1 springs. There are several pools among these, which supply many cattle. '	One remains active; all others inactive
Kilgin, Saxby Downs	'…oval mound of peat covered by pandanus palms. It is about 200 yards by 100 yards in extent and about 10 feet high…[a detailed description of drain and troughing work carried out follows]	Inactive in 1999; by 2012 had apparently reactivated and was feeding a vegetated wetland, although this may have been merely local recharge after good seasons.
Little Kilgin, Saxby Downs	'About a half mile west of Kilgin Spring is a small pandanus peat point close to the paddock fence. It is only 4 yards across and 1 yard high, but has half a dozen little holes in it each of which holds a few gallons of water, and the soakage keeps the sand moist around the base.'	Apparently active, but excavated and being supplemented by a bore
Waddy Springs (north and south), Saxby Downs	'…scattered group of water and mud springs extending north and south for about 1 and a third miles. Most of these have pandanus palms and natural pools of spring water among the roots. A few are bare mud craters, the two largest are improved. North Waddy spring is 1.5 miles south of the station, it is almost 40 yards across and about 1.5 yards high. It has a drain about 15 yards long and discharges about 2880 gpd into wooden troughs, the surplus running into Waddy Creek. The South Waddy spring is nearly 2 miles south of the station. It is a little larger than the north spring and has about 25 yards of drain which delivers about 3360 gpd with 40 yards of iron troughing. The water of both springs is good and non-corrosive.'	All springs inactive: hollows, Pandanus and old trough (at North Waddy) still visible
Gorge Springs, Saxby Downs	'…closely spread over a narrow strip extending two thirds of a mile north west and south east. They are about 3 miles by 150 degrees from the station, and very numerous. The largest will cover a quarter acre and the smallest have 1 or 2 pandanus only. Most have small pools in the roots and there were a few bare mud craters. There are no improvements and no measurable steady flows, but the whole area of sand is soaked with water and carries Tea trees surrounding the palms…'	Inactive: location uncertain because features described by Griffiths no longer exist. At assigned location is a scalded area and some craters indicating extinct mud springs.

Spring and property	JAG description summary, 1896	Current status
Berinda, Saxby Downs	'A depression in the plain runs north east to south west and draining to Berinda creek. The hollow is surrounded by limestone rocks. The peat mound is about 2 yards high. There are about 20 yards of drain which yield about 3750gpd into iron troughs. The water is good and non-corrosive. There is another mound of about one quarter acre, some 150 yards north east, which is unimproved, also 1 or 2 clumps of detached pandanus to the east, one third mile south west are two bare mud craters, the larger of which is 10 yards across and 1.5 yards high and ejects with the mud limestone fragments and also water-worm pellets of quartz and quartzite.'	Inactive: location of former springs evident on ground
Snider, Saxby Downs	'…(named after the horse Snider) located near the Middle of block Paddington. They cover about 100 acres but are boggy and unimproved.'	Inactive: positioned in a sandy depression with Melaleuca nervosa
Middle, Cooradine	'…close to the road and about 8 miles from Cooradine Waterhole. The peaty mound is fenced in the centre water pool is boxed with logging about 2 yards cubical. The water level stands above the adjacent ground and down a spout into troughing at which 1000-2000 cattle are watered (say about 30,000gpd). The surplus water fills a hole about 30 by 10 yards.'	Inactive: numerous signatures in the general vicinity searched; assigned to a signature but no sign of the infrastructure described.
Similar, Cooradine	'Similar to middle spring about 1 mile east, which is at present unimproved, but if developed would probably be equal to middle springs.'	Inactive : ephemeral mud springs in area, but these do not match description
Sandy, Savannah Downs	'…cover a few patches of the barren sandy plain and exude both mud and water, the latter filling a shallow sandy hole at which about 150 cattle can water, output of about 2-3000gpd.'	Inactive: no trace of spring found.
Muk Quibunya, Savannah Downs	'A small isolated spring a few yards across but without available water. It is on block Muk Quibunya about half mile from the creek at the east corner.'	Inactive: no trace of spring found.
Tailing Yard, Savannah Downs	'Near the head station on block Mund Juro… a small spring in the centre of a reedy swamp of about 1 acre, but the spring water is confined to a small pool in the center.'	Inactive; tentatively assigned to low-lying area near Savannah Downs ruins
Savannah Run springs, Bunda Bunda	'From this point [Bunda Spring] a line of detached small springs extend some 30 miles NE on the Savannah Run, which indicate a region of disturbance in the artesian beds.'	Inactive: many of the springs and swamps have been excavated and the larger ones supplemented with piped bore water.
Cuddray, Bunda Bunda	'…on Clunes block nearly at the head of Cooradine Creek…small group of one water and several mud springs. They are at present unimproved and allow a few cattle to get a lick of water.'	Inactive: assigned to location with hollows and small scalds; alternatively, dam may have been sunk on spring
Small Bunda	'…Small springs also occur about 4-5 miles west.'	Inactive: scalded flat coinciding with Griffith's location searched; site with some hollows assigned.
Black Cow, Magenta, Victoria, Woodstock springs, Woodstock	'The line of Savannah Springs is continued past the Black Cow, Magenta, Woodstock, Victoria and other springs concerning which the manager of Savannah Downs had no personal information.'	All inactive: Victoria Ponds assigned to a hollow near bore; location of others not known.

Spring and property	JAG description summary, 1896	Current status
Mill Mill, Solway Downs	'… similar to and about the same size as Kilgin Spring. It is fenced and has 1 drain about 60 yards long (delivering about 20,000gpd) and 120 yards of black iron troughing... Around the spring about a dozen small unimproved springs cover a half mile.'	Inactive: location of main spring is obscure, as there are no signs of infrastructure.
Wombat, Solway Downs	'…about a mile north of Mill Mill spring and has the largest flow of the run. The mound is about the same size as Kilgin and the drain is 20 yards long and delivers some 30,000 gpd into 40 yards of troughing. The surplus flows about 200 yards across a flat and the same distance down a gully, before being absorbed. Water is good quality.'	Inactive: located high in landscape on a limestone ridge covered in alluvial sand; vent marked by old trough frame.
Cudgie Cudgie, Bylong	'Cudgee Cudgee spring is over the boundary on Burleigh.'	Inactive: dry peaty hollow
Washpool Springs, Euroka Springs	'The main waterhole on the east is some 8-10 foot lower than the springs outlet, but the smaller waterhole on the west and amongst the trees are at a high level and are fed directly by the springs and the running water in winter extends down the creek (about 3miles to the Saxby River). 17 December 1896 this stream filled 1.25 inch on 5000gpd at the only spot fit for measurement but the quantity issuing from the springs must be many times the quantity… the springs are quite unimproved…and the bulk of the water no doubt is expelled by the Tea tree forest, and leaks underground to the deep waterhole…The water is of very good quality.	Inactive: features described by Griffiths located
Reedy, Euroka Springs	'Springs contain the largest Tea trees, but the morass is very much obstructed by roots and but little water trickles aboveground into the waterhole. The water is mostly stained brown and of a bad taste.'	Active: five vents, one with a stand of *Typha* amongst a large Melaleuca leucadendra swamp.
Mt Brown Hot spring	'One spring is said to have a nearly scalding temperature but it is hard to find.'	Inactive: assigned to scald south of Mt Brown that does not correspond to any of the other springs.
Upper Springs, Euroka Springs	'…most extensive surface flows. The outflow from the largest single vent about 4.5 feet across…and many more outlets supplied into the same morass at the bend of the water, the bulk of which went underground into the long waterhole, so that at the outlet of the morass the streams only filled about 1 tenth in on 3700gpd. But the total quantity from the springs entering this lagoon is probably from 50-70,000 gallons daily in summer. In winter this water flows down creek some eight miles and is lost in the Saxby billabongs. Water good quality.'	Some active vents feed a pool 30m diameter. Possible extinct springs also found in the area.
Lower, Euroka Springs	'[Near Mt Browne]…similar to the upper springs but the water is of dark colour and inferior quality. It fills a considerable waterhole in summer and overflows down the creek in winter.'	Inactive
Crocodile, Numil Downs	'…amongst the billabongs of the Saxby River…the springs extend about half a square mile and the drainage runs partly south into crocodile water holes about 1 mile, and the same distance another to the billabongs of creek. The water is of poor quality and contains much solid matter. '	Inactive; scalded mounds located in vicinity, but traces of springs likely obscured by floods

Spring and property	JAG description summary, 1896	Current status
Mt Fort Bowen, Fort Bowen	'…near the east corner of the camping reserve and south east of the mountain. The springs are much scattered over the half-mile square in a plain. Several small waterholes are maintained by the springs and some of the water is of good quality.'	Inactive: clumps of paperbarks (*Melaleuca leucadendra*) on a scalded plain mark the probable location of vents; groundwater only 0.5m from surface
Station, Manfred Downs	'…springs at the head station extend for about 70 chains [c.1 mile] nearly north-south, some of them continually overflow. On a small flat about 30 chains [0.4miles] north east of the station is a large group of mud and water springs among which numerous artesian bores have been sunk to improve the natural supply of artesian water. …[The Stud Paddock bore] is situated about 35 chains, 42 degrees from the station house, on block Chillon. It is amongst the mud springs.'	Inactive: none of the springs could be satisfactorily located; the area is now a Mitchell grass plain; waterhole was source of perennial groundwater in the 1960s.
Boonoke, Manfred Downs	'Sunk in 1887. [Boonooke bore] is on block Chillon about 4.5 miles at 15 degrees from its south corner…It was sunk about 50 yards south of a considerable mud spring which has since dried up, but during the last year a new mud spring has started around the casing.'	Inactive: long-term owners have not heard of this bore; Griffith's directions coincide with a current bore on a limestone ridge; spring assigned to scald but field checking required. There are numerous failed bores in this area, although they have not been field checked.
Ruthven, Manfred Downs	'The Ruthven bore is situated on block Chillon about 4.5 miles 22 degrees from south corner. It adjoins the most southern of the Ruthven-Boonooke group of mud springs, which are scattered rather widely over an area 1.5 miles across.'	Inactive: spring aligns with a bore marked on the 1914 run map. This bore is not known by the current long-term owners. There may have been a single complex of springs in the vicinity of the Boonoke and Ruthven bores. Assigned to scald but requires field checking.
Mazeppa, Auckland Downs	'...The Springs (at Bore No 2) are situated on block Mazeppa No. 1 4.5 miles from the north corner… on a clay-plan flat about half mile square. The clay-pan was originally marked by frequent low mud ridges, now almost entirely effaced by sheep trampling. At any of these ridges fresh water can be got by sinking [a hole] one or two foot, but holes sunk at a distance generally give salt or brackish water at about 6 foot deep. There are now three principle wells marked A, B, C on the sketch plan. All of these overflow when not pumped.'	Inactive: three inactive vents are evident, all with significant improvements as described by Griffiths
Lara Springs, Lara	'The springs…nearest the bore are low and boggy and are fenced to keep out sheep. The high mounds east to south-east are from 5 to 7 foot high and although shaky on top have a crust which will carry sheep. These mounds can be seen a considerable distance on the open plain. The group of springs east are smaller. One is boggy and fenced and the other a dry mound.'	Inactive: all spring groups mapped by Griffiths located; now ephemeral scalded hollows
Fullarton Bore, Dalgonally	'An area of several acres adjoining [Fullarton Bore] is occupied by mud and water springs, the depressions around which are at present flooded by the bore water, which also fills several water holes between the river channels for about a mile westwards from the bore.'	Inactive; hollows and mounds remain adjacent to bore and outstation ruins; Dalgonally water spring active 200m to east.

Spring and property	JAG description summary, 1896	Current status
Gilliat Bore, Baroona Downs	'…large mud and water spring covering about 0.25 acre a little to the north and a smaller patch several yards across, each covered with rushes and emitting trickling streams of water. There are also two little patches of mud spring.'	Active; mud and water springs, almost exactly as described by Griffiths; seem to be growing since capping of nearby bore.
Twelve-Mile Bore, Consentes	'Completed May 1891, situated about 5 miles west of the 12 Mile Waterhole on Julia Creek…at the extreme north corner of block Northam. There were two mud springs within a few yards of the bore site which have since dried up.'	Inactive: Nno knowledge of old bore and no sign of springs associated with scalded signatures in this area; spring tentatively assigned to current house bore.
20 Mile (Cat Camp), Baroona	'Situated close alongside of the down creek end of the line of mud and water springs which extend along Julia Creek for about 3 miles near the crossing of the track from Eddington to Manfred. The adjoining spring covers about an acre and there are continuous trickles running in to the creek. The bore is sunk in the gutter down which the water trickles…'	Inactive: extinct springs marked by prickly acacia thickets in sunken hollows on extensive scalds; springs do stay wet for longer than expected.
Pigeon Creek bore, Sunny Plains	'Three foot deep in a treeless plain distant 3.75 miles 163 degrees from north corner…located near a former mud spring in a depression.'	Inactive: vent 15m from old bore on scald.
Belmar (Eureka), Saxby Downs	'…a peat mound rather larger than Kilgin Spring. There are three main and one small cuttings. The three unite and discharge into a small hole a few yards wide. The overflow in winter runs half mile down Eureka creek, but in summer is absorbed by sand before getting to the creek. The water is of excellent quality and the flow is estimated at about double that of the Kilgrin spring, say 60,000gpd.'	Inactive: at the head of a small gully surrounded by red gums, with black peaty material; no mound.
Canadgaberry (Little Eureka), Pialah	'…supplies the Eureka head station which is on block Eureka just over the boundary, yet only some 100 yards away. This spring is a peat and pandanus mound covering half acre. It is improved by a drain and trough. The supply is estimated at about 1,000gpd. The overflow is lost in a small swamp.'	Inactive: aligns with a large excavation now known as Rum Hole; red gum swamp evident to the west.
Sultan, Pialah	'… a group of peat and mud springs covering quarter mile on Ashfield creek close to the north end of the boundary between blocks Pialah and Ashfield. These springs are unimproved.'	Inactive: scalded area in gidgee has hummocks and hollows that are probably old mud springs.
Coolhudbene, Saxby Downs	'…isolated flat water spring without a peat mound and the only vegetation being a few rushes. The supply is measured by bucketsful, say under 100gpd. On a branch of Ashfield creek, near the middle of block Eureka'.	Inactive: scalded signatures on two creeks searched; no satisfactory signatures and spring equivocally assigned to southern scald.
Fort Constantine	'…a line of mud springs along the north side of Courtneys Creek running nearly E-W halfway between the Alice and Kennedys bores. The main spring about 3 miles east of the Alice bore is fenced for about half an acre to prevent cattle bogging.'	Inactive: no trace of springs found.
Leilavale, Barnsdale	'…there is a mud spring on block Leilaville No.3, between Holy Joe and Box Creeks….Both springs are small and exude but a few gallons daily, and their only importance is to mark some local fault or disturbance in the rocks overlying the artesian beds, or of a primitive pinnacle.'	Inactive; area coincides with low limestone ridges and no spring-like features were located; assigned to a scald nearby.
Box Creek, Longford	'Also that there is another higher up Box Creek on block Berwick East, near an old native well… Both springs are small and exude but a few gallons daily…'	Inactive; assigned to depression on scalded flat; native well may coincide with old bore nearby.

Griffiths also provided detailed sketch maps for many of the larger spring groups and individual springs. These have been central to relocating now-extinct springs, and a selection of his maps are shown below (Figure 47, Figure 48, Figure 49).

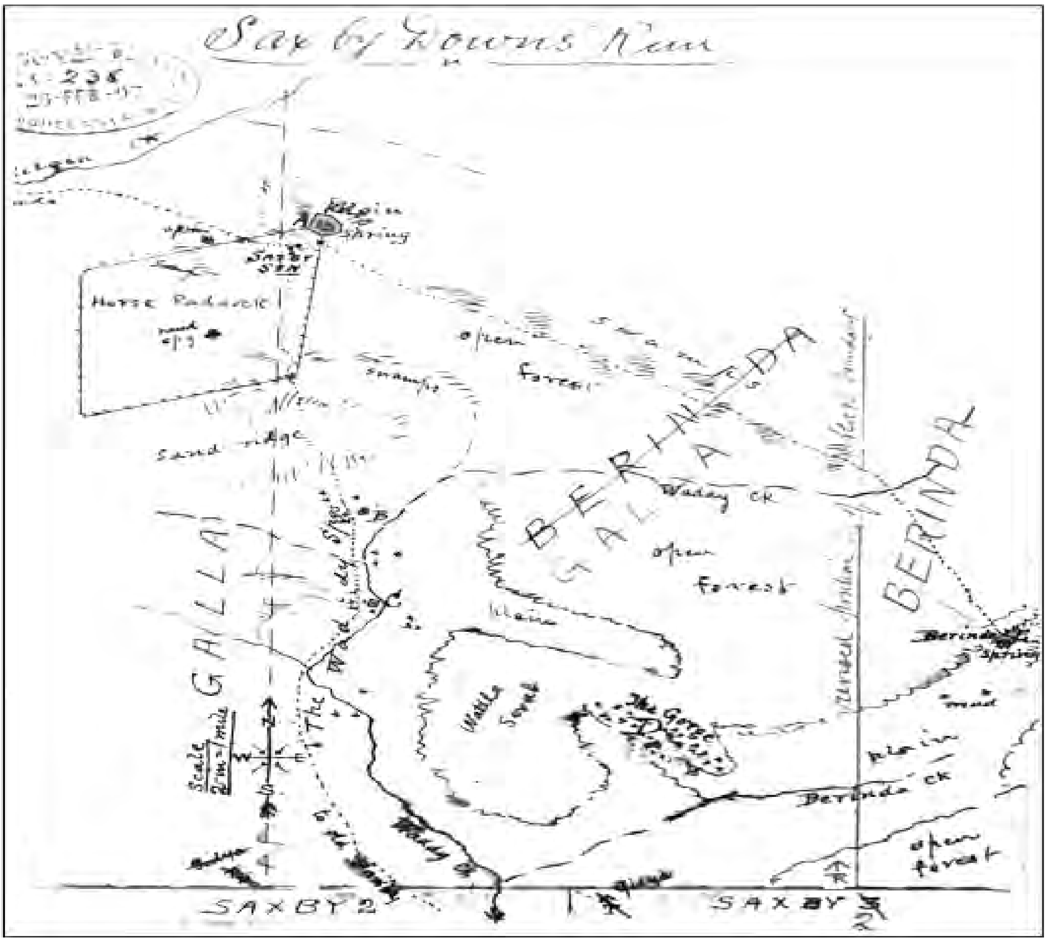


Figure 47. Hand drawn map by J. Alfred Griffiths of the springs located on the Saxby Downs Run, and their location in regard to property boundaries and the Saxby Downs homestead. Each spring is marked with a letter referred to in the text: A is Kilgin Spring, B and C are the north and south Waddy springs and D denotes the Gorge Springs; Berinda Springs are marked to the east.

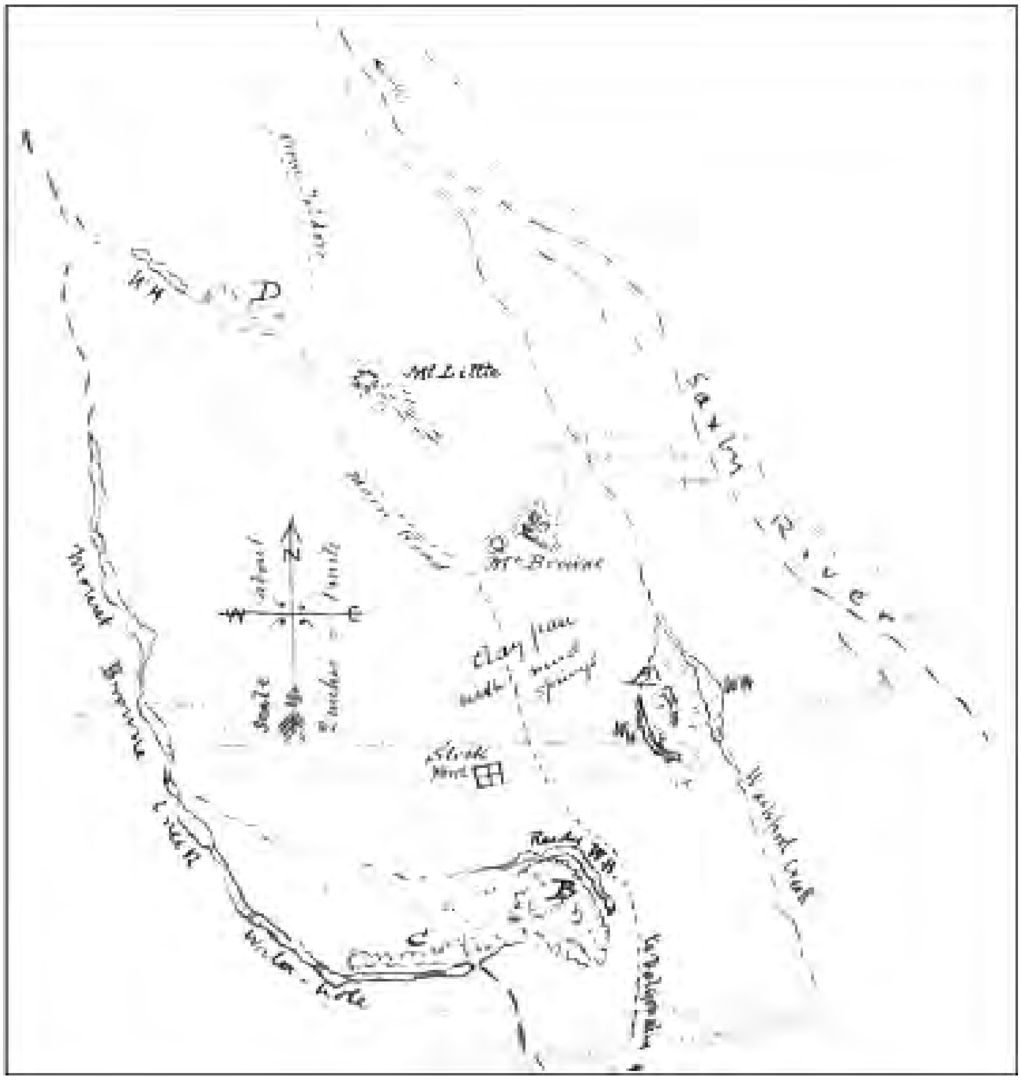


Figure 48. Map drawn by J. Alfred Griffiths of the four main springs on the Millungera Run (1896, p.109): A = Washpool, B = Reedy, C = Upper Springs, D = Lower Springs. Note that Griffiths confused the names of Mounts Browne and Little.

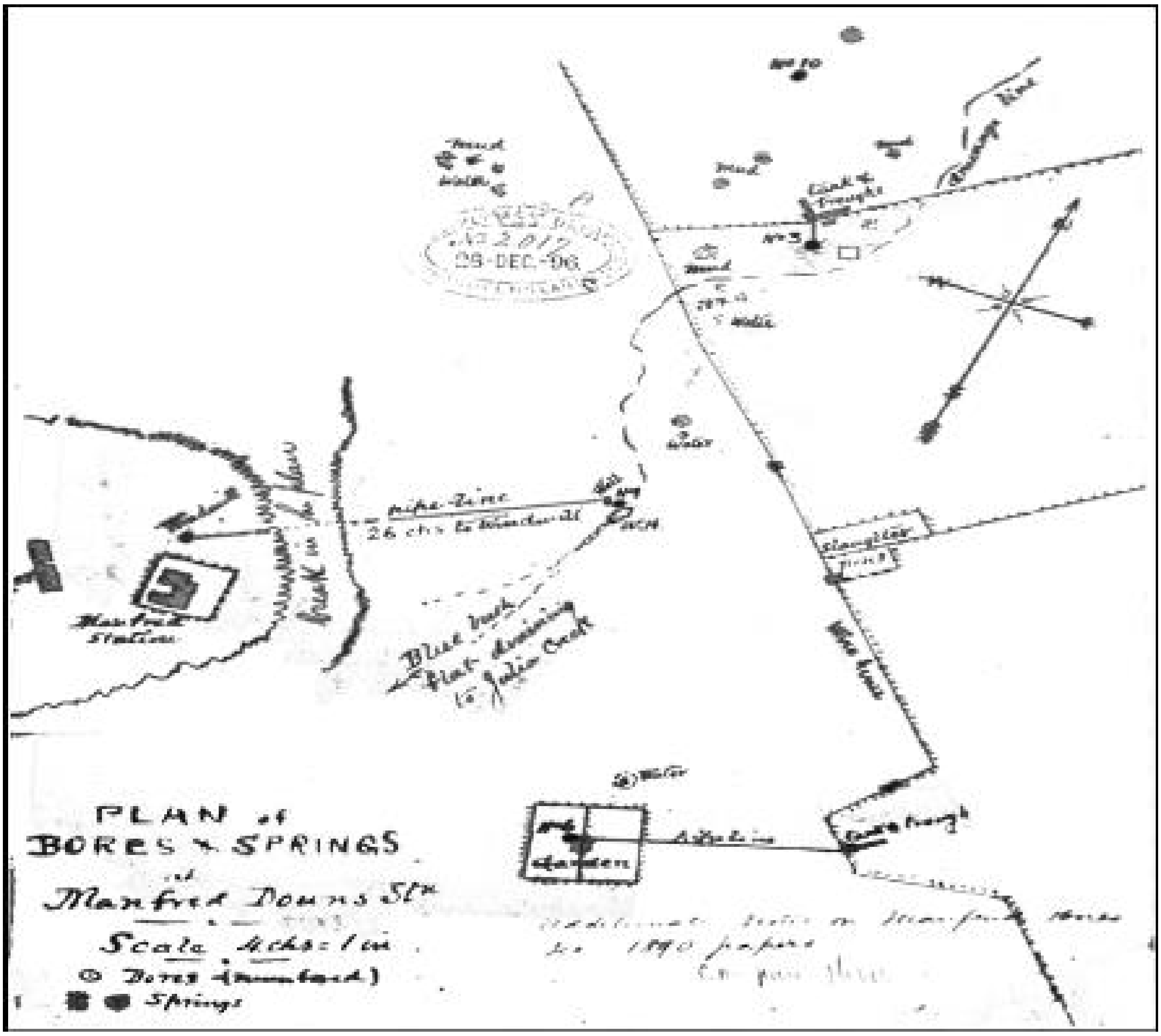


Figure 49. Griffiths' 1896 map of bores and springs around Manfred Downs station. The line of Manfred Creek is still evident; however none of the springs could be located. The entire area is now a Mitchell grass flat with no sign of the old mud springs.

J. Hargreaves from the Water Supply Department published a 'Table of Perennial Springs' in 1917, which names many springs but merely notes whether they have been recently visited by an inspector (most had not been). The only springs he provided more information about are Washpool and Reedy on then-Millungera Run, describing them, respectively, as 'large area of tea-tree and springs' and 'containing cool and warm' springs.

The original survey run plans drafted from the 1890s (Figure 50), and their later versions (Figure 51), proved useful in locating many springs (

Table 12). Only a handful were marked on the 12-mile or 4-mile map series (c. 1920), but this included one (Stony Creek, showing 'Well Yard and Mud Spring') which was the only record of a now-extinct spring (Figure 52).

Table 12. Springs marked on historical maps in Flinders River supergroup

Plan/map	Springs marked
Original Survey Plan B144199 (c.1890s)	Black, Plain, Wombat (Pelham), Currajong, Five-Springs, Black Cow, Magenta, Cuddray, Eureka (Belmar), Sultan
Original survey plan B144232 (c.1890)	Nara
Original survey plan B157153 (1899)	Savannah Run springs,
Original survey plan B144170 (1890s)	Waddy springs, Mill Mill springs
Survey plan YP14 (1919)	Wombat (Solway)
Survey plan RA502 (c. 1890)	Cudgie Cudgie
Survey plan TD9 (c.1890)	Washpool, Reedy, Lower
Original survey plan B144153 (c. 1890)	Crocodile, Fort Bowen
Survey plan TD4 (1912)	Boxhole mud spring
Survey plan MF14 (c.1890s)	Mazeppa
Survey plan MF6 (1897)	Lara
Original survey plan B144148/ B144205 (c.1890) + later survey plans MF21, MF24	Gilliat Bore
Original survey plan B144147(c.1890s)	Fullarton Bore
Survey plan MF5 (c.1890)	Alva Downs
4-mile series 15D (1920s)	Black, Plain, Wombat (Pelham), Currajong, Five-Springs, Woodstock, Black Cow, Victoria Ponds, Magenta, Cuddray
Queensland Run Map Sheet 8 12-mile series (c.1890)	Cudgie Cudgie
4-mile series 15B (circa 1920, 15B).	20 Mile, Cudgie Cudgie
4-mile series 16A (c.1920)	Stoney Creek

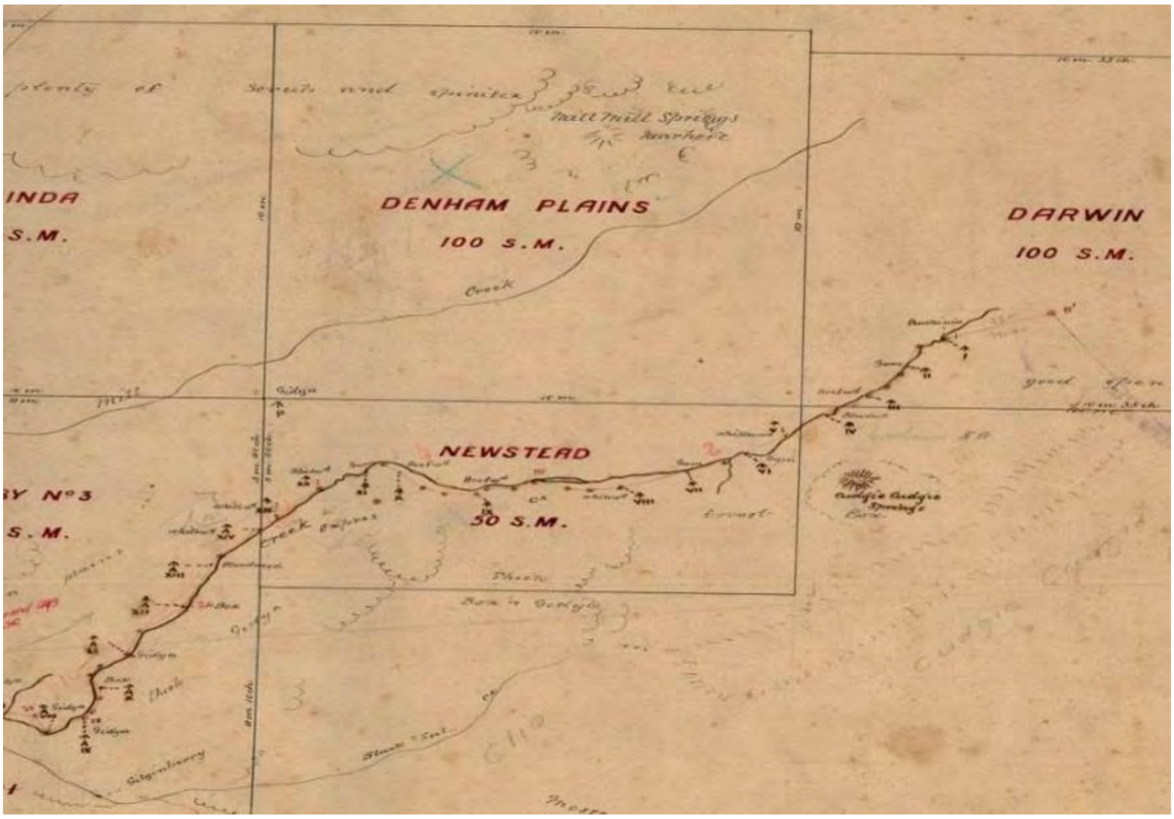


Figure 50. Section of the original 1890s survey plan (reference B144170), showing the Mill Mill springs and Cudgie Cudgie Spring

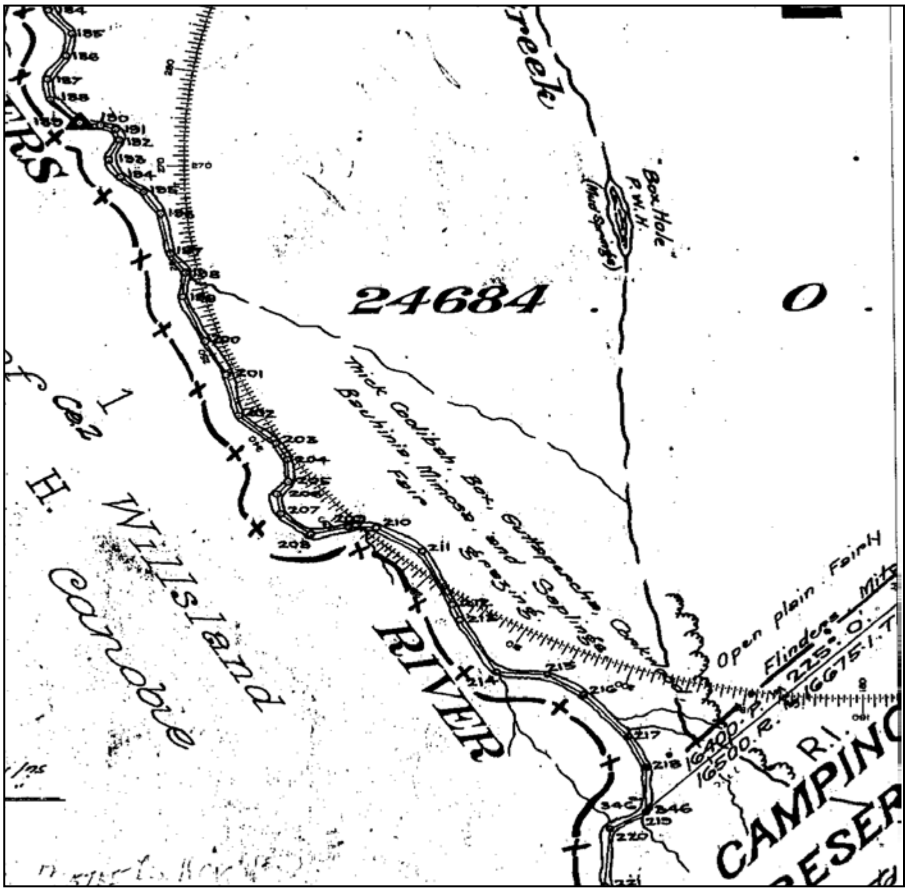


Figure 51. Section from the 1912 survey plan (reference TD4) showing mud springs associated with the Box Hole permanent water hole, north of the Camping reserve on Spring Creek. Apart from a mention by Palmer (1882), this is the only reference to these now-inactive mud springs, which were not described by Griffiths or marked on earlier survey plans.

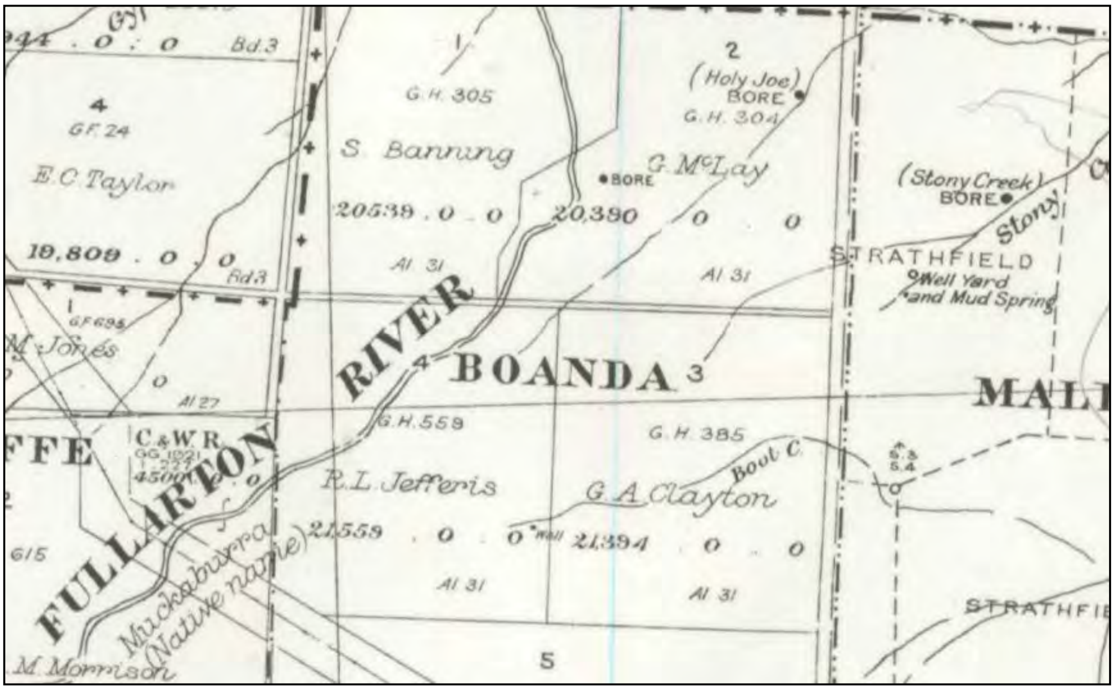


Figure 52. Section of 4 mile series 16A map (circa 1920), showing a well yard and mud spring on block Strathfield on Stoney Creek. This is the only reference to this now-extinct spring.

A report presented to Croydon Shire Council by the District Engineer of the Irrigation and Water Supply Commission titled 'Water in the Gulf: An Engineer's Report' appeared in the Townsville Daily Bulletin on 14 December 1932. It was commissioned to provide advice on the most economical means of providing permanent water supplies to cattle country south and south west of Croydon. It mostly considers springs emanating from basalt in the area, which were reported to be decreasing in flow, but the Gregory Range springs are mentioned briefly:

> *While on this subject it would be as well to mention, that there are large and good quality springs at the heads of the drainage systems, which rise in the Gregory Range. I am informed that several of these appear at the base of the sandstones on top or granite* (1932, p.12).

Specific reference is made to Empress spring on Esmeralda, and Blackbutt and Black springs near Croydon, both of which were said to be diminishing in flow:

> *[Esmeralda Spring is] a natural spring of good quality water, appearing at the base of a sandstone area, on top of granite. Its occurrence near the S.W. edge of the granite rather suggests an artesian leakage, and the accurate analysis should give some information on this point. Personally I am inclined to regard it as such a leakage. In which case the prospects for shallow boring to the south of it would be excellent…*
>
> *…[Blackbutt Spring is] a small local sandstone soak, carrying finely divided white material, probably kaolin from the granitic sands. Only a small domestic supply is now available in a hole 4 feet deep, whereas some years ago there was sufficient for a large garden and several stock. Black Spring, to the south of this, is also falling.*

4.4 Cultural history

4.4.1 Aboriginal history

The area encompassed by the Flinders River supergroup was home to complex and diverse language groups and cultures at the time of European settlement, including the Mitakoodi in the west, the Jgawun and Mayi-Kulan in the Julia Creek district, the Mibera and Wunumara around Richmond in the east, and the Takalaka to the north around Croydon. Historical accounts of which group occupied the uplands to the east, encompassing the southern outcrop springs of the Flinders River group, are inconsistent but the area lies partly within the contemporary Native Title claim area of the Ngawun Mbara people (Wade et al., 2011). These uplands were occupied for at least 28 000 years (Wallis et al., 2009), although archaeological evidence suggests that regular use of sites in the area commenced about 8000 years ago and intensified around 3400 years ago (Morwood, 1990).

Large base camps were located on permanent waters with movement occurring as seasonal conditions permitted, mostly during winter (Wallis and Collins, 2013). Trade and communication occurred more or less continuously between groups across north-western Queensland. Ethnologist W.E. Roth noted that trade routes invariably ran along water courses, most having been 'laid down since time immemorial' and to 'greater or less extent rigidly adhered to' (1897, p.132). Roth describes a complex network of trade routes, meeting places and cultural practices, within which each natural feature including springs would have had a role and a story.

There are hundreds of archaeological sites dotted throughout the Gregory Range. These are mostly found in rock shelters along sandstone escarpments, often in the vicinity of GAB outcrop springs. A high concentration of sites including stone artefact scatters, grinding surfaces and a quarry are located in the Cane Springs area on Esmeralda station (Gorecki et al., 1992). A survey of a gorge near Mickey Springs north-east of Hughenden found 14 rock shelters in the sandstone scarp with evidence of Aboriginal use (including stone artefact scatters, charcoal deposits and faunal remains), as well as an axe-grinding site in the creek and a basalt grindstone stored on a sandstone ledge (Morwood, 1990). All sites were recorded within 400 metres of the springs, suggesting that Aboriginal occupation was effectively tethered to permanent water. Morwood (1990) speculates that the commencement of systematic use of the area was the result of the activation of springs towards the end of the Pleistocene. Rock art sites are also common in the area, consisting mostly of stencilled motifs such as hands, boomerangs, circles, tools, weapons, animals and tracks (Wade et al., 2011). Many sites are probably more secular than ceremonial in nature, as art is mixed with tools and other signs of day-to-day life. Rock art sites and habitation shelters continued to be of cultural significance until the European contact period (Morwood, 1990).

On the lowlands to the west, Maramungee, Muk Quibunya, Cuddray, Waddy, Mill Mill, Canadgaberry, Coolhudbene and Cudgie Cudgie Springs preserve Aboriginal names but little information survives about their use and stories. In many cases the only clues of Aboriginal habitation over hundreds of generations lie in the stone tools lying around the springs. Discharge springs are characterised by stone artefact scatters in varying densities, mostly comprised of unretouched silcrete flakes and cores. Sometimes hearths consisting of heat-retaining stones and charcoal are present (Figure 53). At some springs stone tools are abundant, while at others they are mysteriously absent. Relatively high densities of artefacts including grindstones (Figure 53), stone flakes and cores were found at now-extinct springs north of Julia Creek including Alva, 20 Mile, Sunny Plains and Pigeon Creek, and at the still-active Bauhinia Spring, as well as in the vicinity of Sultan, Coolhudbene, Kilgin and Berinda Springs to the north-east and at Stoney Creek on Kevin Downs to the south-west.

Particularly notable stone tools were located around an inactive spring on the Flinders River (Figure 53). They are large oval shaped stones about 40 cm long by 24 cm wide, roughly worked to a lens shape in cross-section. Because of their size they have considerable weight, and are clearly too large to be axes. They were not transported long distances and have their source in the metamorphic rock outcropping less than one kilometre away. Enquiries with archaeologists Richard Cosgrove and Peter Veth in November 2014 failed to identify a satisfactory explanation for these tools. Other stone artefacts abound in the area.

On the other hand, very few signs of Aboriginal habitation were found around the large springs in sandy forest country on East Creek, Pelham and Bunda Bunda, despite extensive scalds on which stone tools and hearths would be easily visible. Edward Palmer's (1884b) description of a 'haunted' spring on Canobie Run [or Connobie], Boxhole mud spring, perhaps offers an insight into the lack of surface archaeology around some springs:

> *On the Canobie Run there is a lagoon of water fed by a soda spring, and surrounded with tall ti-trees; the lagoon is deep and clear, and the blacks refuse to go in or near it even, but the reason really is a superstitious one for keeping away from it.*

The diversity of archaeological site types at and around the springs, including art sites, scar trees, stone arrangements, apparent ceremonial stones, hearths, grindstones and stone flakes, indicates that springs were important in day-to-day life as well as ceremonial and trade activities. As with springs across the GAB, more thorough archaeological investigation could generate a deeper understanding of the patterns of Aboriginal occupation and their relationship to springs and the wider landscape, complementing early ethnographic accounts (e.g. Palmer, 1884b; Macgillivray, 1886; Roth, 1897) and contemporary archaeological research (e.g. Morwood, 1990; Wallis et al., 2004).

Figure 53. Aboriginal artefacts from Flinders River discharge springs: Hearths and stone flakes (top left), and grindstone base plate (top right), and mysterious lens shaped stones found at an inactive spring (bottom).

4.4.2 European history

As in other districts covered by this project, European settlement was disastrous for the original inhabitants of the Flinders River area. Conflict was evident from the earliest days of the pastoral invasion with Frederick Walker, one of the first white men to travel through the area and a former Inspector of the Native Police in southern Queensland, recording numerous ‘skirmishes’. The first of these centred around a ‘beautiful waterhole-spring’ on the Stawell River where Walker’s party camped on the night of 30 October 1861. The local people were angered by this incursion on what was evidently a very important water place, as acknowledged by Walker. Nevertheless, he considered the massacre, in which at least 12 Aboriginal men were killed, unavoidable as the Aborigines had refused to share the water:

> *We had hardly unsaddled our horses, when the voices of blacks were heard. Jingle, Paddy, and Jemmy Cargara went down the river towards them, when, to their surprise, they were addressed in Yarrinaakoo, the language spoken by the blacks on the Comet,*

> *and told in angry terms to be off and not to come there. My men resented this treatment, but fearing my disapproval should they fire on them, as they wished to do, they came back and reported to me that these blacks were "coola." We now heard them shouting in all directions, very evidently collecting the others who were hunting. In the meanwhile we had our dinner. Shortly after they had collected what they deemed sufficient for their purpose, and we heard one party coming up the river, and another answering their calls from over the ridge near our camp. It was time now for us to be doing, so I directed Mr. Macalister, Mr. Haughton, Jingle, Paddy, and Coreen Jemmy to take steady horses and face the river mob, whilst Jack and Rodney, and Jemmy Cargara stopped with me to protect the camp and meet the hill party. The mounted party met about thirty men, painted and loaded with arms, and they charged them at once. Now was shown the benefit of breech-loaders, for such a continued steady fire was kept up by this small party that the enemy never was able to throw one of their formidable spears. Twelve men were killed, and few if any escaped unwounded. The hill mob probably got alarmed at the sound of the heavy firing, and did not consider it convenient to come to the scratch. The gins and children had been left camped on the river, and, as there was no water there, our possession of the spring was no doubt the 'casus belli'. They might have shared it with us had they chosen to do so. This unavoidable skirmish ensured us a safe night, otherwise I think there would have been some casualty in my party before morning, as they can throw their spears 150 yards.*

A few days later, east of Eureka Springs, two of Walker's men Paddy and Rodney were attacked by a party of Aborigines while digging for water. Paddy fired his rifle and one man was killed (Walker, 6 November 1861). Three weeks later, on the Leichhardt River, there was another violent encounter during which the Aborigines suffered 'a heavy loss' (Walker, 1 December 1861).

This conflict was an ominous harbinger. The Burke Pastoral District was officially declared open in 1864, although drought forced many runs to be abandoned and not resettled until the mid-1870s (Holmes 1963). The period from 1869-74 was marked by massacres and violence, often carried out by the Native Police in response to stock spearing by Aboriginal people. Early survey plans show a Native Police Barracks established close to the now-inactive Coolhudbene Spring, not far from where Walker's Paddy shot a man in 1861 (Figure 54). By the 1880s, traditional life had mostly collapsed through violence and the effects of disease, alcohol, opium and dislocation, and Aboriginal people began to occupy fringe-camps around stations. From around the turn of the century, many of these people were forcibly removed to reserves such as Woorabinda (Morwood, 1990).

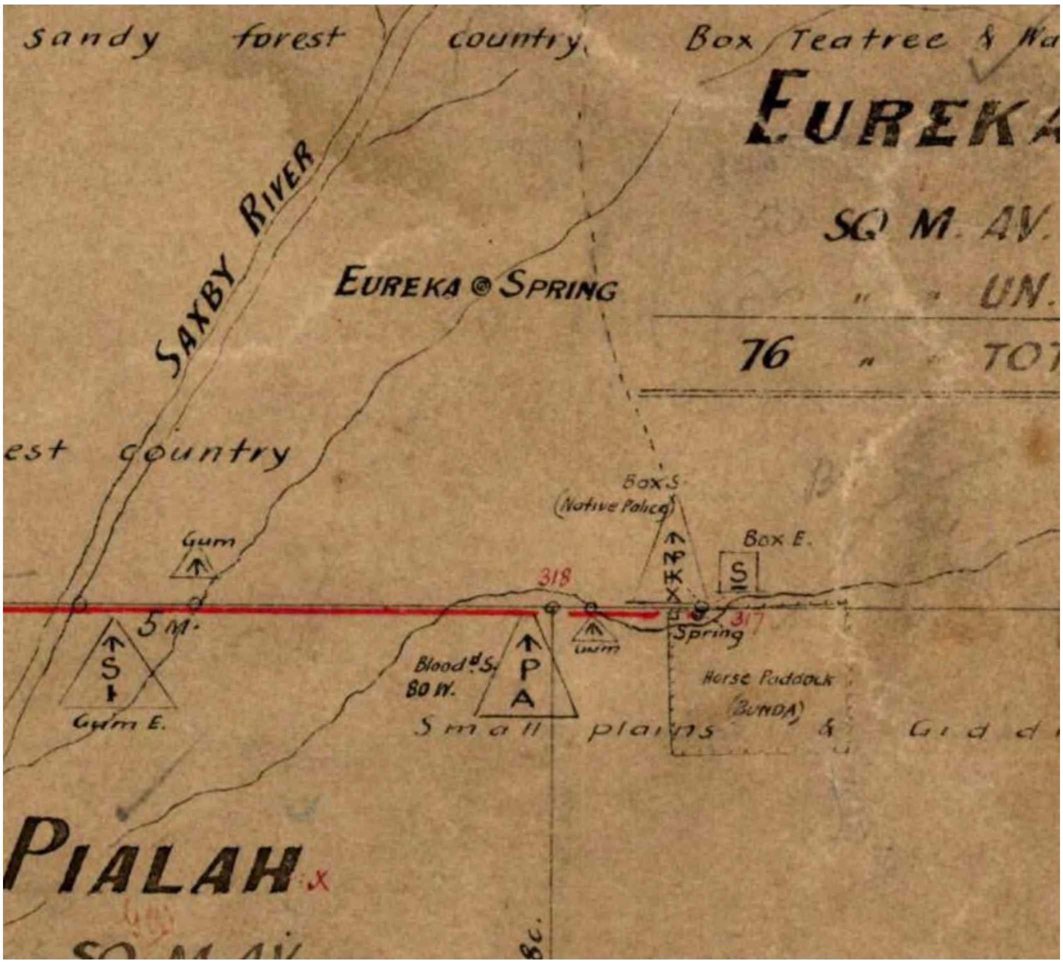


Figure 54. Section of the original survey plan (reference B144199, circa 1890) showing an unnamed spring on the border of the block Pialah and Ashfield, assumed to be Sultan Spring. This is south of a 'Native Police Camp', which is in the approximate location of another spring described by Griffiths as Coolhudbene.

As discussed above, Walker and his party came upon the Pelham springs a couple of days after Paddy's encounter east of Eureka springs, and were extremely grateful for these oases in a hot, dry November as they pushed north by west. Following the paths of explorers and early pastoral prospectors, which no doubt followed well-worn Aboriginal pathways (Roth 1897), the first roads followed lines of springs. The Savannah Downs-Pelham road passed the line of springs on present-day Cooradine, East Creek and Pelham, including Middle, Currajong, Plain, Black and Cockatoo (Figure 55).

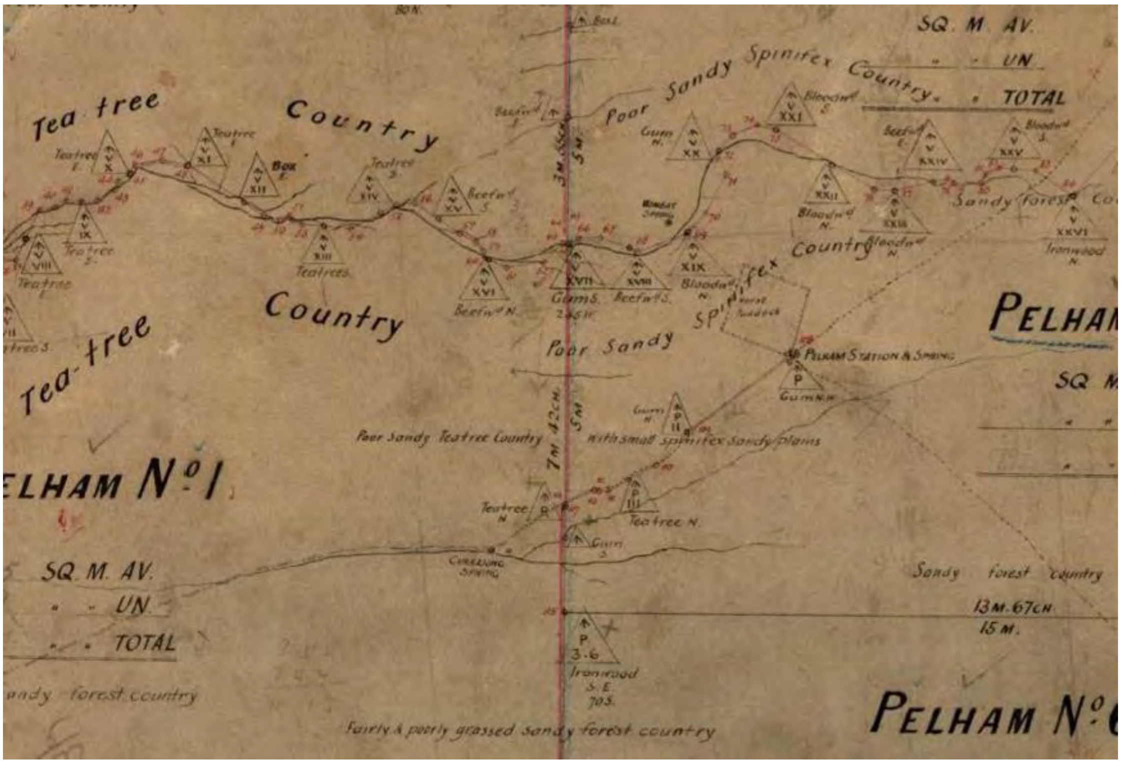


Figure 55. 1891 original survey plan (reference B144199), showing Pelham station & spring, now known as Cockatoo Spring, and Currajong Spring to the south-west, both on main track through the area.

Camping reserves were located at Fort Bowen, on the old Georgetown-Cloncurry road, and 20 Mile springs north of Julia Creek for early travellers, while Consentes Water Facility bore was sunk on mud springs on the old Normanton-Julia Creek Road (Figure 56). Few stories seem to have survived from these isolated outposts, although there is an anecdote relating to the 20 Mile Springs recounted by George O'Brien. A chap by the name of Shrewdie Royes was very enamoured with a pretty girl who was the daughter of the post-master at Donors Hill. He came up with a desperate plan which might allow him to endear himself to the girl's parents. A nasty 'accident' would surely result in some worker's compensation. The grisly incident occurred at the 20 Mile springs and involved Shrewdie cutting off his own finger. The story did not end happily for Shrewdie. He was paid compo, and he did deliver an impressive kerosene fridge to Donors Hill, but the girl was stolen by another suitor. Let's hope his broken heart was mended because the bones of his finger may still lie on the scalded ground at the 20 mile springs (Figure 57).

Figure 56. Springs at Consentes Water Facility, Julia Creek District, July 1955, Queensland Archives, http://trove.nla.gov.au/version/193314993.

Figure 57. 20 Mile springs: slightly muddy hollows fringed by prickly Acacia thickets on extensive scalds south-west of Julia Creek, and the resting place of Shrewdie Royes' severed finger.

Early homesteads, outstations and huts were built at springs, and the water used for both human and animal needs. Saxby Downs homestead is built beside Kilgin Spring, while the original Eurkea station was built at Canabadgerry Spring. Outstations and huts were built beside springs at Nara, Mazeppa and Lara. On the south-western side of Mt Fort Bowen there are ruins of the old Euroka Springs house, as well as foundations for a tank, machinery and a stone wall forming a small dam (Figure 58). This infrastructure was built by legendary cattle-man, philanthropist and bush poet Tom

Quilty (Figure 58) and his family. Tom left Euroka Springs for Western Australia in 1937, with the much-younger daughter of a neighbouring property owner (Clement, 2002). His family remained there until 1945, when they moved to Brisbane. The magnificent Manfred Downs limestone homestead still stands on the downs north of Julia Creek, although the springs that provided its original water supply have vanished. At other extinct springs, rusted ships tanks and troughs, stone and boxed wells and hand-pumps remain as reminders of past human endeavour sustained by groundwater (Figure 59).

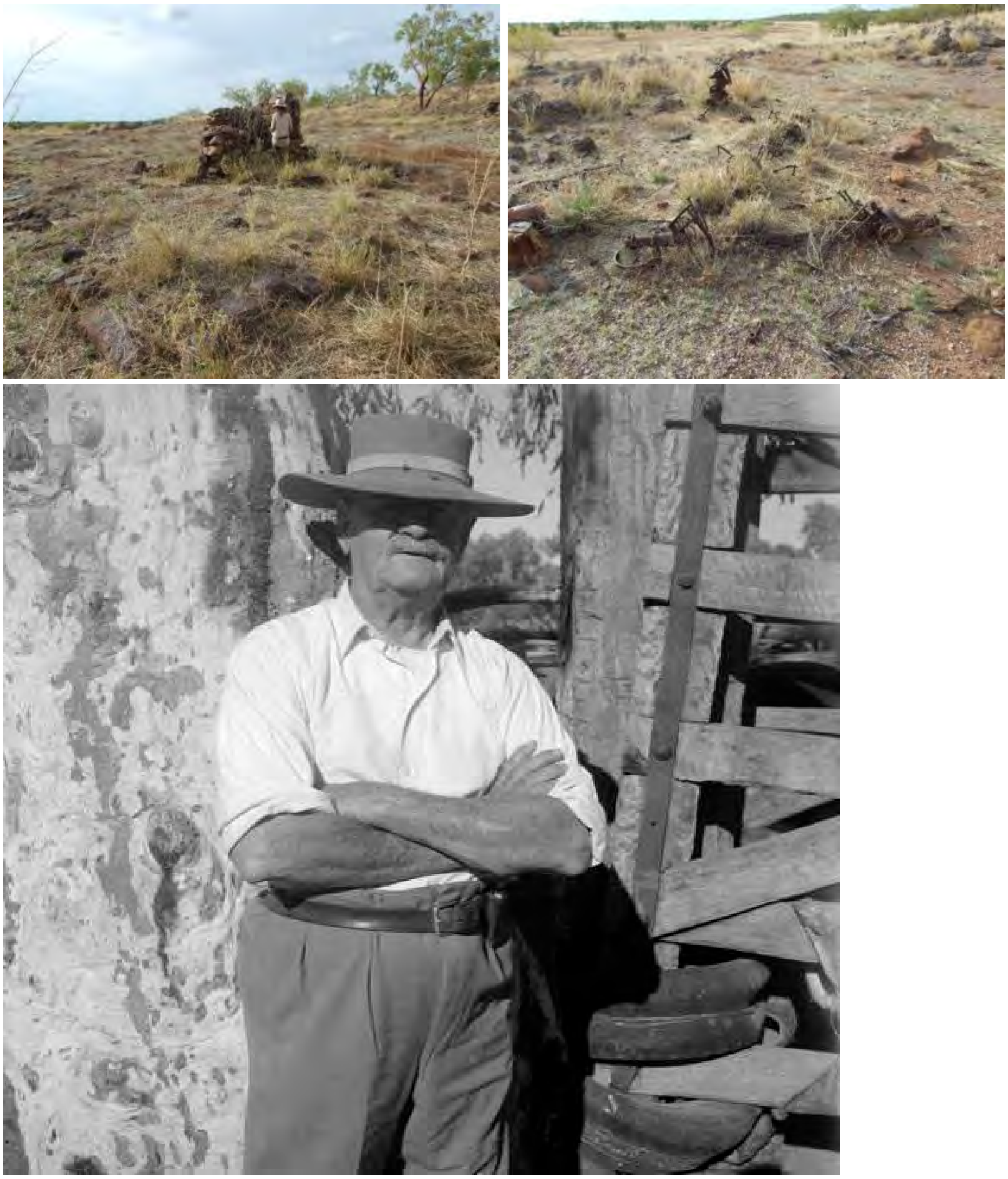


Figure 58. Remains of the Quilty's hut at Mt Fort Bowen, built above the now-inactive springs (top), and (bottom) the legendary Tom Quilty, who honed his horsemanship riding with a band of wild young horsemen known as the 'Forest Devils' before settling at Euroka with his young family (source: National Library of Australia, nla.pic-an23616835-v).

Figure 59. Ships tanks, such as this one embedded in scalded ground at the now-extinct Alva spring north of Julia Creek (top left), boxed and stone wells, such as this one at Mazeppa Springs (top right), and hand pumps as shown on 1897 survey plan and found at now-inactive Lara Springs (bottom), provided means of accessing clean spring water.

Along the edge of the uplands to the north and east, the GAB outcrop springs became important during the gold rush in the Croydon area between 1885 and 1906. The mills and batteries to process the gold required a reliable source of water, and the lack of surface water proved the major impediment to operations in the gold-fields during the dry season (Laurie, 1951). Hales Battery about 16 km east of Croydon was fed by a natural spring (probably the spring now referred to as Big Spring) and became known as 'The Springs'. In the days before widespread bores, miners were forced to retreat to springs in dry times, as reported by the Under-Secretary of Mines on a visit to the Croydon Goldfield in December 1885:

> *Arrived at Croydon on the 19th November. The water is low, and very bad, and I had to carry water from five to eight miles daily to visit where the reefs are pegged off. I found that the reefs are mostly large, the prospects showing very good gold…The extent of the auriferous country is very large, extending along the Western boundary of the Etheridge goldfield, probably to Woolgar.*
>
> *As no rain is falling, the miners are leaving daily for some springs 15 miles distant, to camp and await the rainfall. Alluvial gold exists here, and I believe it will yield well when water is available* (Newcastle Morning Herald and Miners' Advocate, 10 December 1885, p.5).

Gardens established on the springs at present-day Alehvale station grew fresh fruit and vegetables for the burgeoning community, which peaked at 6500 residents in 1887 and fluctuated around 3000-4000 until the gold-fields crashed in 1906 (Laurie, 1951). These gardens also became something of an oasis for sporting hunters and souls weary of the dry rocky hills. The Capricornian reported in 1889 that:

> *'Old Chester', the Croydon Market Garden Company's property, is becoming a favourite holiday resort. This project was initiated and a company successfully floated by our energetic Police Magistrate, Mr. Chester. The property has been acquired for some time, and the first fruits are now being received in town. The soil is very fertile and is watered by natural springs, the water being spread all over the ground by irrigating channels. The project bids fair to prove remunerative, and the change from the usual arid country is very refreshing, all around old Chester being green and fresh, and there is good sport obtainable in the shape of rock wallaby and pigeon shooting* (2 November 1889, p.31)

The more accessible springs in otherwise dry country also proved invaluable as water sources for cattle before bores became widespread. According to correspondent 'Norton Disney', writing in the North Queensland Register, they provided some benediction to otherwise worthless country:

> *It is a blessing to see springs of water on some of the worst country there is on the Gulf watershed. If one takes the 'desert' country and the sandy country which runs south from Croydon, he will find springs of water all over this stretch of country…It is a peculiarity of Queensland country that good country and natural water in any great quantity never go together. Thus it is a blessing that country which is often fourth rate or of no value at all has good water on it* (29 August 1904, p.29)

However, these springs were often not useful in the natural state. Norton Disney continued:

> *These springs require to be opened out. As a rule, one sees simply a heap of pandanus and rushes; but when a trench has been cut and cattle kept out of the spring itself, the water is clear and clean…I remember one selector who built his house near one, and now has water laid on all over his place from a spring which was only opened out to a depth of two feet.*

Accordingly, much effort was devoted to cutting drains, excavating springs and erecting troughs, most spectacularly at Kilgin spring, as detailed by J. Alfred Griffiths and depicted on his accompanying sketch map (Figure 60):

> *In October 1884 when the cattle were first brought here the mound was covered with rushes and ferns amongst the palms and there was no pool at which the cattle could drink properly, so a tank was excavated near the north west end and shallow drains made from the spring. This gave good water. In 1889, to increase the yield, the drains were deepened to 5 to 6 feet, after this the water began to deteriorate and became almost unfit for use from the strong acid taste of the peat. In 1888, 120 yards of iron troughing were erected at the north west end, but after deepening the drains the troughs were so rapidly corroded that they had to be abandoned, and in 1892 a sloping drinking pit…was sunk and lined with logs…the small shallow drain…on the north east corner was opened and gave good potable water, which since then has supplied the station for domestic purposes.*
>
> *At present, there are about 80 yards of drain…Since 1889 the water from the deep drains has steadily improved in quality indicating that the impurities are not deep seated, but are mainly in the peat and are being gradually washed out. No doubt the quality of water can be somewhat increased by extending the drains, but subsequent boring has obviated the need for this.*

Many subsequent visitors to Kilgin Spring commented on these impressive ‘improvements’. Drains were cut into most peaty springs to improve flow, and sometimes entire mounds were excavated (Figure 60, Figure 61). Fences were also erected around most springs to prevent stock bogging (Figure 62). All the springs on Saxby Run were fenced and the water drained into iron troughing (Figure 63), which allowed cattle to obtain clean water without the risk of bogging (Morning Bulletin 1910, p.3). The springs also provided an opportunity for a rare and ultimately abandoned inland attempt at growing plantains, at Plain Spring on East Creek (Figure 64).

Figure 60. 1896 sketch map of the Kilgin Spring drawn by J.A. Griffiths, showing drains, troughs and lagoons.

Figure 61. Peaty mound which has been excavated to fill a pond, which overflows through drains to improve cattle access, Cockatoo Spring, Pelham (left), and silt scoop at the spring (right), testament to the fate of many of the peat mounds described by Griffiths.

Figure 62. Remains of fence described by Griffiths to prevent stock bogging in the now-inactive springs on Lara.

Figure 63. Old troughs adjacent to now-inactive springs at Fort Bowen (left) and Mazeppa springs (right).

Figure 64. 1940s photo at Plain Spring. The caption reads: 'Far north-west artesian leakage of excellent quality near the intake areas. Plantains set good bunches, but apparently in this climate other bananas do not mature' (Ogilvie, 1945).

The mud springs were also regarded as curiosities in a curious land, albeit dangerous ones for unwary stock, as noted by 'Christophus' in an article titled 'A trip to the Burke', which appeared in The Queenslander in 1883. He may be describing the springs around Mt Fort Bowen and Mt Little, which are 35 miles from Dalgonally station, although they were originally part of the Millungera Run:

> *…it is a grand sight at sunset when returning to camp to see a small flock of pigeons rise and fly onwards. By-and-by they are joined by one or two more, then, perhaps, by another small flock, and this continues until their ranks swell to thousands, and they darken the sky around the waterhole.*
>
> *Their favourite watering places, however, are the soda and mud springs, which are situated about 35 miles from the station. These springs are regular traps for cattle, who try to get at the green feed growing round them, and die in the attempt, for once they get in they sink as rapidly as if they had fallen into quicksand. Some of these mud springs are mounds 3ft. high, others level with the ground, and naturally these latter are the most dangerous. The plains here are immense, like some great sea, and there is a good supply of grass* (The Queenslander, 25 August 1883, p.316).

Where effective fences were not built around springs, the bogging of cattle provided a stinking spectacle for travellers who may have anticipated bubbling, clear oases. Andrew Gibb Maitland, a geologist with the Queensland Government who conducted early surveys of the Great Artesian Basin, visited Cuddray Spring in the mid-1890s, and described it as '*merely a mudhole filled with very dirty water, in which are the remains of many dead cattle.'* Local legend had it that the springs could also be the downfall of native wildlife and even people, with Edward Palmer writing in his Letter to the Editor of the Queenslander in 1882 that:

> *One of them [the mud springs at Fort Bowen] was so soft and open that a native dog running across one sank out of sight in it, and was swallowed alive…Into one small mud spring in this collection a long pole was driven by the hand till it disappeared; and the next day it was thrown up with a quantity of thin brown mud, in which were a lot of broken bones, rust coloured —like bones of a black fellow.*

The Kilgin and Fort Bowen springs became the most well-known springs in the district and feature in numerous newspaper articles from the early 1900s. A photo of springs on Saxby Downs appeared in The Queenslander on 1 May 1909, with the caption: 'So dense are the pandanus palms around these springs that the other trees are frequently "shouldered" to the ground. Under the deep shade it is almost dark at midday.' While it is difficult to make out much from the photo, (Figure 65) this is probably Kilgin Spring, and is the first known photograph of a spring in the Flinders River group.

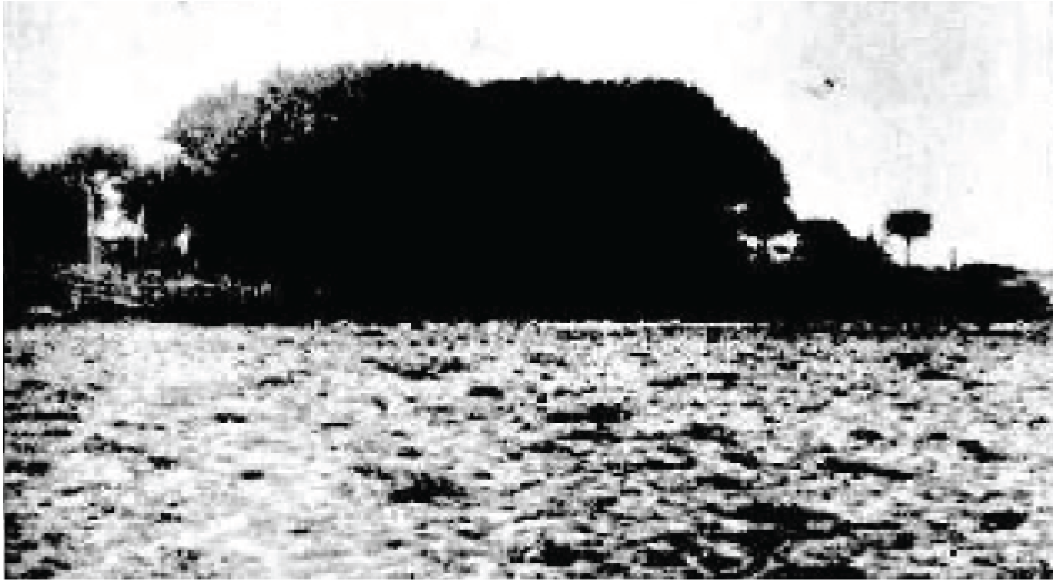


Figure 65. 1909 photograph of springs on Saxby Downs, probably Kilgin Spring (source: The Queenslander, 1 May 1909, p.25).

Correspondent 'Tellegalla' described the Fort Bowen and Mt Browne springs in detail in the Morning Bulletin in 1910. While impressed by the strange properties of the ground, he was less enamoured by the water quality:

> *At Fort Bowen and in its vicinity there is also a large number of springs. Fort Bowen is on the old Cloncurry-Georgetown and Croydon-road. A mountain of conglomerate rises up on a plain between the Cloncurry and Saxby rivers. At this place years ago there was an hotel, and it must have been a haven of refuge for any who might be stuck up there in floodtime… At this place there is a chain of waterholes, which are fed by the springs about there. There is a flat plain near these holes, and on this area a number of little mud heaps like ant heaps. If one is knocked over a trickle of water will issue from it, and if one jumps on this flat he will shake about half-an-acre of its surface. Further on there is another big patch of similar mounds. These places are mostly a trap for stock and the water has too much soda in it. Some springs and bore waters have the effect of bringing on symptoms of a filthy disease. Tea made from these waters has the tannin all brought out in the brew and is hardly drinkable* (6 August 1910, p.3).

Another description of these springs appeared in a letter to the editor published in the Townsville Daily Bulletin in 1922:

> *Sir,— Reading about the bore on Millungera in your paper, put me in mind of some very peculiar country on the same place, 30 miles down the Saxby from there. Three small hills crop up called Mt. Brown, and alongside of them there are three clumps of springs. Each spring is almost a complete circle, covering about four acres each, and tremendous high paper bark tea-tree grow in the centre. It is impossible to penetrate into them to examine the centre. Two of them are ordinary, having big water holes alongside that never vary in any season except the wet. The other is nearly boiling, you cannot put your hand in it. The water tastes a little sodary, but is good to drink. There are a lot of small mud springs around there also, you can see some of them working at times. If a beast gets into one he is a goner; they sometimes do. At the same place a billabong runs from*

the Flinders to the Saxby, although they do not junction for over a hundred miles below there. About 12 miles below there is another hill rising right out of the plain on the Old Norman-Cloncurry road called Fort Bowen. They are the only hills to be found in that country. On one side of Fort Bowen there are also hundreds of small mud springs. I worked on Millungera and Taldora- about 10 years from 1887. I have a fancy those places would be a good spot to bore for oil. — Yours, etc., H. F. BLIGH (Townsville Daily Bulletin, 11 February 1922, p.7).

However, for a brief moment in 1918, Eureka spring on Saxby Downs (Figure 66) attained a level of fame never before or since afforded to a desert spring, when it ‘exploded’ like a miniature volcano. Accounts of the bizarre behaviour of this spring appeared in at least fifty newspapers both in Australia and overseas, with headings such as ‘A Queensland Volcano’, ‘A Queensland Geyser’, ‘The Saxby Downs Eruption’ and ‘Strange Phenomena’. Residents had apparently been reporting strange rumbling noises and minor earth tremors in the years leading up to the apparent eruption. The following extract is taken from *The Farmer and Settler*:

What is described as a miniature volcano burst into activity about four weeks ago at Eurata [Eureka] Springs, which are situated about twenty-five miles north-east of Saxby Downs. Mr. C. W. Hickson, manager of the Downs, states that previous to the eruption these springs covered an area of fifteen acres, and that now, in place of water, there is nothing to be seen but dense volumes of black and yellow smoke, which rise to about forty feet in the air. The country in the vicinity is volcanic, and consists of limestone and lava. For many years the local residents have heard distant rumbling noises, accompanied by slight earth tremors.

Lumps of metal that have been thrown into the springs have caused loud explosions, pieces of burnt lava being thrown up (4 October 1918, p.4)

The following year, The Northern Miner reported that the station manager Mr Hickson had received the following reply from Commonwealth Meteorologist Mr Hunt regarding the burning spring:

Your account of the burning area at Eurata [Eureka] Springs proved very interesting. Examination of the sample sent bears out your conclusion that the "black earth" is an impure vegetable deposit which may be classed as a poor lignite or merely as a carbonaceous shale (i.e., a mudstone containing a proportion of vegetable matter). Ignition may have been caused by lightning, by a bush fire (of which there should be other traces) or by "spontaneous" action due to the oxidation of iron and sulphur generating sufficient heat to make the mass smoulder…the occurrence bears some analogy to Mt. Wingen, the so called "burning mountain" in the Liverpool Ranges in New South Wales… (22 February 1919, p.7).

Figure 66. Eureka spring in 1999. In 1918 its spectacular burning made it the most famous spring in the GAB, appearing in newspapers in Australia and overseas. It now lies long-dry in an unassuming seldom-visited patch of sandy forest.

As in other areas of the GAB, the springs provided clues to the existence of vast underground reservoirs, particularly valuable in country with scant natural surface water. Edward Palmer (1884) saw this potential, writing:

> *The occurrence of these hot and cold mineral springs, suggests the possibility of obtaining supplies of water on the artesian principle over some portion at least of these extensive plains. Some mud springs, as they are called, opened at Manfred by a small shaft at the side, produced a permanent flow of good water.*

From 1884, bores were sunk on and adjacent to springs, where flowing water was assured. They were later drilled at increasing distances from the springs, where they were of greatest value in opening up country to livestock (Towner, 1962).

In late 1889, George Gow travelled by boat from Melbourne to Townsville, by train to Hughenden and then by coach to Manfred Downs, then a vast sheep station, where he would take a position as overseer of one of the outstations. In his reminiscences, transcribed by Archibald Crowley, there is a passage on the artesian springs and early bores on Manfred Downs:

> *Gow soon got into the way of things at his out-station. Two days after his arrival he was sent with some men to the other out-station, Mullundera, to assist in mustering and drafting sheep. There he saw for the first time an artesian bore with the water flowing over the top. The first deep bore in Queensland was, according to John Hugh Moor [manager at Manfred Downs], put down under his direction on Manfred Downs by Joe Boggs, a Yankee in 1889.*

The manager became convinced of the existence of artesian water by the occurrence of mud springs at various places on the run. Mud springs, as Gow knew them on Manfred Downs, were mostly round, cone-shaped mounds of a greyish colour, some about nine feet high with a turned up saucer-shaped top. The outside was quite hard, and a horse could climb up, but the saucer top was usually just liquid mud, into which an animal might disappear, leaving no trace for years until his bones would be brought to the top by an eruption of mud. Other springs might not be so soft and the animal would simply bog, while odd ones remain hard on top for years, until the artesian water, forcing its way up, would suddenly make them break out again. At intervals they would erupt liquid mud for days, spreading in a thin layer over the mound, each eruption adding a trifle to the bulk of the cone. Mud springs, dangerous to stock, had to be fenced.

Odd mud springs were level with the ground, and did not overflow and form a turned up saucer-like top, as did the majority. Occasionally these became a little damp and soft on the surface. Probably there was no great force of water below them. One day a mare named Gay Lass, which Gow had been riding and had tied to a tree, broke away and galloped off. Suddenly coming on one of these flat springs, she bogged down to the saddle flaps, and could not extricate herself. The bridle-rein was broken down at the bit, and with a stick Gow secured it, enabling him to render the mare some assistance, so that she got out. But what a mess; gluey mud up to the saddle flaps! The only remedy was to mount her, ride into the river and move to and fro in water reaching the top of the mud on her body, which gradually was removed.

Shallow bores of 100 to 200 feet, put down at these mounds might give a good flow of water, but soon became exhausted. They would then have to be shut off for a day or so till they regained volume. The water was clear and cold, and had a soda taste. Deep artesian bores ranging from 800 to 1,200 feet, gave supplies of up to 200,000 gallons day of warm water, mineralised, but excellent for stock and domestic purposes. One bore toward Alec's Creek, which came through the north-eastern portion of the run and joined the Flinders, flowed into a shallow creek or gully, the water being so hot that men could not bathe close to it.

A strange feature of these bores, which were most arranged to run into shallow creeks, was that rushes like those that grow in the Leeton and Griffith irrigation channels soon appeared, also a variety of small fish, which had not previously been seen in any local water (Gow, n.d.).

The Manfred Downs bores were indeed the earliest attempts to procure artesian water in northern Queensland. Many other bores were soon drilled on now-extinct mud springs, including Pigeon Creek, Twelve-Mile, Fullarton and Gilliat Bores, as well as the Boonoke, Ruthven and Twelve-Mile Bores which are difficult to locate north of Julia Creek (Griffiths, 1896). The latter three bores were not able to be located, but they almost certainly sounded the death-knell for the springs described by Griffiths. The 1910 correspondence of 'Tellegalla' reads as a prescient elegy for the now-forgotten springs of the Flinders River:

There are some splendid springs of water in the north of this state and which have been the standbys of many places for years. Bore water only came into vogue in the north-west about 1894, and before that there were no standbys like the springs (Morning Bulletin, 6 August 1910, p.3).

Four years later, the decline in both the springs and bores was the subject of investigations by the Artesian Water Commission, which met at Hughenden on July 17 1914. The Queenslander reported that:

> *…A. M. S. Thompson was asked for information as to the natural springs on Saxby Downs. He said there were several mud springs on Saxby Downs. One of them used to give 100,000 gallons per day, but at present the quantity was less than 10,000 gallons. A bore was now sunk about 150 yards away, but the water was not the same, nor as good. It had an aperient effect. There were a number of bores on Saxby Downs. They had all decreased in flow. He attributed this to the big tappings on the lower country on Bunda…* (25 July 1914, p.38).

By the late 1920s, the drying up of former springs was a well-known phenomenon, although the cause was not yet accepted wisdom:

> *… A few years ago there were a number of mud springs in this district [Millungera area], but most of these have dried up, for what reason nobody seems to know. Perhaps a sequence of seasons with a rain fall below normal is partly responsible, or perhaps the putting down of bores has resulted in a lowering of the artesian basin* (The Australasian, 24 November 1928, p.41).

The outcrop springs on the intake beds of the GAB in the Gregory Range have been mostly immune to aquifer drawdown, while about half of the peat springs in the north-east of the supergroup remain active. Further south, some discharge springs such as 20 Mile, Alva Downs and the Manfred Station lagoon remained active until the 1950s, when bore-sinking became more precise and affordable. Today, all bar three of the 50-odd clusters of water and mud springs inhabited by Aboriginal people for millennia before supporting the fledgling pastoral industry are extinct, marked by white scalds and hollow depressions (Figure 67).

Figure 67. Searching in vain for signs of groundwater at Sunny Plains springs, October 2011.

4.5 Biological values

4.5.1 Outcrop springs

The large springs associated with outcropping sandstone in side gullies of the Gregory Range are typically dominated by large paperbark trees (*Melaleuca leucadendra*) with an understorey of sedges (e.g. *Baumea rubiginosa* and *Fimbristylis nutans)* and grasses (e.g. *Ischaemum australe*). Some rare species associated with these springs include *Adenostemma lavenia* and *Fimbristylis blakei*, while the tree ferns *Cyathea cooperi* in the spring-fed gullies of the Gregory Range represent highly disjunct populations. *Fimbristylis blakei* is endemic to spring wetlands. There are no endemic invertebrates associated with these relatively acid waters. These low levels of endemism are typical of outcrop springs throughout the GAB (Fensham et al., 2011).

4.5.2 Discharge springs

In contrast, GAB discharge springs in the Barcaldine, Springvale (see this report, sections 3.5.2 and 5.5), Eulo, Bourke (Silcock et al., 2013) and Dalhousie, Lake Frome and Lake Eyre supergroups (Worthington-Wilmer et al., 2008; Fensham et al., 2010; Murphy et al., 2012) are home to endemic plant, fish and invertebrate populations. However, the discharge springs of the Flinders River group either did not support or have not retained specialised organisms. The populations of *Pandanus spiralis* are a distinctive feature of the springs, but this species also occurs along some rivers and also occasionally on inland dunes. The large peaty acid springs on Pelham such as Black and Tucketts provide habitat for the sedge *Fimbristylis complanata,* which appears to be relatively restricted in northern Australia. There are no endemic invertebrates or fish. However, the springs in the region have greatly reduced flow rates and often high degrees of modification through excavation and draining of mounds and there may have been substantial extinction, including of specialised organisms that will never be known.

The extraordinary endemism of discharge springs is typically associated with shallow-water alkaline wetlands, with their distinctive habitat structure and water chemistry (Fensham et al., 2011). Examples of such wetlands are preserved at the three remaining active springs in the southern Flinders River supergroup: Dalgonally, Gilliat Bore and Bauhinia Downs (Figure 68). *Cyperus laevigatus,* a widespread sedge often associated with other endemics, is dominant in these wetlands. This could indicate that endemics were always absent from the Flinders River supergroup.

However, the early descriptions and specimens of Edward Palmer suggest otherwise. Palmer describes vegetated wetlands at both Fort Bowen and Mt Browne. His 1884 plant collections for now-extinct springs at Mt Fort Bowen includes discharge spring signature species *Cenchrus purpurescens* and *Scheonus falcatus*, as well as a record of an *Eragrostis* species which may be spring endemic *Eragrostis fenshamii*. Palmer's observations of spring vegetation at Fort Bowen and Mt Browne are corroborated by Meston (1923, p. 14), who wrote that 'the ground [surrounding the spring vents] is hollow and treacherous, the surface matted together by dense vegetation'. Palmer (1884a) also noted the presence of small fish to six inches long in a spring, probably the vanished Manfred Station springs. This observation was made well before gambusia (*Gambusia holbrookii*), which now dominate many springs wetlands, were introduced to Australia, and these fish may have been spring endemics.

Palmer's record is sufficient to be certain that there has been considerable local extinction of spring dependent wetland species, and suggests that there may have been springs in the Flinders River supergroup that contained endemic species. While it is unlikely that mud springs ever contained endemics, the large alkaline water-springs described by Griffiths such as Lara, Waddy, Gorge, Berinda, Manfred Station and Mazeppa may once have contained specialised flora and fauna, which will never be known. Groundwater scald indicator species *Sporobolus partimpatens* and *Trianthema* sp. (Coorabulka R.W. Purdie 1404) are present at some sites, including extinct springs.

Figure 68. Dalgonally (top left), Gilliat Bore (top right) and Bauhinia springs (bottom) are the only shallow-water alkaline discharge springs remaining active in the Flinders River supergroup.

4.6 Key threats and management

The national bore capping scheme, initiated in the 1980s, addresses the dramatic effects of uncontrolled bores (Figure 69) on artesian pressure in the GAB. As pressure restores, there is the possibility that there will be expansion of surviving springs, or even reactivation of inactive ones. The Gilliat Bore spring is getting bigger every year, probably in response to the capping of nearby Macleod bore (Suzie McCowen, pers.comm.), while the nearby Dalgonally spring is also thought to have increased in size in recent years (John Lynch, pers.comm.). The Kilgin spring at Saxby Downs was inactive in 1999 but was running water in 2012 (Figure 70). However, this may be a result of recent wet years and local recharge. Only with ongoing monitoring, using the data gathered here as a baseline, can we ascertain whether springs such as Kilgin have reactivated. However, bore capping seems to have come too late for most of the discharge springs in the Flinders River group, and there were no signs of reactivation at other extinct springs.

Figure 69. Bluebush No. 14 Bore, Millungera. An example of a high flowing uncapped bore in the vicinity of the Flinders River supergroup. Unrestricted bores like this have been linked with the loss of many springs.

Figure 70. In 1999 Kilgin spring was peaty flat with no discharge (above). When re-visited in 2012 there were signs of groundwater activity and some wetland vegetation had established (below). However it is yet to be seen whether this is a sign of renewed groundwater flow or a residual effect of preceding wet years.

Not all of the outcrop springs in the Gregory Range have been visited. However, they tend to occur in inaccessible country subject to minimal human impacts and have low conservation values. Helicopter surveys in November 2014 verified that they can be reliably mapped using the NDVI signature from Landsat imagery captured during relatively dry times.

The location of at least 20 discharge springs in the Flinders River supergroup remains mysterious: Sandy Spring, Muk Quibunyah and Tailing Yard springs on Savannah Downs; Middle and ‘Similar’ springs on Cooradine; Dead Dog and ‘S’ on Pelham; the Fort Constantine spring; Twelve-Mile Bore spring on Consentes; Peru spring on Bodell; Leilavale spring on Barnsdale; and three springs on Woodstock. Most of these are described by Griffiths, with good locations based on old block names, but are not marked on survey plans or later maps. There are no likely signatures and the current owners are not aware of any springs in the area. All sign of the Manfred Downs station springs seems to have disappeared, while Boonoke and Ruthven, two bores sunk on mud springs to the north-east, remain elusive. There are more ‘lost springs’ in the Flinders River supergroup than in the rest of the GAB combined. Often in the search for lost springs, something will trigger the memory of a long-term landholder or resident, and the site of a spring will be obvious. Without such cues and with no large features on the ground, springs resemble the proverbial needles in a haystack, lost in the vastness of grassland and low sandy forest and the dust of time.

4.6.1 Groundwater use by mining

The Cannington Mine and its associated borefield is located approximately 140 km south south-west of Cloncurry and is one of the largest silver and lead mines in the world (Figure 35). The borefield extracts water from the Longsight Sandstone, a formation within the Great Artesian Basin. The mine has a water licence currently authorising the extraction of 6.05 ML per day and has been operating since 1997. Between 1997 and 2012 extraction ranged between 2.93 ML/day and 5.36 ML/day at an average rate of 4.34 ML/day. In recent times, the mine has proposed to extend the life of the mine to year 2024 through extension of underground workings. The proposed extension project has recently progressed through the EIS process. The extension is expected to increase the water requirements to an approximate total of 6.40 ML/day from the borefield. The mine is currently applying to DNRM for this additional water.

There are drawdowns close to the borefield up to 20m, however the actual observed depressurisation for 2012 extends only about 15km radius from the borefield (Schlumberger Water Services, 2012). This is substantially less than the impact predicted from a groundwater model (Schlumberger Water Services, 2012).

The Osbourne Mine is located approximately 50 km south-west of the Cannington Mine and extracts copper and gold. The mine has a water supply borefield located on ML 90057. The borefield is authorised to extract 2.59ML per day from the Longsight Sandstone and has been operating since 1996. The area of depressurisation is slightly less than Cannington (<15km radius). In November 2014, Chinova Resources, owners of Osbourne Mine announced that the mine is planned to be closed late 2015.

The Cannington Mine is in the far southern section of the Flinders River supergroup (Figure 35). The nearest spring to the Cannington Mine is Blackeye Spring (32 km). It had become inactive long before the groundwater extractions associated with Cannington and Osborne Mines. The impact of the borefields associated with these mines is sufficiently remote (83 km) from the nearest active springs, the Mt Datson Springs in the Springvale supergroup, to not be a concern for springs conservation.

5 Springvale Supergroup

5.1 Overview

Of all the desert springs, the Springvale supergroup seems to most epitomise the lure of water in a dry land, its strangeness and mystery, and also the rapidity with which the accumulated layers of natural history have become obscured: the ghost springs of the pale Hamilton River flats; the forgotten weed-infested depressions where once precious water rose from the ground on vast grasslands; the tiny mud-puddles fringed by ancient human tools, now glimpsed only by passing cattle and the shadows of black kites.

The Springvale supergroup is comprised solely of discharge springs and covers about 8000 km^2. The main line of springs follows the alluvial plains of the Hamilton River, which flows south by south-west into the Georgina (Figure 72). To the south, Elizabeth and Springvale springs are situated beside Spring Creek, a tributary of the Diamantina River. There are two outlying groups of small mud springs 70 km to the south-west on the vast open plains east of the Georgina River. Only 18% of the springs at the individual wetland scale are extinct, but this is largely because of the large number still active at Elizabeth and Mt Datson Springs. Of the 12 spring complexes five are completely inactive and three are partially inactive.

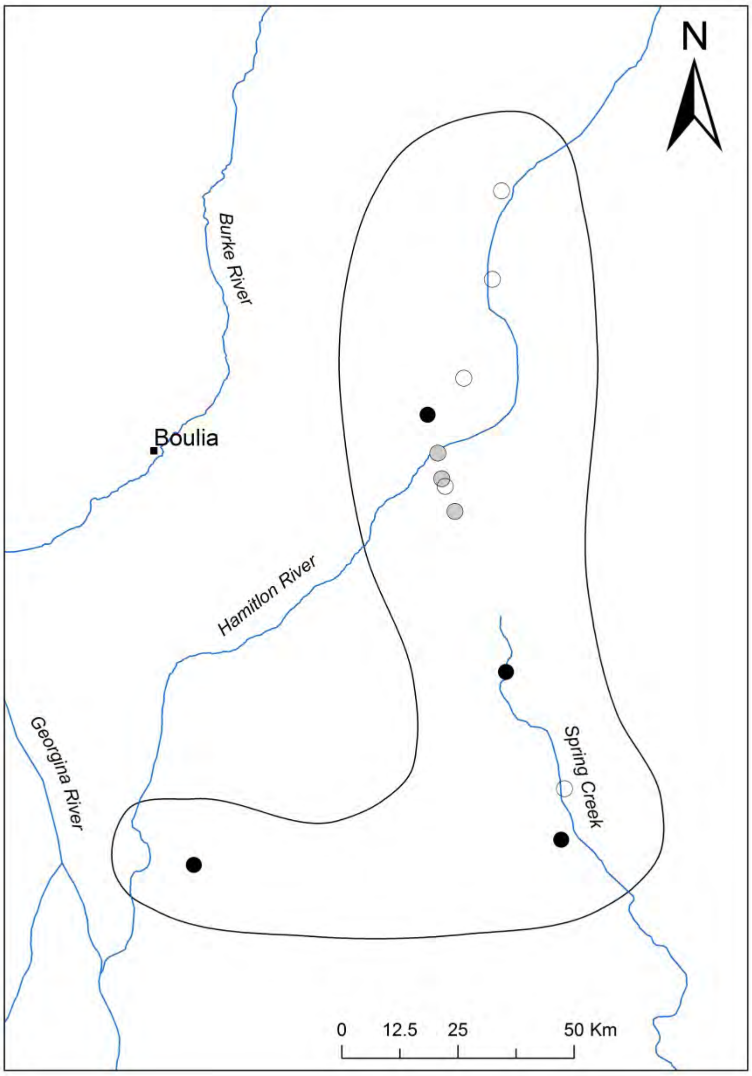


Figure 71. Spring complexes within the Springvale supergroup. Spring complexes with 100% active springs (solid), partially (1%-99%) active (grey) and 100% inactive (open symbols) are identified.

Table 13. Summary of the status of the springs in the Springvale supergroup at the complex, wetland and vent scale.

	Complex			Spring		Vent	
	Active	Partially active (1-99% of wetlands)	Inactive	Active	Inactive	Active	Inactive
Outcrop	0	0	0	0	0	0	0
Discharge	4	3	5	121	26	339	26

5.2 Hydrogeology

5.2.1 Regional hydrology

The basement of the Eromanga Basin in the vicinity of the Springvale supergroup is up to 1000 m deep and is variously composed of Proterozoic sediments and granites. There is a major unconformity between this basement and the overlying Longsight Sandstone of lower Cretaceous age. The Longsight sandstone (Hooray Sandstone equivalent) is the main aquifer unit in the region and in the vicinity of the springs is between 15 and 110 m below the surface. The Longsight Sandstone is overlain by a sequence of Cretaceous sediments, mostly comprised of fine-grained sediments including the Wallumbilla Formation, the Toolebuc Formation (limestone), the Allaru Mudstone and the Mackunda Formation. There are also Tertiary deposits including sandstones and limestones.

Fault structures are generally aligned north-south and probably arose in the Proterozoic (Figure 72). Minor movements along these structures, including the Burke River structure, during the early Tertiary have created faults and folds in the Cretaceous sediments allowing groundwater to discharge through springs.

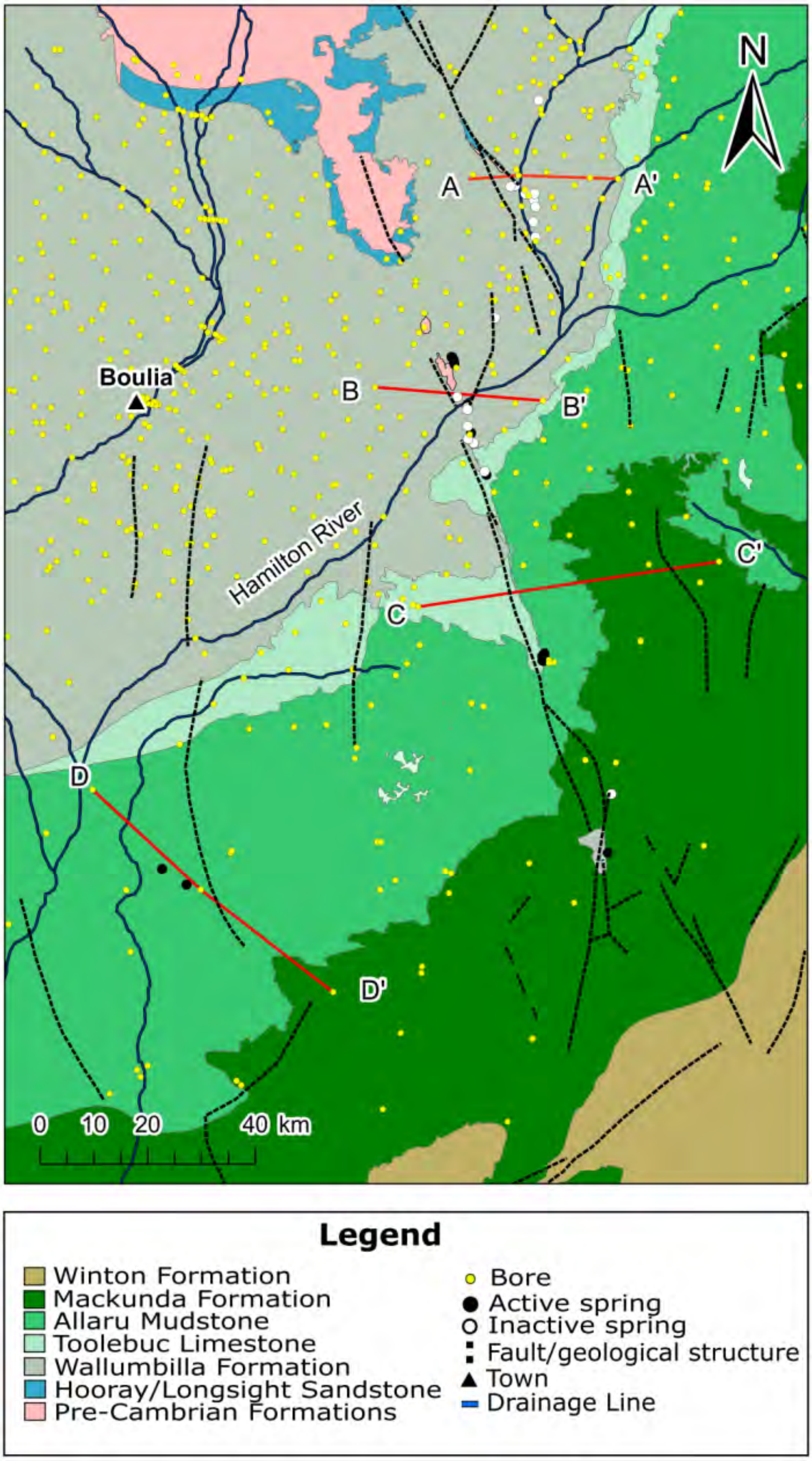


Figure 72. Discharge springs in the Springvale supergroup and the associated surface geology with some important structural features identified. The position of the stratigraphic lines represented below is indicated.

5.2.2 Hydrology of the springs

Springs in the Warenda area occur where the Longsight Sandstone approaches the ground surface along the Mommedah anticline in the vicinity of the channels associated with the Hamilton River (Figure 73). There is also some possible faulting assisting the flow of groundwater through the aquitard that is only ~10 m thick in this area (Figure 73). In this area there has been considerable reduction in the potentiometric surface and the springs are currently inactive.

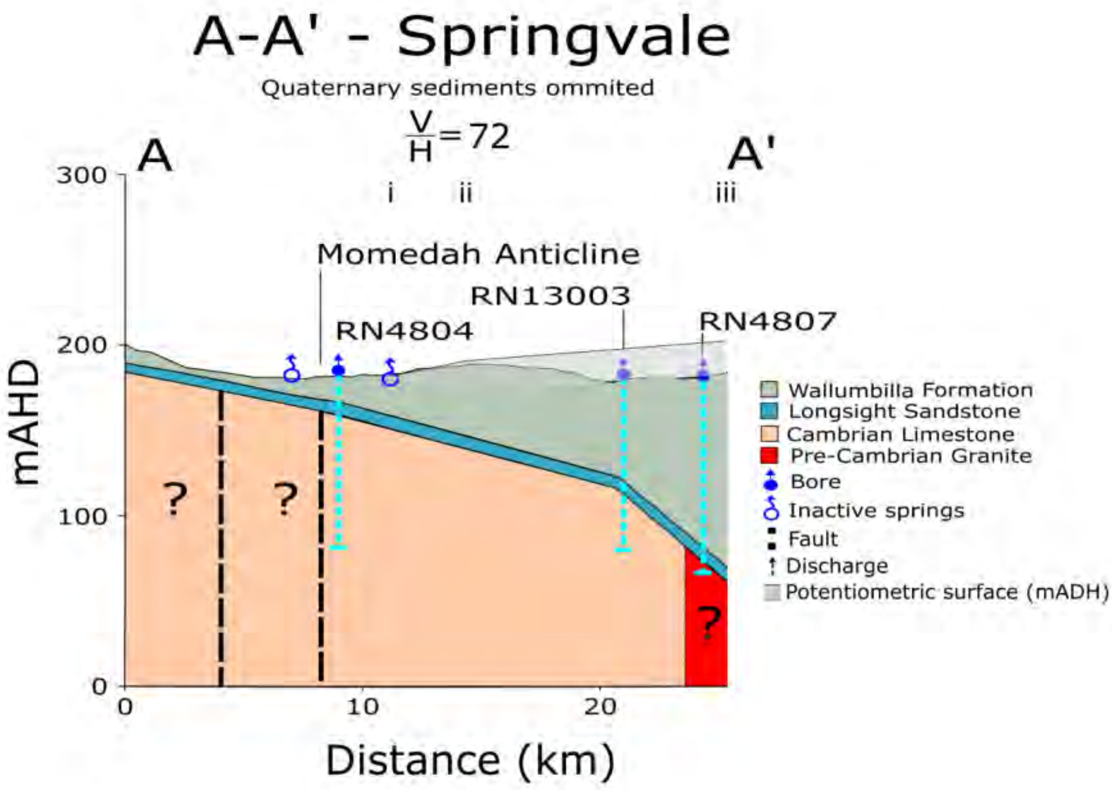


Figure 73. Stratigraphy through Springvale discharge springs (see A-A', Figure 72 for location). Where bores are projected onto the stratigraphic line the difference in elevation is indicated by the position of the bore symbol in relation to the ground surface. The range in the potentiometric head over time is represented by the limits of the grey bar and the roman numerals indicate the location of the bores that inform the head. i: RN4794, min. date 1891: SWL 0.7, max.date 1896: SWL 1.52; ii: RN4808, min.date 1926: SWL: -13.72, max.date 1896: SWL 2.74; iii: RN4806, min.date 1965: SWL -4.88, max.date 1896: SWL 15.54.

Most of the springs in this supergroup are aligned along a northerly trending fault the Burke River Structure (Figure 72, Figure 74) (Habermehl, 1982). The fault has resulted in substantial displacement of the underlying Proterozoic and Paleozoic rocks and folded and faulted the Mesozoic sediments to the extent that groundwater discharges from the uppermost water-bearing aquifer the Longsight Sandstone (Hooray Sandstone equivalent). The Elizabeth Springs are clearly aligned with the southern end of the Burke River Structure a prominent fault (approximately 30m displacement) providing a conduit between the aquifer and the springs through 190 m of aquitard sediments (Figure 75).

The fault structure seems to provide a discontinuity for groundwater flows represented by a standing water level of 184 m, 15 km east of the fault and 143 m, 15 km to the west of the fault (Figure 75). Diminished groundwater flows during the pastoral period have resulted in substantially reduced flows at Elizabeth Springs.

Figure 74. Burke River Fault structure in the vicinity of Elizabeth Springs, with outcropping Toolebuc Limestone.

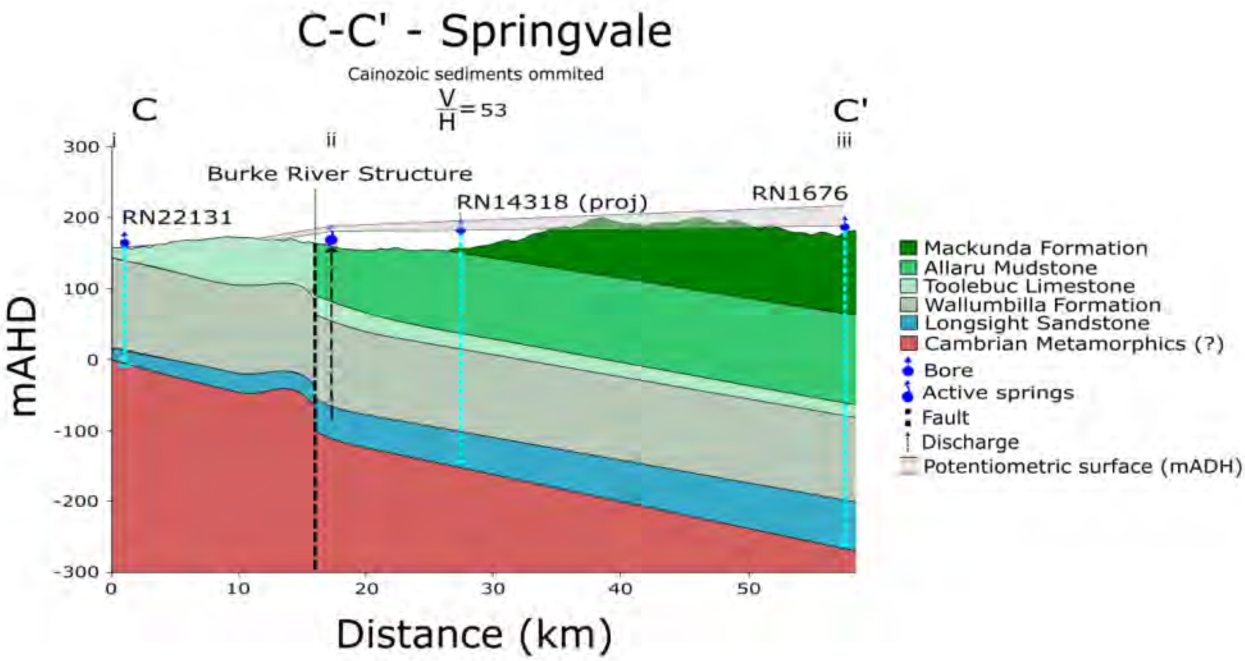


Figure 75. Stratigraphy through Springvale discharge springs (see C-C', Figure 72 for location). Where bores are projected onto the stratigraphic line the difference in elevation is indicated by the position of the bore symbol in relation to the ground surface. The range in the potentiometric head over time is represented by the limits of the grey bar and the roman numerals indicate the location of the bores that inform the head. i: RN4869, min. date 1969: SWL -9.14, max.date 1939: SWL 0; ii: RN5102, min.date 1995: SWL: 2.04, max.date 1970: SWL 7.04; iii: RN1676, min.date 1996: SWL 6.23, max.date 1917: SWL 33.1.

Early measurements of artesian head are up to 33 m and recent measurements are in the vicinity of 6 m. This substantial decline has resulted in some bores to the west of the Burke River fault having become sub-artesian. Historical estimates of flows at Elizabeth Springs suggest that flows have declined from 53 l/sec in 1896 (see section 5.3) to between 9 and 13 l/sec between 1951 and 2002 (determined from aerial photography and satellite imagery, R. Fensham unpublished data). Many of the springs in the Springvale supergroup have ceased to flow altogether (Table 13).

Springs on Warra, south of the Hamilton River, many of which are inactive, are also aligned with the Burke River Structure (Figure 72). At the northern end of the Burke River Structure and north of the Hamilton River, the Mt Datson Springs are associated with folding and perhaps also faulting of outcropping Cambrian limestone at Mt Datson to the north of the springs (Figure 72). In this location the aquifer is relatively shallow and the springs coincide with an area of relatively low elevation and therefore maximal artesian head which is in the vicinity of 7 m, despite considerable drawdown during the pastoral period (Figure 76). The springs in this location occur in association with drainage channels bisecting a shallow Tertiary limestone ridge (Figure 72; Figure 77).

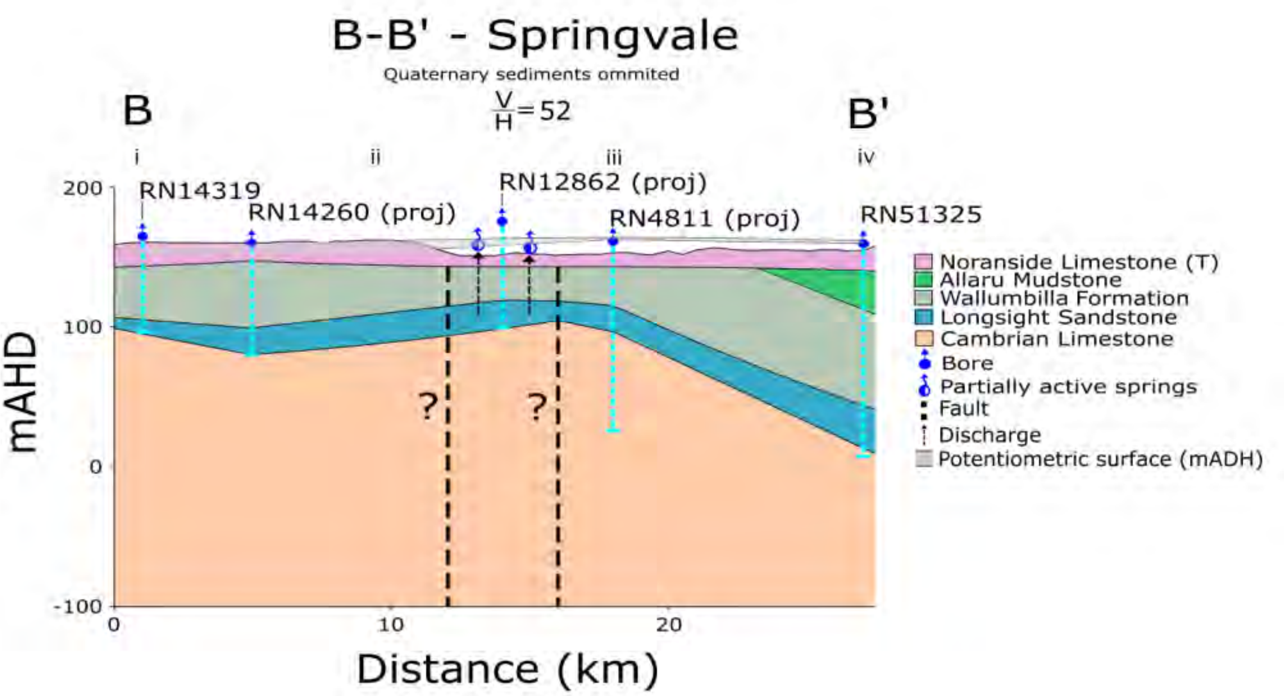


Figure 76. Stratigraphy through Springvale discharge springs (see B-B', Figure 72 for location).
Where bores are projected onto the stratigraphic line the difference in elevation is indicated by the position of the bore symbol in relation to the ground surface. The range in the potentiometric head over time is represented by the limits of the grey bar and the roman numerals indicate the location of the bores that inform the head. i: RN4866, min. date 2001: SWL 3.47, max.date 1918: SWL 7.01; ii:RN12880, min.date 1992: SWL: 3.76, max.date 1955: SWL 9.86; iii: RN4811, min.date 1896: SWL 4.27, max.date 1913: SWL 5.64; iv: RN51325, min.date 1998: SWL: 4.35, max.date 2013: SWL 6.55.

Figure 77. Mt Datson springs emanating from drainage depressions flowing off a low limestone ridge (background).

The Coorabulka springs are associated with a fault structure providing a conduit through the aquitard which is more than 100 m thick in this area (Figure 78). Some of the springs which are not directly aligned with a mapped fault probably identify the location of other unmapped structures. There is a substantially positive artesian head in this area, although this has diminished substantially during the pastoral period. This has possibly resulted in diminished spring flows, but this is not evident from the sparse historical record.

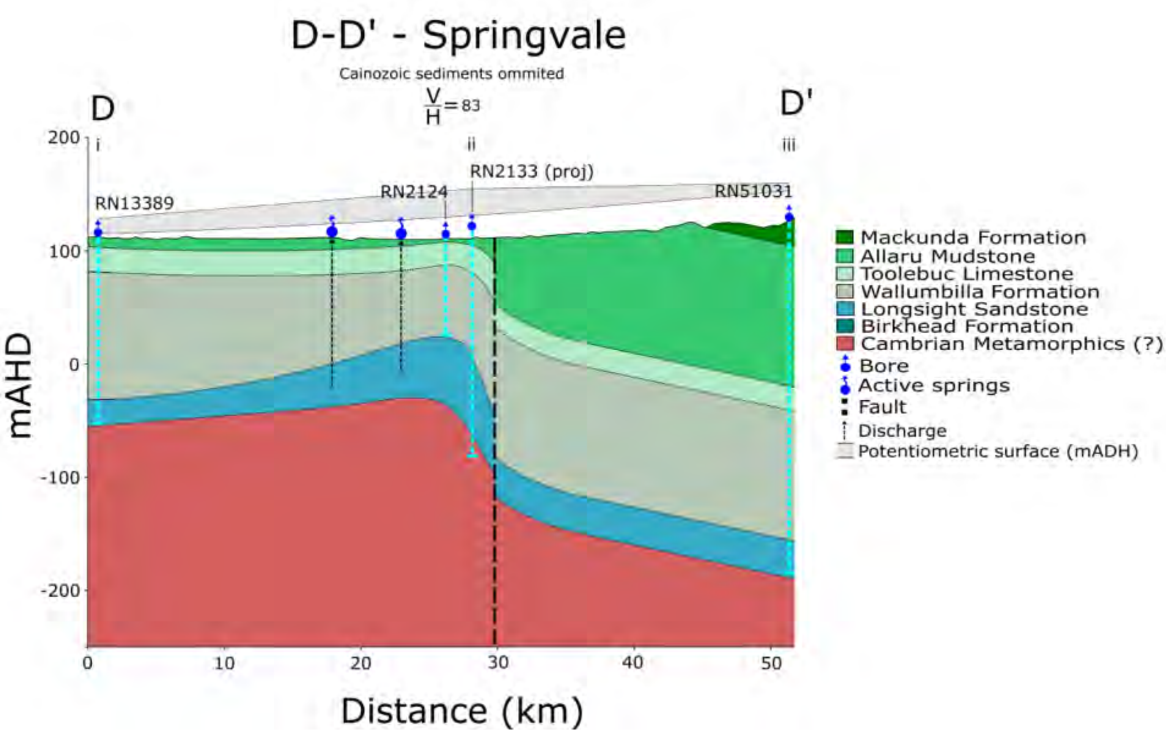


Figure 78. Stratigraphy through Springvale discharge springs (see D-D', Figure 72 for location).
Where bores are projected onto the stratigraphic line the difference in elevation is indicated by the position of the bore symbol in relation to the ground surface. The range in the potentiometric head over time is represented by the limits of the grey bar and the roman numerals indicate the location of the bores that inform the head. i: RN13389, min. date 2001: SWL 2.06, max.date 1957: SWL 17.61; ii:RN2123, min.date 1973: SWL: 11.88, max.date 1987: SWL 36.27; iii: RN51031, min.date 2001: SWL 23.69, max.date2010: SWL 29.66.

5.3 Historical record

The ill-fated Burke and Wills expedition passed just to the west of the Springvale supergroup in 1861, on their rush to cross the continent. It was left to a less famous but more enduring explorer, the indefatigable William Hodgkinson, to provide the first written description of springs in this group. Hodgkinson had started on the original Burke and Wills expedition and later joined John McKinlay's search party for the doomed explorers, before later leading his own expedition to report on the pastoral potential of the Diamantina and Georgina River country.

Having crossed the rugged mountains south of Cloncurry, he was travelling south over the grasslands east of Boulia when, on 13 May 1876, he described a group of springs west of the Hamilton River. These were probably the now-extinct Momedah Springs, although it is difficult to locate his camp precisely:

> *Three miles NNE from this camp passed a group of springs; some dormant, clogged up by the mounds of earth formed by their sediment; some active and pouring out considerable supplies of water, abundance of which, undoubtedly permanent, was in the vicinity; and this, combined with the magnificent feed clothing the rolling downs bordering the creek, formed a fine site for a station.*

J. Alfred Griffiths visited most springs in the Springvale supergroup in 1896, and his field notes provide by far the most detailed record of springs prior to bore drilling (Table 13). They contain especially detailed descriptions of Elizabeth, Warra, Mt Datson and the Warenda Springs, including flow rates, modifications and improvements, accompanied by sketch maps (Figure 79). They are the only record of many now-extinct springs.

Table 14. Springs described by J. Alfred Griffiths in Springvale Supergroup, 1896, and their current status (springs appear in north to south order in table).

Spring	JAG description, 1896	Current status
Pathungra	… cover about one acre of ground with many openings. Three shafts and wells have been sunk to assist the flow and one gave about 20,000gpd… Some springs had been tapped by wells or shafts, and they once watered up to 4000 cattle during periods of drought.	All inactive; scalded area west of river channels with abundant Aboriginal and European artefacts
Mommedah	'There were originally several wet places on which wells were sunk. Now the springs are tapped by bore….'	All inactive; extensive scalded area with many artefacts
Donkey	'…half a mile east of the Mommedah Springs on the mid-channels. A well had been sunk in 1889 and a slabbed drinking hole was formed, but the yield was never tested owing to the break up of drought…'	Inactive; assigned to area of scalded ground with some old fencing in channels, but difficult to locate precisely
Hamilton River springs	'From Donkey Springs for about 8 miles down the river there are springs at intervals of quarter to half mile, mostly in the eastern channels, some merely damp places and others mud springs many of which are fenced around to prevent cattle bogging. Some overflow into waterholes in channels, and others appear as a small permanent pool at the bottom of an otherwise unpromising sandy channel.'	All inactive; hummocks and depressions on extensive scalded country along river, which may be old springs
Palparara	'Springs which overflow into a large permanent waterhole in the most easterly channel. The largest hole has been enlarged by a well about 15 feet deep and its yield is estimated at about 7000gpd. Other springs extend about 2 miles south (some being slabbed and fenced) and end in a group of large mud craters some of which have now caved in, being apparently drained by the proximity of bore number 2, about half a mile further south.'	All inactive; there was a metal tank amongst the Tea Trees in the Hamilton Channels which was known to Bill Cameron as the Palparara spring. It has not flowed in living memory. Large mud-craters to south have not been searched for.

Spring	JAG description, 1896	Current status
Boundary	'…a small spring…which will supply enough water for a man and his horse, say about 20gpd'.	Scalded with humps and hollows, but no groundwater indicator plant species
Mt Datson	'All over the area are mud springs and swamps…total supply 1000gpd; [second black ¼ mile south:]…with the drains in good order, this block is stated to have yielded about 20,000gpd…[third block, a strip of drained springs:] 16,470gpd.'	15 active vents documented over 1.1km, but flows much-reduced
Bulla Bulla	'The line [Mt Datson Springs] ends north of the river at the Bulla Bulla Spring close to the Winton-Boulia Rd which has encouraged the growth of a scrubby timber patch of several acres… Several of the Bulla mud craters emit small trickles of water but they soak into the surrounding sand before reaching the adjoining waterholes.'	Inactive; thickets of *Callistemon* sp. and clear signs of groundwater activity in this area, but no concentrated discharge areas with surface water that qualify as springs.
Reedy	'About half an acre is fenced at the main spring which has been drained by a ring and cross drains and a tank has been excavated to store water. At present however all the water runs down the centre channel directly to the creek… flow of about 5000gpd [20,000gpd when spring cleaned out]. Close south of the fence are several large mud craters which stand up several feet with nearly vertical sides. A small patch of bog beyond is fenced to keep out cattle. Faint trickles of water issue at these places from this. About one quarter mile south is a large peaty crater of bog covering one or two acres and swelling 3-4 feet above the plain…'	The main Reedy Springs is still active and forms a circular wetland about 30 m in diameter; other springs are inactive.
Tea-Tree	'…on a small claypan plain between the Bunda and Horse Creeks, and about 2.5 miles from Reedy Springs. Nearly 4 acres are fenced in extending about 18 chains north from a main channel of the Horse Creek. Several small trickles of water run from the northern end of the block but not measureable. At the southern end the flow is greater…I estimate between 1000 and 2000gpd. The swamp close to Horse Creek has standing pools of water several feet above the level of the main waterhole.'	Inactive springs located within a large area of tufa (100 x 30 m); evidence of old trough, fence-posts and a well as mapped by Griffiths. Water appeared at bottom of well in about 2000
Little Tea-Tree	'…about 9 acres are fenced mainly to exclude cattle, as the hot flow is too small to be utilized conveniently. In a drought the water is only sufficient for a small camp.'	Just active: two patches of boggy ground without free water; old fence still evident.
Unfenced Mud	'No use is made of these springs, and they are full of cattle bones from beasts which have died or been bogged in seeking water.'	Inactive; align with scalded flat; no sign of spring activity.
Furlong	'…a small line of unfenced mud and water springs (extending 1 furlong by 170 degrees)…No use is made of these springs, and they are full of cattle bones from beasts which have died or been bogged in seeking water.'	Active: continuous line extends for about 90m + numerous outliers; springs wobble and are vegetated by *Cyperus laevigatus*
Warra Warra	'…for half mile to the south east the ground is full of mud and water craters, the most remote of which are fenced in and stand on the edge of a vast clay pan.. principal fence encloses about 2.5 acres, and other small bogs of a few perches each are also fenced…Only a trickle of water was flowing into the tank, the bulk escaping in many directions in small dribbles. When the drains were cleared there was a strong flow from the gravel and boulders at a depth of about 4 feet… yield estimated 7000gpd was obtained.'	Active, feeding a wetland vegetated by *Cyperus laevigatus* 10 m x 8 m. Although diminished from Griffith's day, has been constant for past 50 years; infrastructure described by Griffiths still clearly apparent. Mud springs to the north are inactive.
Elizabeth	[Very detailed description and maps, but total flow rate estimated as 53 Litres/second]	Many active vents; total flow rate estimated at 36.4 L/s in 2008, (has increased since bore capping)

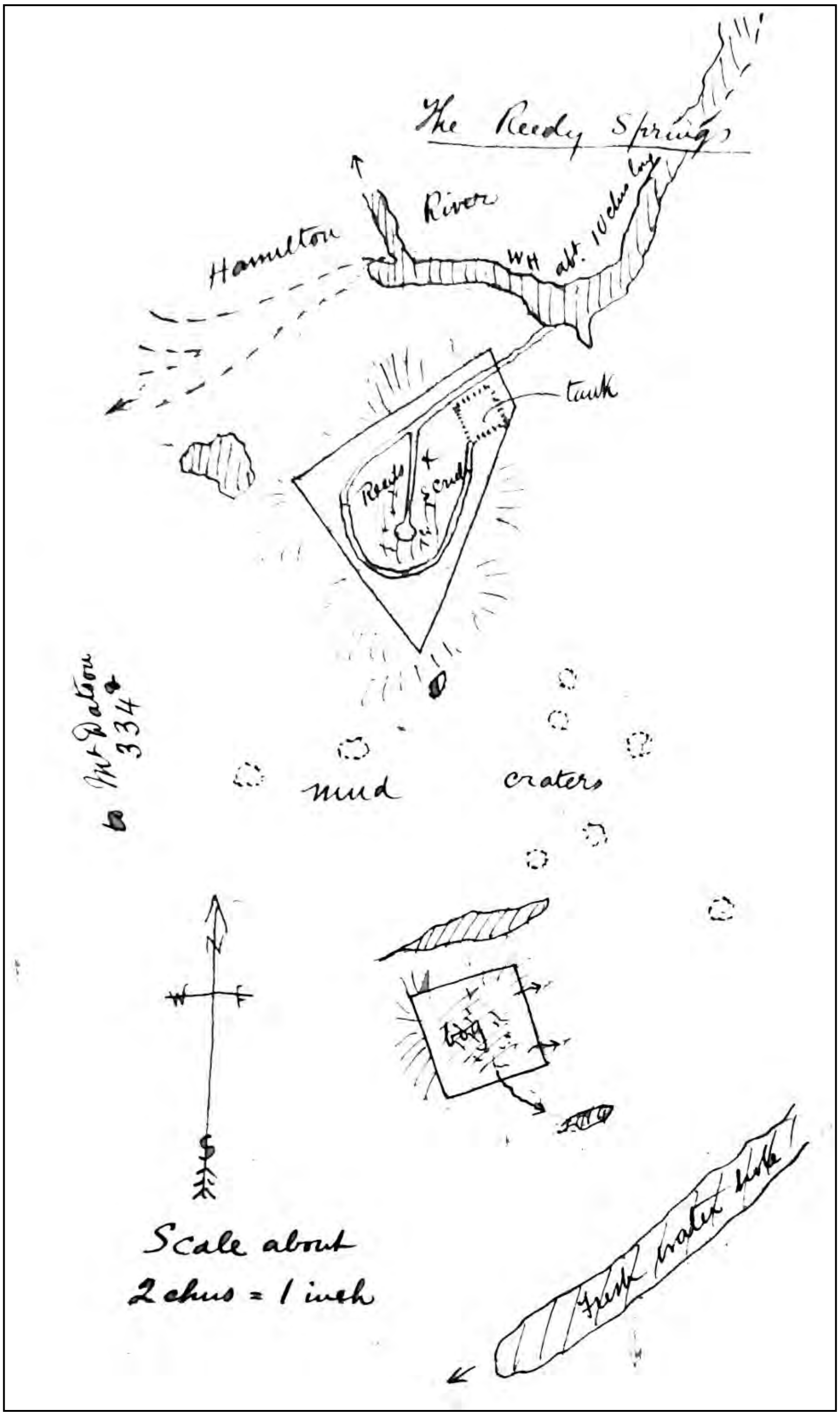


Figure 79. Hand drawn map of the Reedy Springs by J. Alfred Griffiths showing the bog, mud craters and main Reedy Spring feeding into a waterhole.

Griffith's descriptions are the first detailed record of Elizabeth Springs. He sketched the group of vents (Figure 80), described the general characteristics of the mounded springs, measured the flow rates from drains which had been dug from several mounds (609,240 g.p.d) and estimated that:

> '*the total flow is not far short of 1,000,000 gallons daily [4.546 ML/day]. In their original natural state the surplus water ran down the creek about 3 miles…By cutting drains*

through these obstructions [hummocks of sandy peat 2-6 foot high] the lessee has so economised the flow that the stream now runs when required in dry seasons, about 20 miles or more down the creek and fills the lagoon opposite the head station.

The work of one man is required continuously to keep the channels clear, but recent rains has rendered this unnecessary and at present the water flowing just above the station was a mere trickle of about 1000gpd, where with clear channels and creek bed the stream is stated to have a section of about three-quarters of a square foot after running 18 or 20 miles over limestone country.

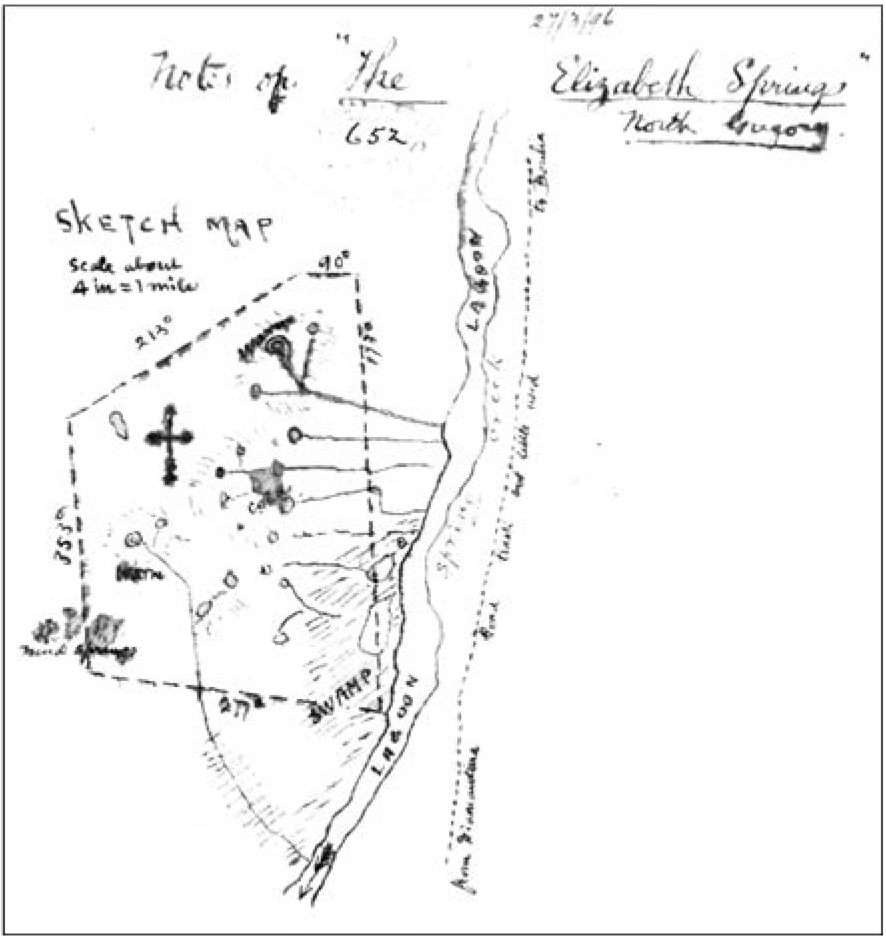


Figure 80. Hand drawn sketch of the Elizabeth Springs by J.Alfred Griffiths from 1986. Note the numerous springs that drain into the lagoon and Spring Creek.

From these descriptions it is evident that the original Elizabeth Springs had a substantial discharge, but the distance of the outflow down Spring Creek was clearly dependent on concerted maintenance of the artificial drains. Other estimates that suggested that the flow from Elizabeth Springs initially ran Spring Creek about 80 miles (Whitehouse, 1954) or 40 miles (David, 1950) probably reflected the artificial enhancement of outflow with well-maintained drains.

Only four spring groups are marked on original survey plans, drawn around 1890: Bulla Bulla on plan G250.49, Mt Datson (Pikes) on plan G250.137 (Figure 81), Elizabeth on plan G250.49 and Black Eye Spring on plan G250.67. The 4 mile map series, drawn around 1920, show Coorabulka and Pigeongah (4 mile series 12A; Figure 82), Palparara and Black Eye Springs (both on map 12C). The old plans were also useful in aligning the blocks and boundaries recorded by Griffiths in describing the location of the springs, even where springs were not marked.

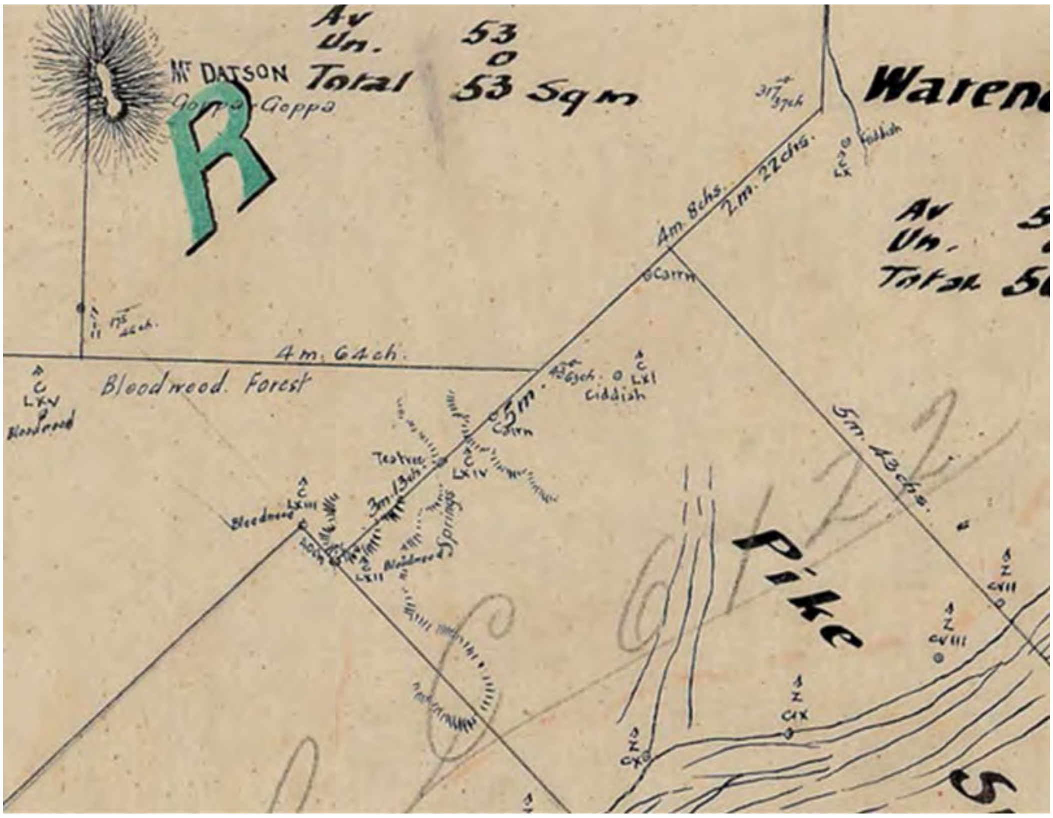


Figure 81. Survey plan G250.137, showing springs south-east of Mt Datson (Goppa Goppa) springs on Block Pike Springs.

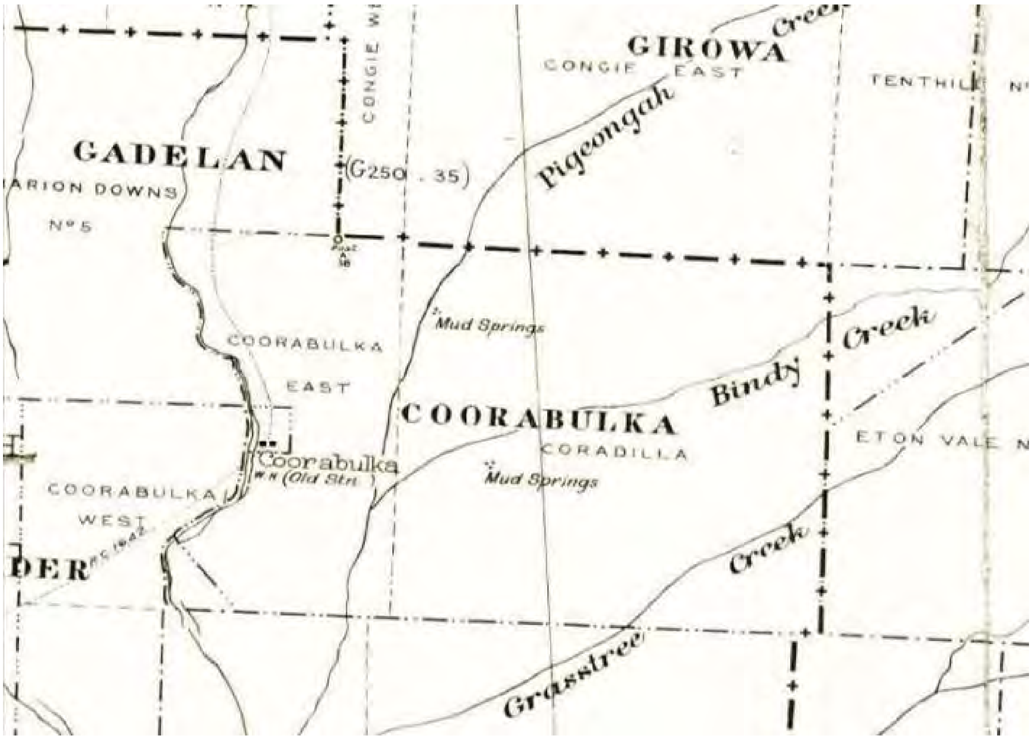


Figure 82. 4 mile series 12A (circa 1920) showing two groups of mud springs on Coorabulka. The northern group are Pigeongah Springs; the southern group below Bindy Creek are Coorabulka Springs; both groups remain active.

5.4 Cultural history

5.4.1 Aboriginal history

For thousands of years, the Pitta Pitta and Maiwali people called the area east of Boulia home, and their lives were centred on reliable sources of water. Early Channel Country pastoralist and writer Alice 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’ (1934:49), and no doubt the springs were as important to the Pitta Pitta and Maiwali as the Saharan oases are to the Bedouins and Berbers.

Aboriginal people had an encyclopaedic and intimate knowledge of waters, including their location, permanence under various conditions, quality of water, likely extent of flooding and so on (Brim-Box et al., 2008). In the Channel Country, elders drew ‘sand maps’ – huge drawings covering an acre or more, which they drew on cleared sand patches outside their gunyahs for the instruction of children (Duncan-Kemp, 1934). Waterholes, springs and wells were features 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.

Coorabulka, Pigeongah, Warra Warra, Bulla Bulla, Palparara, Mommedah and Pathungra preserve Aboriginal names but the stories and significance of the springs for Aboriginal people have mostly been lost. Stone tools around the springs, including grindstone fragments and base-plates, axes, flakes and cores, remain as mute testament to long occupation (Figure 83, Figure 84). There are artefact scatters at all springs in the Springvale supergroup, with particularly high densities recorded at Coorabulka, Pathungra, Mommedah and Warra Warra springs. A more thorough investigation of the surface archaeology around the springs would inform a deeper understanding of the patterns of Aboriginal occupation of the Channel Country, adding to the detailed work of Simmons (2007) at nearby Diamantina Lakes.

This dense surface archaeology hints at the importance of springs to people over millennia, as refuges during dry times, nodes on travel and communication routes, and meeting places. Prior to European settlement, the Lake Eyre Basin was intersected by routes of trade, exchange and communication (McBryde, 2000). The Georgina and Diamantina Rivers were both well-used trade routes, and the springs provided vital stepping-stones between the two rivers. According to ‘Bowyang Bill’, writing in the Narromine News and Trangie Advocate, ‘In the old days before ‘white feller been come along’, Elizabeth Springs was a favourite meeting place for aboriginals from the far north-east, who traded in pituri with the more southern tribes’ (15 March 1935, p.6). Large volumes of this desert narcotic, *Duboisia hopwoodii*, were traded from the Mulligan River on the eastern edge of the Simpson Desert to the north, east and south (Silcock et al., 2012), and reliable water sources 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 (Watson, 1983).

In May 1876, explorer William Hodgkinson encountered a group of 30-40 people west of the Hamilton River near a group of permanent springs, possibly Mommedah Springs (see description above). The country was showing signs of drought and people were congregating around the few remaining permanent waters:

> *…Tracks of natives numerous and fresh, the shells of mussels which form an important article of their diet, and heaps of portulac stacked ready for beating out the seed, lying in every direction…*(Hodgkinson 1877, 13 May 1875)

These people were less than happy about the intrusion of the white men and seemed poised for ambush, although the encounter ended peaceably. In a pattern repeated across Australia, Hodgkinson passed through the area without conflict (and was even rescued by a local man while flailing in the flooded Diamantina a couple of weeks later), but the subsequent permanent incursion of pastoralists and their cattle onto precious springs and waterholes from the 1870s inevitably led to conflict. Numerous massacres occurred throughout the Channel Country, although details are usually shrouded (Watson, 1998). Other people succumbed to disease, mostly venereal, starvation or were removed to missions including one established in 1902 on Whitula Waterhole near Windorah in an attempt to ease the suffering of Aboriginal people who, deprived of the physical and spiritual nourishment of their traditional life, were starving and dying of disease in the Federation Drought. By the 1890s, only small camps remained of originally large populations (Duncan-Kemp, 1934; Tolcher, 1986) and waters in the Channel Country had become 'orphaned' and were said to be crying out in pain (Duncan-Kemp, in Watson 1998).

In 1935, The Sydney Mail reported on the 'mystery springs' and their purported Aboriginal mythology:

> *About fifty miles south-east of Boulia township, in the far west of Queensland, are two mystery springs. Situated only a few yards from Spring Creek, a tributary of the Hamilton River, these springs are two of the most remarkable in Australia. One, which is known as Elizabeth Spring, consists of a circular hole four or five feet in diameter in which tepid water is continually bubbling up and overflowing into Spring Creek. The water, which is perfectly clear, is peculiar in that the human body cannot sink in it owing solely to the force of the water bubbling up from below. About fifty yards from this spring is another called the Lubra Spring. Consisting of another circular hole between four and five feet in diameter, this spring is exactly the opposite to the Elizabeth Spring, for its water is always icy cold and is of a jet black colour. The human body sinks like a stone in it. According to the aborigines of the locality, the water in this spring turned black ages ago when a lubra jumped into it and was never seen again!* (7 August 1935, p.2)

By this time, there were few Aboriginal people visiting the springs and this story likely represents a simplified and possibly misinterpreted fragment of a once rich, complex cosmology in which the springs were a central part.


Figure 83. The now-extinct Mommedah Springs, near where explorer William Hodgkinson saw a large group of people in May 1876 (left), and stone tools found near another spring (right).

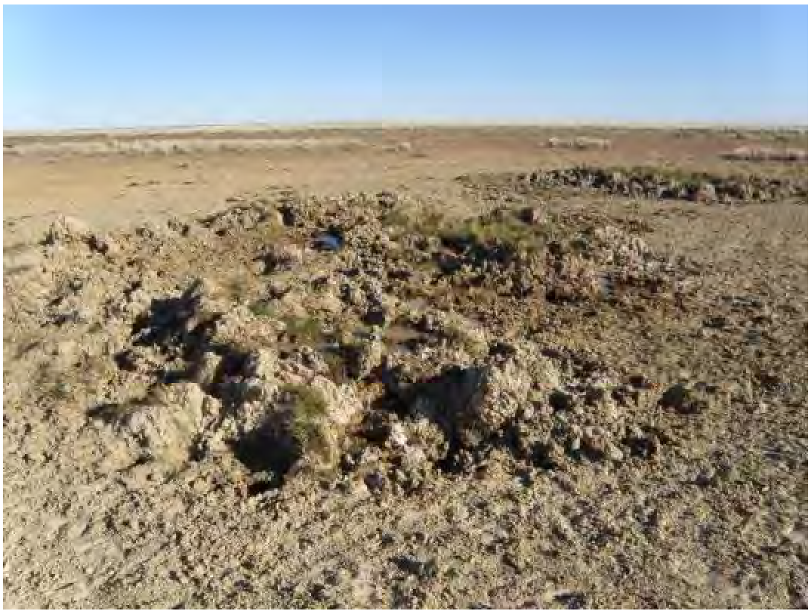


Figure 84. Despite being tiny ponds on vast treeless plains, lying >5 km from the nearest source of water these springs (left) were well-visited by Aboriginal people, as evidenced by many stone flakes and half of a large grindstone baseplate (right).

5.4.2 European history

Springs provided the only source of permanent water in the 8000 km^2 area encompassed by the Springvale supergroup, and quickly became vital for the pioneer pastoralists as they had been for Aboriginal people. With the exception of the permanent Bulla Bulla and Warracoota Waterholes on the Hamilton River and Spring Creek respectively, and the semi-permanent Old Station Waterhole on King Creek, there is no lasting water between the Diamantina and Georgina River except for the springs (Silcock, 2009).

Out of necessity, springs were a focus of early pastoral settlement. This is evidenced by the remains of huts, wells, yards, iron, bricks, glass, tanks and troughs at most springs. The remnants of an impressive stone wall on Blackeye Creek can be seen at Blackeye Spring (Figure 85), the most northerly spring of the Springvale supergroup on the eastern slopes of the Selwyn Range. Griffiths' notes about 'improvements' made at all large springs, especially the Mt Datson, Warenda, Warra and Elizabeth groups, show the reliance on these waters (Figure 86). All had extensive networks of drains cut to direct flow into excavated pools and improve access for stock. At Elizabeth Springs a man was engaged for the specific duty of maintaining the groundwater supply and its delivery through a network of drains (Figure 80).

Figure 85. Remains of overshot wall on Blackeye Creek, Answer Downs (right).

Figure 86. Well in tufa at Tea-Tree Spring, Warra (left), and remains of small earth tank (now dry) described by Griffiths at Warra Warra spring (right)

Stock routes and roads followed the lines of major rivers and springs where water could be found for horses and travelling stock. The 'short-cut road' from Brighton Downs on the Diamantina River west 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 to Elizabeth Springs, and meet the 'short-cut road' 20 miles from the Hamilton Channels. Newspapers from the 1880s contain information for travellers on the availability of water and grass, and highlight the importance of springs as stop-overs. For example, the Morning Bulletin reported on 17 January 1884 (p.3) that:

> *Starting from Boulia, the first water is at Warenda Station, on the Hamilton, thirty-five miles…From Warenda to Warroo-Warroo Springs, about eight miles; from there to Elizabeth springs, about twenty two miles; no water between. Here a lot of carriers are waiting for rain to enable them to reach Boulia…*

Travel to the springs did not have to be confined to the utilitarian, however. Railway Commissioner Mr Evans enthused that Elizabeth Springs 'will be a resort for many travellers when the facilities for reaching there are provided by means of the great Western railway' (The Queensland Times, 15 December 1911, p.7). A town was surveyed at the springs, which was intended to be a health resort where guests could bathe in the salubrious spring water (Bode, 1929). The survey plan and first 20 miles of rail line from Winton were as far as this plan progressed, presumably interrupted by both World War I and practical considerations.

Over time, a local mythology built up around the springs, involving tales of outlaws and close calls, weightlessness and strange lights. As with Tertiary springs hidden in the hills (Section 9), the more remote springs could as well be used by shady characters escaping the law as honest yeomanry of the frontier. In the 1890s, the Morning Bulletin reported that a gang who had robbed the Mayne Hotel and stolen horses were:

> *…evidently piloted by a man who knows every inch of the wild range country that extends on the other side of the Lower Diamantina, between Brighton Downs and Boulia, as those on their tracks (twelve days old) found that they had watered their sixteen horses at a spring in the ranges in the Warenda country, to which only one horse at a time could be led down, and after all the horses had been watered they had gone straight to another spring four miles away, and there camped. They stuck up Cluny Station, and helped themselves, and the manager made a try after them, but with only one revolver in his party he could not do otherwise than return when warned off by the desperadoes armed with Winchester rifles* (29 October 1894, p.5).

This may refer to the elusive 'Pot Jostler' spring, which is marked on survey plans and was searched unsuccessfully for in the hills on Braeside (part of Brighton Downs), or perhaps another forgotten spring. A now-extinct mud-spring on Warenda proved the saving grace of a contemporaneous but more law-abiding traveller, mounted policeman Mr R. Buffham. Travelling with a 'new chum' jackeroo to Boulia in drought conditions in 1884, the pair decided to take a short cut:

> *They had hoped to find water at one of the Warenda wells, but it was dry. Pushing on, with the thermometer at about 160 in the sun, they encountered a terrific dust storm. After it subsided they tried to go on, but after a few miles the jackeroo turned it up. He laid down under a tree and refused to budge. Buffham set out and followed a bit of a creek. After a weary tramp he struck a mud spring and water. When he came back to the jackeroo he saw him running away as hard as he could foot it, his clothes scattered over the plain. After a hard chase Buffham ran him down* ('Death of an Old Identity', Western Champion, 7 March 1908, p.9).

Perhaps tired of such close calls and privations including Gulf fever, sandy blight, Barcoo rot and encountering so many weevils in his flour that he had to tie it down, Mr Buffham resigned from the police force and set up a soap-making business at Jericho. At the time of his death he was the caretaker of the 18 Mile Tank near Longreach.

Springs were not always seen as life-giving oases. A 1936 article by 'Syd Swagman' in the Sunday Mail was somewhat histrionically titled 'Mud Springs Are An Enigma of the West; They Clutch More Fatally Than Quicksand'. He paints the mud springs as fearful sucking death-traps for man and beast:

> *…At the Hamilton River, which at this spot is five miles wide and broken up into about 40 different channels, the springs are irregularly spaced over an area of about 100 square miles. In appearance they are just rough mounds of mud and stones, anything from two to 20 feet in height. Riding over the mud spring country one comes upon what appears to be an innocent mound, often enclosed in a rough barbed-wire fence. Inside the fence may be seen the blackened skull of a horse or bullock, or perhaps a thighbone protruding from a crust of dried mud. These are the victims of their own unwariness. If one should venture inside the fence, the thin crust of mud would give away, and one would find himself in a clutch more fatal than quicksand. Stamp on the ground outside the fence and the mound inside will shake like a huge jelly. The spring is bottomless; the suction, tremendous. An animal walking on to the mound disappears in a few minutes,*

> *and months, or even years after, the bones will work to the surface and lie there as grim warnings…* (Sunday Mail, 26 July 1936, p.26).

The strange properties of the water-springs were also much remarked upon, particularly the 'mystery springs', part of the Elizabeth Springs group: one was clear, warm and buoyant, while in another barely 50 yards away 'the human body sinks like a stone' in the cold black water (Sydney Mail, 7 August 1935, p.2). This story was recounted in W.H. Corfield's reminiscences, published in the Townsville Daily Bulletin:

> *This spring was a circular hole of about three feet in diameter, in which warm water was continually bubbling up. The overflow ran into Spring Creek, and ran for 15 miles, emptying into a large hole opposite the head station. A peculiarity of this spring was that if one jumped into it the force of the water caused the body to rebound like a rubber ball, and small particles of sand coming up with the water caused a stinging sensation. The depth of the spring was unknown. About 40 yards from this spring there was another hole, the water of which was quite cold, and of an inky colour. This hole had attributes opposite to the other, that is, a body will sink quickly in its water. The blacks had a tradition that a gin jumped into it and was never seen again* (4 May 1954, p.5).

The extraordinary buoyancy of the former spring features in numerous articles from the 1920s, including in The Capricornian, whose source had apparently sacrificed a three-year-old child to test the waters:

> *It is generally known that salt briny water is, because of its density, much more buoyant than fresh water. Elizabeth Springs, within the boundary of Springvale Station, near Boulia, Central Queensland, is making a strenuous endeavour to upset that theory, for the water in this small though deep lake is free from brine and fit for household use, but it is impossible for a swimmer to sink in it. As the accompanying photograph shows, persons can float in the water with comparatively little of their bodies submerged, and a three-year-old child who was thrown into the lake bobbed about on the surface of the water like a cork…(*22 May 1920, p.32).

These feats of buoyancy are captured in a photo from the early 1900s (Figure 87). Not surprisingly, visitors were not as keen to test the purported more sinister properties of the black spring:

> *The Commissioner for Railways (Mr. Charles Evans) and the chief engineer (Mr. N.G. Bell) returned last night from their adventurous tour in North West Queensland… Mr. Evans referred in terms of high admiration to the attractions of a place called Elizabeth Springs. There are a large number of warm-water springs, said to be very deep, and in, some cases there is some influence at work from underneath that makes it impossible to sink in the water. Members of the party jumped in, feet fore most, from a bank, but they could not penetrate the water for more than a few feet. The Hindoo in charge of the springs, pointed to one spring, where the tendency was to draw down any object that was in the water. Needless to say, there was no inclination to test the remarkable power of this spring* ('The Railway Commissioner: Return from the North-West, An Adventurous Trip', The Queensland Times, 15 December 1911, p.7).

Figure 87. An excavated pool at Elizabeth Springs provided the setting for Dead Sea-esque feats of buoyancy, much-remarked upon in newspapers and travellers' reports.

Even more mysteriously, the springs – or more specifically the gases liberated from them – were invoked to explain the archetypal Channel Country mystery: the Min Min or Warenda Light (Pettigrew, 2003). The Sydney Mail reported:

> *This thing frequents the Hamilton channels about fifty miles from Boulia, Western Queensland, and it may be seen at any time, or may disappear for months and months. At that crossing the Hamilton River is about five miles wide, with something like 45 channels, and some miles farther downstream there are the famous mud-springs, scattered about at irregular intervals over perhaps an area of a hundred square miles. This light, a luminous greeny ball of fire — or so it seems — appears to float from three to ten feet above the ground, moving erratically, and when-seen for the first time, and after the possibility of car headlights is dismissed, the spectator's thoughts automatically swing to the supernatural — at least, mine did when I first saw the thing at 2 o'clock on a winter's morning. The explanation, superficially, would appear to be luminous gases liberated from the mud springs. Deeper than that I dare not go…More likely than not it is a cousin to the will-o'-the-wisp of English marshes, though it would seem strange to find a dancing light transplanted from the wet marshes to that area of eleven-inch rain fall* (11 March 1936, p.2).

The manager of Warenda encountered the Min Min light while riding near Slasher's Creek on a winter's evening in 1912, and provided a vivid description of his experience in the Longreach Leader on Friday 13 May 1949. After scathingly discounting the popular theory of luminescent fungi, he also attributes these ethereal phenomena to the mud springs and references the English will-o'-the-wisp:

> *Without trying to deal with any other hypotheses here's my idea for what it's worth. That's the country of mud springs. From memory, and within 20 to 50 miles, there are dozens of mud springs. I really must tell you about them some day, if I haven't already done so. There are the Tea Tree Springs, Pike Springs, Palparara, Pathungra, others in numbers. All these fellows emit gas. I've smelt them. At some seasons they're more flatulent than at others. That is the area of shallow flowing bores - big flows and not one of them 500 feet deep. These fellows are all gaseous. I don't know if that gas is inflammable, self-igniting. I don't know and I've never seen an English will-o'-the-wisp. That ball of light, I understand, floats off marshy places which emit inflammable gas. If I were guessing, and this is only a guess, I'd say that Min Min Light is a first cousin, if not a closer relation, of an English will-o'-the-wisp: I was satisfied to see it go out and leave me the time I refer to; now I'm older I'd like it to come closer if I was granted a second look at it* (13 May 1949, p.13).

Despite their utilitarian value and fascination, both scientific and mystical, the springs did not always provide sufficient and accessible water for thirsty stock in a dry land, as lamented by the Morning Bulletin:

> *Herbert Downs, 45 miles distant, is quite deserted, and they have rented some country on Warenda, where the springs were supposed to be permanent, but after watering about 10,000 of their cattle for some weeks, the supply was found to be insufficient…* (7 December 1892, p.12).

They did, however, provide evidence of a vast groundwater resource below the feet of the fledgling pastoral industry. An 1892 article in the Queensland Country Life by B.H. Purcell reported on attempts to secure a reliable water supply on the Warenda Run:

> *Large dams and tanks were put down at heavy expense with varying success, the wet season being most unreliable. Eventually [Warenda owner] Mr. Wienholt determined to try boring for artesian water, being fully convinced by the nature of the country that he would strike it anywhere. How far his judgment proved correct will be shown by the phenomenal success of his undertaking* (26 November 1892, p.1052).

Early bores were drilled on or near springs, where a groundwater supply was assured. Purcell describes Mommedah bore, which was sunk on a spring in the early 1890s. It discharged 19,160 gallons per day and kept a large waterhole full. He then rode past the ‘famous Palparara springs’, but his eyes and imagination were fixed firmly on the bore to the south, which had no doubt sounded death knell of the springs:

> *As we rode down the river we passed the famous Palparara springs. These fine springs were opened out to supply the stook during a drought, and nobly they did their work. A few miles further on we suddenly saw a white column like ice reaching to the ground. This was Palparara bore…When the supply rose to 70,600 gallons (temperature, 84 deg.) the bore was taken down another 19ft. The sight of the water falling in sparkling spray made us long for a shower bath. The spot being secluded, we were not long in taking advantage of the opportunity…The water struck us with considerable force. This fine stream runs into a waterhole about two and a-half miles long, and keeps it always full* (Queensland Country Life, 26 November 1892, p.1052).

The springs had done their work admirably, but were the signpost for their own demise. Purcell continued on his grand bore tour, past No. 3 bore on Polygammon Creek (at 14 000 gallons per day running the creek for some five miles), Slasher’s Bore (creating a vast lake and flowing stream), and finally Bunda No.6 bore, its 1,015,025 gallons per day appearing ‘as a column of ice from the distance…the water falls with a deafening thud upon the stones round the casing. On it rushes in one endless stream, clear and sparkling’. This supply flowed into the Hamilton where it was joined by the Slasher Bore water, making in all thirty and a-half miles of running stream!

Purcell describes the downs as a pastoral paradise filled with contented beasts and seas of grass moving in a ‘heavenly’ afternoon breeze in the shadow of ‘solemn, stately’ Mt Datson (Cuppa Cuppa or Goppa Goppa to the now-vanished original inhabitants of the country):

> *Things are changed for them [the cattle] since boring began. Water, pure and fresh, is always there; bogging is a thing of the past; no longer do they rush, maddened with thirst, into small muddy water- holes. Driving round the face of the dam we came to the bore, ever flowing. What a sight! Could some of the old explorers but visit these changed scenes, they would wonder where they were* (Queensland Country Life, 26 November 1892, p.1052).

Ultimately Purcell arrived at Horse Creek, where the boring plant was hard at work, driven by an experienced Canadian named Beldon. Asked about the likelihood of the bores giving out, Beldon replied: ‘No, no, there is not the slightest chance of that happening…with bores as far apart as these there is not the slightest chance of the water supply failing in the smallest degree.’ The boring plant continued to move rapidly around the Run, until Warenda, Goodwood and Fort William had realised the owner’s vision of forming ‘one of the grandest watered properties in Queensland’. Graziers had for decades been forced to rely on rain and scant natural waterholes; now stock could utilise the virgin pastures of the back country even during dry times. The bores fed dreams of irrigation, and even general improvement in ‘climate, rainfall, temperature and healthiness’ of the country due to the presence of flowing water.

Henry Lamond, a former manager of Warenda, enthused in an article titled ‘Paradise Pastures’ in The Queensland Country Life: ‘I know no part of Queensland where water is so shallow, so cheap to obtain, in such quantities, and of such excellent quality. No, sir. I do not!’ (10 September 1936, p.6). He did mention the springs, but they were clearly of secondary interest to the remarkable shallow flowing bores:

> *In that country, of course, are the famed Elizabeth Springs, on Spring vale; the not so famed Ti-tree Springs, on Warenda; mud springs here and there, flowing, wells of a scant 20 feet in depth and one bore, which I had put down, under my management on a station in that area, and which struck flowing water at 14 feet…On the eastern side of the Hamilton, particularly, a man gets flowing bores at post-hole depths. I think, and I'm pretty sure in this, that the deepest bore on Warenda on the eastern side of the Hamilton, is under 500 feet. Flows range from a dribble to a quarter of a million a day. Some, I understand, have gone hack now and have to be pumped. What of it? When a plant can complete a bore in four days – as I had done there – what is the cost in gallons of a water improvement of that sort?*

The springs had been useful for a short time, but could not compete with towering fountains of bore water bursting forth from the plains. The springs had rapidly become mere footnotes in the development of the Channel Country plains.

5.5 Biological values

The springs in the region have greatly reduced flow rates and many are extinct, suggesting that there may have been substantial local extinctions, including of specialised organisms that will never be known. Elizabeth and Reedy springs are the only two surviving wetlands that contain endemic species in the Springvale supergroup (Figure 88). Elizabeth Springs is the most important site for conservation in the Springvale Supergroup, and indeed one of the most important sites in the Great Artesian Basin and inland Australia. The open water pools are the habitat for the Elizabeth Springs goby (*Chlamydogobius micropterus*), a small fish known from no other locality. Two other species also occur nowhere else: the snail *Jardinella isolata* and *Isotoma* sp. (Elizabeth Springs R.J. Fensham 3676.), that we maintain as the non-endemic *Isotoma fluviatilis* until circumscription. *Isotoma* sp. (Elizabeth Springs R.J. Fensham 3676.) occurs at five springs spread over about 300m, with an estimated area of occupancy of 65m2 and population size of about 500 plants, and if recognised as a species should be listed as Endangered (Silcock et al., 2014).

Utricularia ameliae is only known from Elizabeth Springs, where a conservative population estimate is 500 plants. A *Utricularia* also occurs at Reedy Springs to the north that is probably this species, but it has not been recorded in flower. The robust perennial grass *Eragrostis fenshamii* is only known from Elizabeth and Reedy Springs, and Yowah Creek and Masseys Spring in the Eulo supergroup. Elizabeth and Reedy Springs also contain the only Queensland populations of the glabrous form of *Eriocaulon carsonii*, which is also known from GAB springs in South Australia. Reedy Springs contains a snail related but distinct from the *Jardinella* at Elizabeth Springs (*Jardinella* sp. AMS C.447677). Elizabeth Springs also contains disjunct arid-zone populations of widespread wetland grasses *Cenchrus purpurascens* and *Phragmites australis*.

Figure 88. Distinctive species from Elizabeth Springs (clockwise from top left: Elizabeth Springs Goby (*Chlamydogobius micropterus*), snail *Jardinella isolata*, *Utricularia ameliae* and *Isotoma* sp. (Elizabeth Springs R.J. Fensham 3676.).

Coorabulka Springs is the reference locality of groundwater scald indicator species *Trianthema* sp. (Coorabulka R.W. Purdie 1404) (Figure 89), and both Coorabulka and Pigeongah Springs to the north contain disjunct populations of *Cyperus laevigatus*. There are active and inactive bilby burrows and feed scrapes at Coorabulka Spring, although this is related to the calcrete substrate being preferred for burrows rather than the presence of springs (McRae, 2004).

Figure 89. Large pink hummocks of *Trianthema sp*. (Coorabulka R.W. Purdie 1404), reaching its zenith amongst *Cyperus laevigatus* at its type locality, Coorabulka Springs.

5.6 Key threats and management

The extinction of so many spring wetlands in the Springvale Supergroup highlights the importance of Elizabeth and Reedy springs, as the only surviving springs containing endemic species. Both sites are fenced from pigs and livestock, although the fence at Elizabeth Springs was breached in 2013 and heavily trampled by cattle. The lack of disturbance is of some concern for the persistence of the goby and the free water pools need to be monitored and management adjusted accordingly to ensure suitable habitat. Regular monitoring of populations of other endemic species is also recommended. In particular, *Utricularia ameliae* is a recently-described species, and a survey of Elizabeth Springs should document how many spring wetlands the species occurs in and obtain total population estimates. The species also needs to be collected while in flower from Reedy Spring on Warra.

6 Permian Galilee Group

6.1 Overview

On the exposed areas of the Galilee Basin sediments to the east of the Barcaldine supergroup are two small groups of springs that under the current definition are not part of the Great Artesian Basin (Figure 5). The Permian Galilee group overlie the Colinlea Sandstone, a lower unit of Permian age in the Galilee Basin which underlies the Eromanga Basin (the largest of the Basins collectively referred to as the Great Artesian Basin). The springs interpreted as having a source in the Permian sediments of the Galilee Basin are the outcrop Albro Springs, two vents with moderate flows (combined flow ~40 l/min), and the discharge Mellaluka (three vents with combined flow ~1200 l/min) and Lignum Spring (~0.5l/min) (Table 15).

Table 15. Summary of the status of the springs in the Galilee Permian springs at the complex, wetland and vent scale.

	Complex			Wetland		Vent	
	Active	Partially active	Inactive	Active	Inactive	Active	Inactive
Outcrop	1	0	0	2	0	2	0
Discharge	1	0	0	2	0	4	0

6.2 Hydrogeology

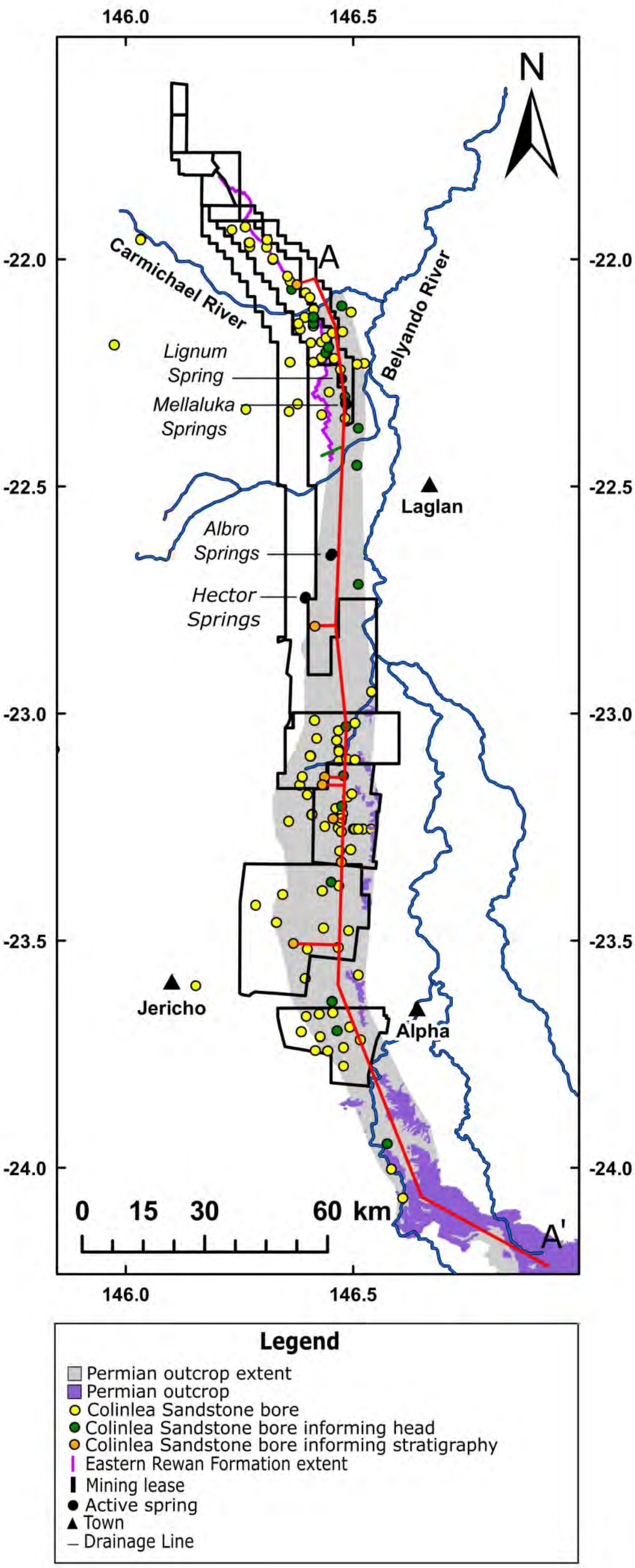
6.2.1 Regional Geology

The Galilee Basin is a geological basin comprising a series of sedimentary formations deposited during the Permian and Triassic periods. The oldest sediments are of early Permian age and are overlain by the Colinlea Sandstone and the Bandanna Formation. Overlying the Permian deposits are the Triassic sediments, the Rewan Formation and Dunda Beds. The Dunda Beds are generally classified as consisting of coarse-grained sediments and therefore a water-bearing aquifer. The Rewan Formation generally consists of fine-grained material and is therefore generally considered as a confining aquitard. However, both these strata are non-uniform and include both coarse and fine-grained facies. The sediments dip east to west at an angle of about 1-2 degrees, although this dip angle seems to steepen slightly in the north near the Carmichael River

On the eastern edge of the Galilee Basin, the Colinlea Sandstone approaches the surface but in many areas is overlain by Tertiary sediments and Quaternary deposits. In the south-eastern corner of the Galilee Basin, the Colinlea Sandstone has extensive outcrop on the foothills of the Carnarvon Ranges (Figure 90). In the vicinity of the Permian Galilee Springs the base of the Galilee Basin sediments is composed of the Early Permian-Late Carboniferous Joe Joe Formation. There is an unconformity between the Joe Joe Formation and the overlying Colinlea Sandstone.

The Bandanna Formation overlies the Colinlea Sandstone. These units can be indistinguishable and are often grouped as the Betts Creek Beds. The Betts Creek Beds include coal seams that are generally referred to as seams A to F. These deposits are currently being targeted by mining proposals. In the Colinlea Sandstone, the coal seams occur amidst coarse-grained material that contains groundwater which is exploited by both artesian and non-artesian pastoral bores. The sediments dip east to west at an angle of about 1-2 degrees, although this dip angle seems to steepen slightly in the north near the Carmichael River. Overlying the Betts Creek Beds is the Rewan Formation, the oldest of the Triassic sedimentary layers. This sedimentary unit includes fine-grained material and is only rarely exploited for groundwater.

The surface extent of the Betts Creek Beds is difficult to define because its surface is weathered and it is buried beneath Cainozoic material including recent alluvium associated with the Belyando River and its tributaries. The extent of the Betts Creek Beds (Figure 90) has been interpreted from sources defined in Table 16.



146.0
146.5
N
-22.0
-22.5
-23.0
-23.5
-24.0
A
A'
Carmichael River
Belyando River
Lignum Spring
Mellaluka Springs
Albro Springs
Hector Springs
Laglan
Jericho
Alpha
0 15 30 60 km
Legend
Permian outcrop extent
Permian outcrop
Colinlea Sandstone bore
Colinlea Sandstone bore informing head
Colinlea Sandstone bore informing stratigraphy
Eastern Rewan Formation extent
Mining lease
Active spring
Town
Drainage Line

Figure 90. Surface extent of Permian sediments in the Galilee Basin as derived from sources in Table 16. The Permian sediments are equivalent to the Betts Creek Beds except in the southern area (south of -23.85) where other Permian units associated with the Betts Creek Beds outcrop (referred to in this region as the Blackwater Group). The Colinlea Sandstone is not represented north of the Carmichael River but the eastern edge of the Rewan Formation is represented. The green line identifies the stratigraphy represented in Figure 91. The red line identifies the position of the stratigraphy represented on Figure 92.

Table 16. Source information for defining the surface extent of the Betts Creek Beds.

Latitude Range	Source
Western extent of Betts Creek Beds (eastern edge of Rewan Formation	
21.8 – 22.4	Geo-rectification of mapped Westmost Permian Overburden (inc Bandanna Formation) Adani (p. 12, GHD, 2013b)
22.4 – 22.8	Inference
22.8 – 24.2	Interpreted and supplied by Bleakley, A. , Jericho 55-14 (Vine et al., 1972b) and Tambo 55-2 (Exon et al., 1969)
24.2 – 24.3	Eastern edge of Rewan Formation Outcrop, Tambo 55-2 (Exon et al., 1969)
Eastern extent of Betts Creek Beds	
22.1 – 24.0	Colinlea outcrop, Galilee 55-10 (Vine et al., 1972a), inferred from Artesian Bores.
24.0 – 23.0	Colinlea outcrop, Jericho 55-14 (Vine et al., 1972b)
24.0 – 24.2	Colinlea outcrop, Tambo 55-2 (Exon et al., 1969)

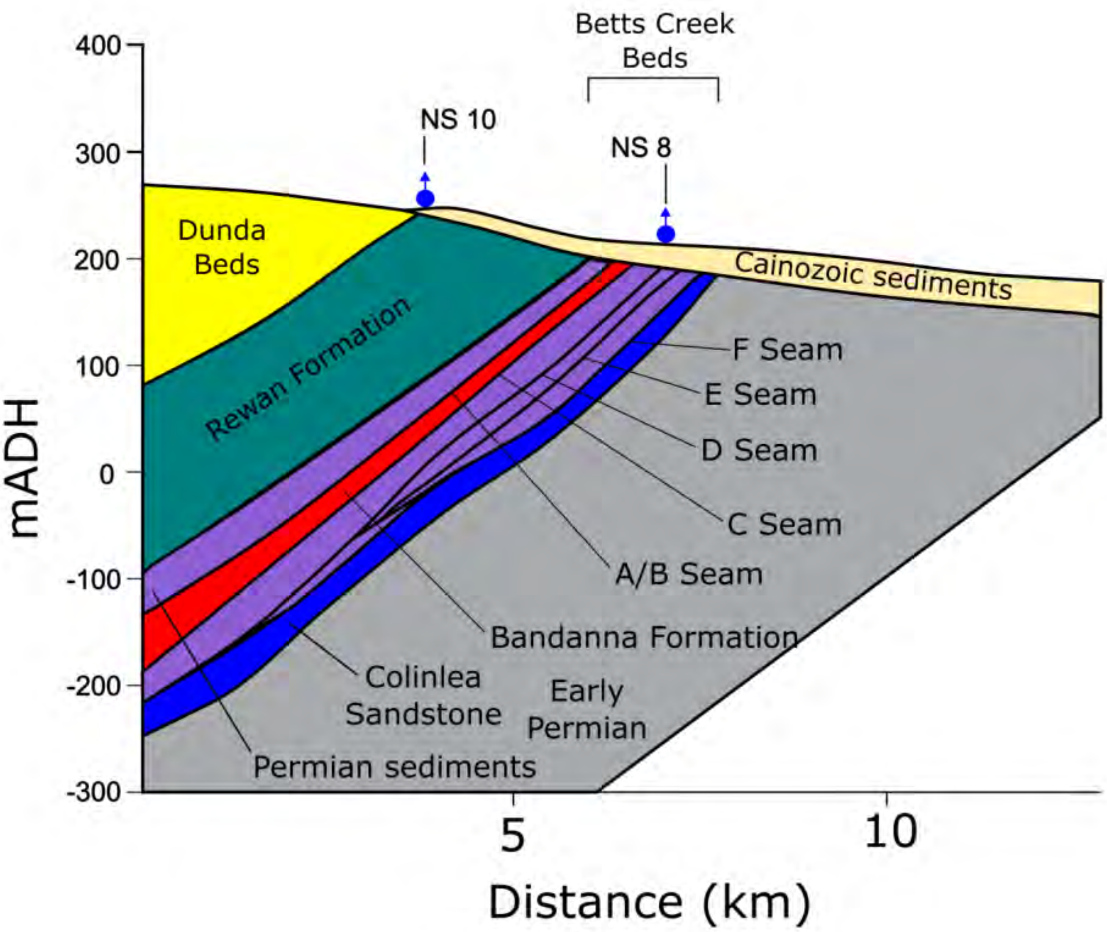


Figure 91. Stratigraphy (see Figure 90) detailing the coal seams within the Betts Creek Formation (Colinlea Sandstone and Bandanna Formation) and their relationship with other sediments in the Galilee Basin.

6.2.2 Hydrology of the springs

The Permian Galilee Springs form a south-north line to the west of the Belyando River (Figure 90). These springs appear to overlie the basement strata of the Colinlea sandstone in the vicinity of the E and F coal seams (Figure 91). Off-set from this line to the south-west is Hector Springs (Figure 90). Due to its position and the inferred hydraulic head in the Colinlea Sandstone (Figure 92), Hector Springs has been interpreted as having its source in the Triassic units of the Galilee Basin and is considered in a separate section of this report (see section 7).

The potentiometric surface derived from bores in the Colinlea Sandstone strongly suggests a predominantly south-north flow from the areas of outcrop at about 570 m altitude (Figure 92). This gradient is parallel with the ground surface, but perpendicular to the westward dip of the sediments. A downslope gradient in groundwater flow may be expected to the west given the dip in sediments (Figure 91). However, throughflow along the westward dipping sediments may be constrained because of a lack of connectivity between the deep sediments of the Galilee Basin at their western margin and the overlying basal units of the Eromanga Basin. The south-north flow structure seems to be the dominant influence on hydraulic head and spring flows.

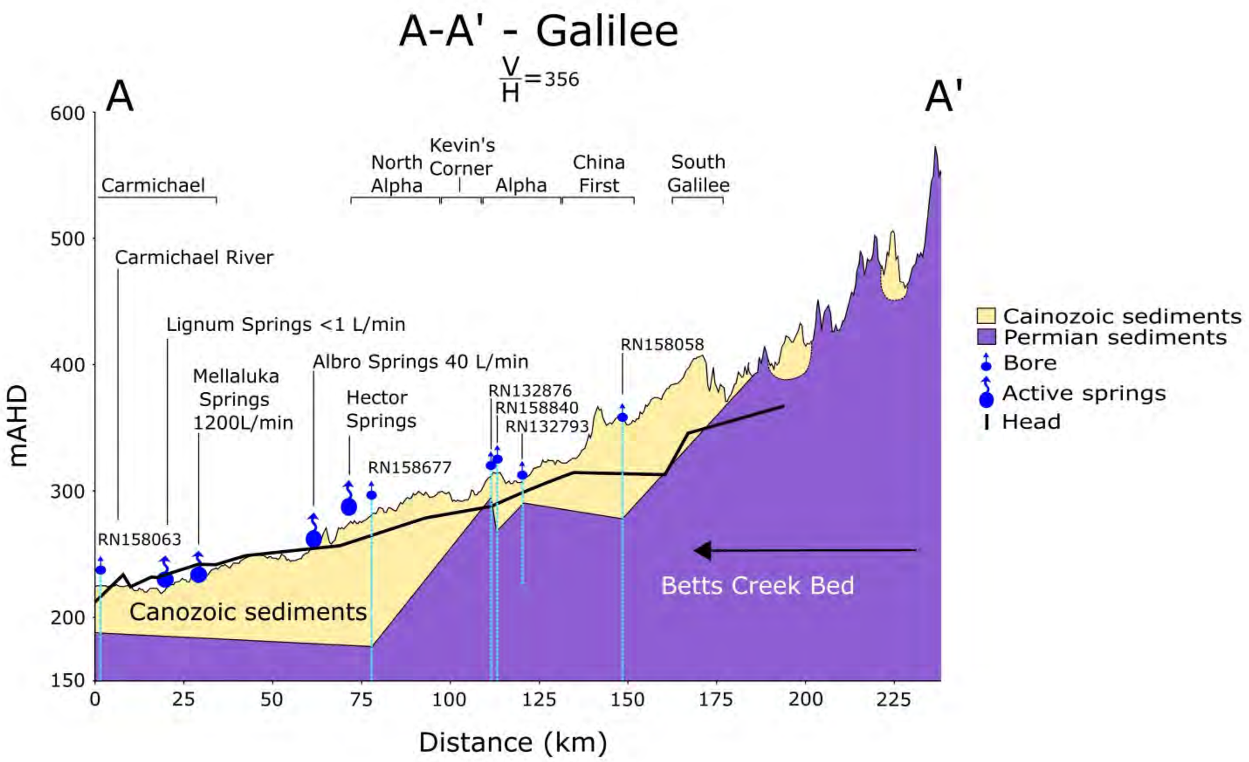


Figure 92. North-south stratigraphy (see Figure 90) identifying the Permian sediments of the Galilee Basin, and the location of bores from which the stratigraphy and potentiometric head have been derived. Direction of inferred groundwater flow from south to north is indicated by the large arrow.

There is a marginal but positive artesian head at Albro Springs and Mellaluka, while Lignum springs coincide with an area in the Colinlea Sandstone where artesian head reaches its maximum height (Figure 92). The reason that the springs emerge through the overlying Cainozoic sediments, including consolidated Tertiary sandstone and recent alluvium at particular locations is difficult to define. Given the marginal artesian head at Albro Springs it is likely that these springs are positioned where the surface of the Colinlea Sandstone is shallow or outcropping.

6.3 Historical record

There are few historical references to these springs. The first European to visit the area, Major Thomas Mitchell in winter 1846, followed the Belyando River in pursuit of a river providing a passage to the north-west. By early August it was becoming apparent to Mitchell that the river was not turning in the desired westerly direction. He continued following the river, closely inspecting the lie of the land to the west and making small forays in that direction. The party passed within a few kilometres of both the Albro and Laglan springs, but Mitchell was searching for a grand north-western flowing stream, not a swampy mound. Finally, on 11 August 1846, he realised unequivocally that the Belyando was the same stream Leichhardt had seen joining the Suttor the previous year, and began to retrace his steps back to the Salvator.

J. Alfred Griffiths did not mention any of the Galilee springs during his tour of bores and springs in the 1890s. None of the springs are marked on the original Survey of Runs, South Gregory District M.57.104, probably dating from the 1880s. The Mellaluka house springs are marked as Laglan Springs on the 4 mile series 1 sheet 10D (1929) (Figure 93).

Albro and Laglan springs are both marked on modern 1:250 000 topographic maps, while Lignum spring is marked as an unnamed waterhole. The Laglan and Albro springs received only occasional passing mentions in newspaper articles from 1910-1940, as discussed below.

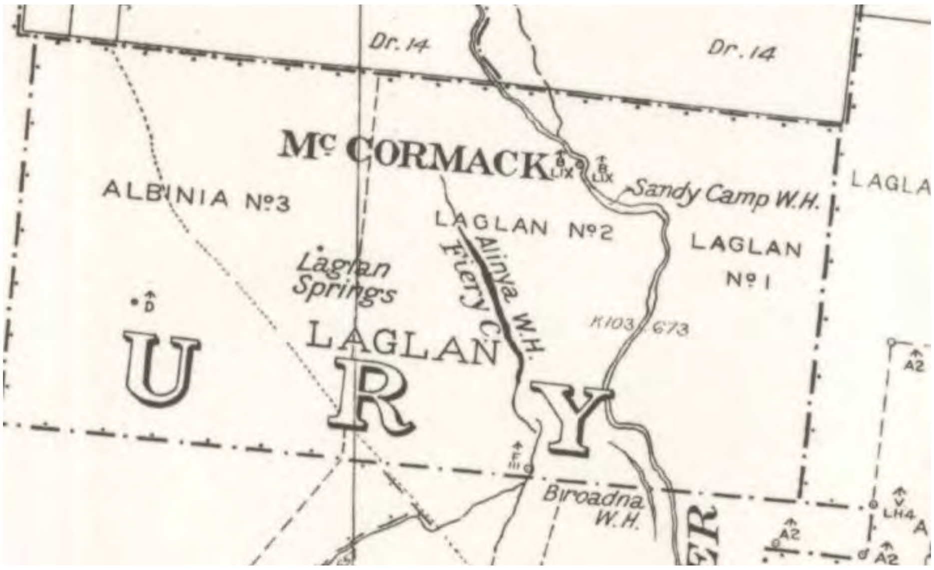


Figure 93. Mellaluka Springs marked as Laglan Springs on the 4 mile series 1, sheet 10D (1929)

6.4 Cultural history

6.4.1 Aboriginal history

The upper Belyando River was home to the Jagalingu people, while the Mian group occupied the lower Belyando. The journal of Major Thomas Mitchell (Mitchell, 1847) makes it clear that the district was home to a large number of people. He passed piles of mussel shells, fireplaces and huts and on 5 August he noted many human footprints in the gilgais around Fiery Creek, midway between Albro and Laglan springs. On 10 August, 17 Aboriginal men came into the explorers' camp. An old man told Mitchell the river was called the 'Belyando'. On the return journey back to the Salvator, Mitchell wrote:

> *'We found much of the grass on fire, and heard the natives' voices although we saw none. We crossed some patches of dry swamp where the clods had been very extensively turned up by the natives, but for what purpose Yuranigh could not form any conjecture. These clods were so very large and hard that we were obliged to throw them aside, and clear a way for the carts to pass. The whole resembled ground broken up by the hoe, the naked surface having been previously so cracked by drought as to render this upturning possible without a hoe. There might be about two acres in the patch we crossed, and we perceived at a distance, other portions of the ground in a similar state'* (13 August 1846).

The impression of a well-peopled country is corroborated by later authors, one of whom remembers a group of Aboriginal people west of Epping Vale numbering at least 500 (Newton, 1971). These people no doubt used and cared for the springs as valuable water sources in an area with little permanent natural surface water. However, no stories have survived and very little surface archaeology was found during spring surveys.

6.4.2 European history

The block Albro Springs took its name from the springs, although today it is known only as Albro and the springs straddle the boundary of Degulla and Lestree Downs. 'Albro Springs' features in newspapers articles from the late 1930s concerning the opening of a new stock route from the southern boundary of Albro Springs down the western side of the Belyando. However, it seems that this stock route did not pass the springs, relying solely on riverine waterholes. Both springs are today used locally for stock water, with the spring on Lestree Downs excavated (Figure 94) and both Albro springs equipped with pumps (Figure 95).

Figure 94. Albro spring 1 on Lestree Downs: an excavated pool 20 x 15m wide.

Figure 95. Windmill and tanks adjacent to Albro spring 1, Lestree Downs.

Darrel Story took up Mellaluka when it was portioned from Laglan station in 1967. The Mellaluka house was built on Laglan [Mellaluka] Springs (Figure 93) which provided a permanent source of water before nearby bores were sunk. Laglan [Mellaluka] Springs (Figure 96) were apparently a well-known locality prior to Mellaluka being resumed. It was a temporary camp for kangaroo-shooters and figured in a bush tragedy, when a lost constable died just short of the spring, as reported by the Western Champion in 1913:

> *Inspector M. Masterson, of the Rockhampton Police District, received a telegram about the 21st, from Acting-Sergeant Loney, Clermont, to the effect that the Aramac police had telegraphed that Doonganbulla reported that Constable Murray had been lost in the bush between Laglan and Doonganbulla since the previous Wednesday. Constable Murray left Clermont to patrol the locality mentioned, having with him a strong troop horse and another horse carrying a swag and rations. Arriving at Doonganbulla the constable left his horses there and started to prosecute his patrol farther on the 17th with a station horse, which carried rations and a waterbag in addition to the rider. The horse turned up at Doonganbulla on the 19th Nov. having neither bridle, waterbag nor rations. Naturally*

> *expecting an accident had happened, the station hands turned out in search of Murray, and found his tracks, but they became obliterated in the sandy country through a shower of rain. The party then re turned and rang up the police at Aramac, the nearest point (70 miles), and the authorities at once took steps to find the missing man. A constable and tracker were sent out from Clermont and Barcaldine, a tracker from Jericho, while a number of civilians joined in the search. As the days passed there was very little hope of finding the constable alive, owing to the heat and the known scarcity of water in the desert country. There is such a sameness in the country, which is heavily-timbered, sandy, and coarse-grassed, that (on the authority of Mr. P. H. Mathews who knows it well) a man may be easily lost. Actg.-Sergt. T. Smith received a telephone message from Constable Houston on Thursday morning stating that the search party came across the remains of the unfortunate policeman at 7 a.m. on Wednesday, after a tracking of some 40 miles. The man had been dead about a week. A bridle and empty waterbag were found half-a-mile from where the body was discovered, and deceased was actually half-a-mile from a spring, where there was a kangaroo-shooter's camp, and going in that direction…* (6 December 1913, p.9)

The Morning Bulletin reported on October 7 1938 (p.8) that the two-storey Laglan homestead had burnt to the ground. Details of the fire were vague as only one boy was at the homestead, the other workers being camped at 'the Springs' where they were mustering.

Figure 96. Mellaluka (Laglan) Springs from the south (December 2014) showing house behind springs.

6.5 Biological values

No endemic species are found in this group of springs, with only a couple of widespread wetland generalist species recorded in Albro and Lignum springs. The wetland vegetation in the Mellaluka Spring is dominated by the sedge *Baumea rubiginosa*, the fern *Cyclosorus interruptus* and the grasses *Imperata cylindrica* and *Phragmites australis*. The flora is relatively diverse, but all of the plant species have relatively widespread distributions on other wetlands. In 1960 the orchid *Spiranthes sinensis* (Figure 97) was collected by Queensland Government Botanist Selwyn Everist. This species has a widespread global distribution, but the population at Mellaluka is very disjunct. It was present but not flowering in 1998, but has not been seen since.

Figure 97. *Spiranthes sinensis,* pictured here growing in Japan, is a cosmopolitan orchid with a global distribution, found at Mellaluka springs; © Daniel Wieczorek 2005, danwiz.com.

6.6 Key threats and management

6.6.1 Coal and coal-seam gas developments

There are numerous proposals to mine coal deposits within the Colinlea Sandstone as indicated by the leases identified on Figure 90. The extraction of coal from the Permian sediments will involve dewatering of the sandstone within and around the coal seams. GHD (2013b, p. 30-31) predicts a ‘maximum long term’, ‘best estimate parameter set’ drawdown of the Permian age units at Mellaluka Spring around 9 m. This prediction is particularly sensitive to the modelled hydraulic conductivity in the vicinity of Coal Seam D. If horizontal and vertical hydraulic conductivity were increased by a factor of 10, drawdown may be as high as 18 m, or as low as 2.2 m if the average recharge applied to the model was increased from 3 to 30 mm/year.

Our collation of potentiometric head suggests that the artesian head at Mellaluka Spring is 14.1m. Thus the modelling suggests that impacts at Mellaluka Spring will vary from modest to the spring drying up. It is also apparent that there are numerous other coal mining developments in the areas of the Colinlea Sandstone that have been inferred here to represent the recharge areas for the springs. Albro, Mellaluka and Lignum Springs are all imperilled by the cumulative impacts of the proposed mining developments in the Galilee Basin. It is difficult to determine if there are potential impacts of coal-mining on ground-water quality.

7 Triassic Galilee Group

7.1 Overview

A small group of outcrop springs (

Table 17) associated with the Triassic units in the Galilee Basin are geologically distinct from the Permian Galilee group (Figure 5). They are all small, have been extensively modified, and have no apparent biological conservation values. The southernmost is Hunter Springs, consisting of two small vents in a sandstone amphitheatre, further north are the Greentree Springs that are now inactive, and northernmost are the Hector Springs consisting of three main vents (all excavated) and several smaller weeping vents (Figure 98).

Table 17. Summary of the status of the springs in the Galilee Triassic springs at the complex, wetland and vent scale.

	Complex			Wetland		Vent	
	Active	Partially active	Inactive	Active	Inactive	Active	Inactive
Outcrop	2	0	1	11	1	11	1
Discharge	0	0	0	0	0	0	0

7.2 Hydrogeology

7.2.1 Geological setting

The Triassic units in the Galilee Basin consist of the Rewan Formation overlain by the Dunda Beds and the Clematis Sandstone.

7.2.2 Hydrology of the springs

All of these three spring clusters are interpreted as gravity-fed outcrop springs within the Dunda Beds, although Hector Springs occur about 2 km to the east of the mapped outcropping of the Dunda Beds (Figure 98). The vicinity of the Hector Springs to the Dunda Beds and the insufficient hydraulic head from the nearby aquifer in the Colinlea Sandstone (see section 6.2.2) suggests a gravity-fed origin from the Dunda Beds. The description of Hector Spring as a 'well' on the 1929 4 mile map (Figure 99) suggests that these springs always had modest flows. For Hunter Springs there are large areas of higher elevation outcropping Dunda Beds to provide a permanent water source (Figure 98), given the modest flows at these springs. The Greentree Springs were described as 'fine springs' (see section 7.4.2), but ceased to flow in the 19th century. Whatever their original discharging volume, there are large areas of outcropping Dunda Beds at higher elevation to these springs to have provided substantial discharge (Figure 98).

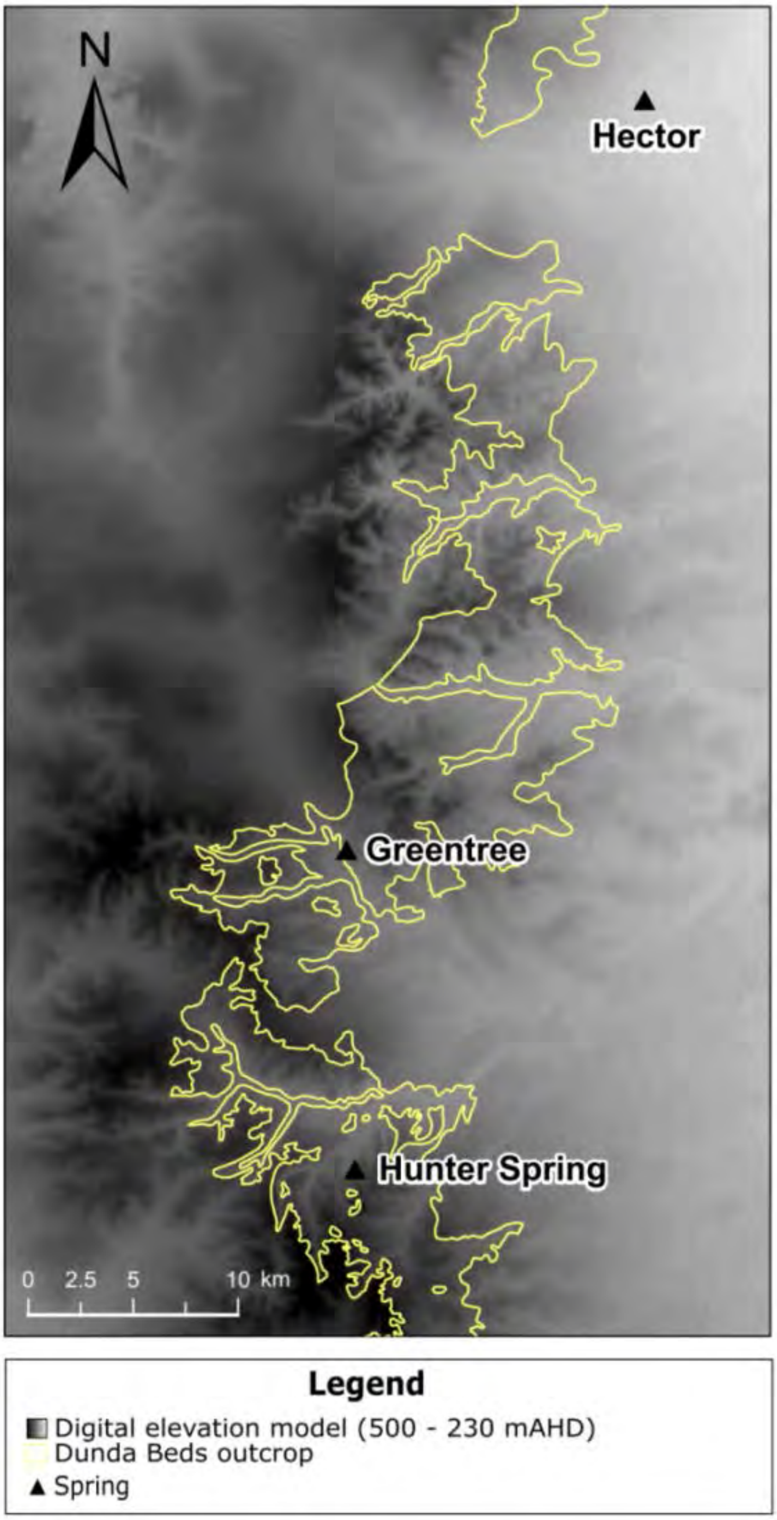


Figure 98. Location of the Galilee Triassic springs indicating their position in relation to the Dunda Beds; dark shading indicates large areas of higher elevation terrain to serve as a recharge area to supply these 'outcrop' springs. Greentree Spring is at -23.104, 146.249, 56 km NNE of Jericho.

7.3 Historical record

None of these springs are marked on the Survey of Runs, South Gregory District M.57.104 (circa 1880) or the 4 mile series 1 sheet 10D (1929), although Hector spring is marked as a well and tank (Figure 99). All are small remote springs situated in 'desert' country away from major rivers, and were not visited by early explorers, surveyors or Government inspectors such as J. Alfred Griffiths. The first mention of the Greentree springs appears in The Brisbane Courier in April 1890, in an article titled 'The Far West – A Sketch'. The author recounts a far-reaching tour of western Queensland and mentions numerous springs, including 'Green Tree':

> *…In the same desert country [as Labona] at Green Tree there are fine springs. Then west of Green Tree you come on the native wells* (The Brisbane Courier, 25 April 1890, p.7).

No written references to Hector or Hunter springs were found.

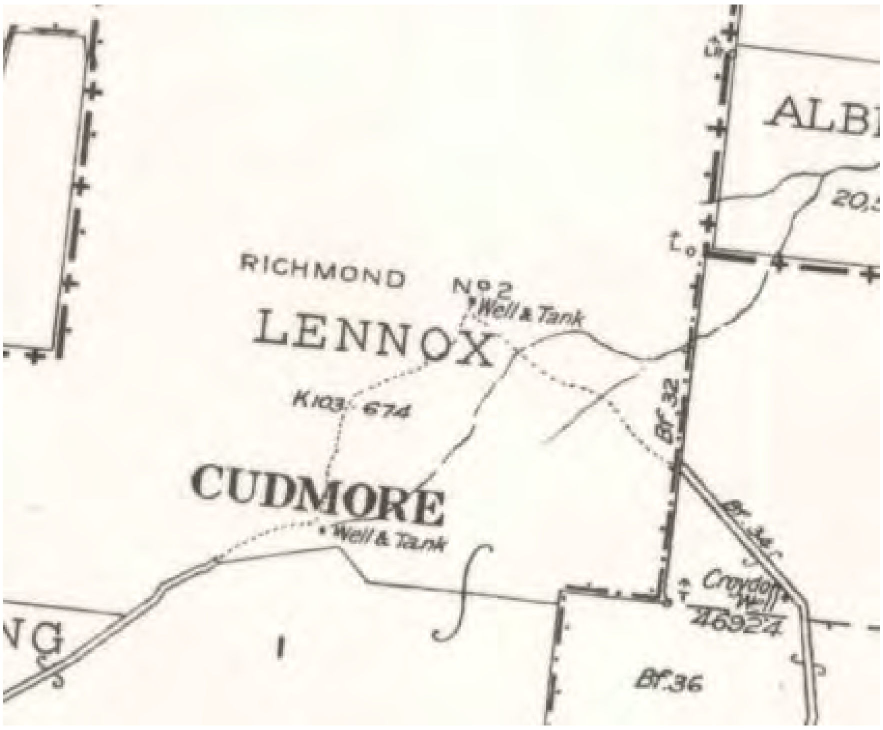


Figure 99. Hector Spring is marked as a 'Well' (under 'No. 2') on the 4-Mile Series 1 sheet 10D (1929)

7.4 Cultural history

7.4.1 Aboriginal history

No Aboriginal artefacts were seen in the immediate vicinity of Hunter or Greentree springs, although there are archaeological sites in the area including rock art on sandstone overhangs (Department of National Parks Recreation Sport and Racing, 2013). Stone flakes, cores, grindstone pieces and hearths were found along a small drainage line 200 m south-east of the third Hector spring (Figure 100), suggesting this was once an important Aboriginal campsite.

Figure 100. Grindstone handpiece (left) and cores and flakes (right) found on scalded gully near Hector springs.

7.4.2 European history

The Greentree springs were known from the early days of European settlement in the area, and were on the old track from Pine Hill to Aramac. They were highly valued as rare sources of water in the desert country:

> *The old road to Pine Hill goes through Chevy Chase. In the 1884 drought a spot known as Old Greentree was in great demand among the carriers owing to the springs. I heard casually the other day that the springs had dried up. Not too far from Old Greentree was a hotel, and some good stories could be written of the happenings at this place...* (Northern Miner, 29 November 1915).

The remains of this hotel (mostly piles of old bottles) and an old stone dam can still be seen on Chevy Chase (Figure 101) although any sign of the springs have disappeared. There was also a sawmill at Greentree in the 1870s (Aramac Shire Council, n.d.).

Figure 101. Possible site of the 'fine Greentree springs' (left), in creeklines near site of the old hotel (right), April 2015.

There are the remains of impressive wooden yards at Hunter Spring (Figure 102). These were built in the 1950s; Ewan recalls them being expensive to build, to the tune of 50 big rum bottles. There are also old wooden stakes around both spring vents, possibly to stop stock bogging as the water levels became low. In the 1940s at the end of a big drought, there were hundreds of dead horses strewn around the dry springs, and this is the only time in living memory they have been completely dry. The Mackay family continues to enjoy picnics under the towering lemon-scented gums at the spring from time to time (Figure 103).

Two of the three Hector springs are excavated to improve supply and access for cattle, and there are the usual signs of pastoral presence including fences, yards, wire, tin and bottles.

Figure 102. Remains of yards at Hunter springs, Hobartville.

Figure 103. Modern spring visitors: a picnic at Hunter springs in April 2015.

7.5 Biological values

All of the plant and invertebrate species recorded from these springs are cosmopolitan wetland species. In general outcrop springs have much lower incidence of endemic species than discharge springs (Fensham et al., 2011) and it is likely that endemic species were never associated with these outcrop springs.

7.6 Key threats and management

These springs emanate from local sandstone aquifers, and as such there are no threats associated with mining developments.

8 Doongmabulla Galilee Group

8.1 Overview

The springs at Doongmabulla form an isolated cluster of wetlands associated with the Carmichael River and its tributaries (Figure 5). They have been included within the Barcaldine Supergroup but are treated separately here because unlike the other springs in this supergroup they are associated with the Galilee Basin rather than the Eromanga Basin. Due to limitations in available data their source aquifer is ambiguous and unlike the other Barcaldine supergroup springs, depending on their source aquifer, they may be under threat from mining developments in the Galilee Basin.

The springs include relatively large spring wetlands and consist of 187 vents forming 160 separate wetlands (Figure 104; Table 18). The Doongmabulla Galilee Group springs are located on two properties, Doongmabulla and Labona. The springs occur near the confluence of the Carmichael River and Bimbah Creek, and downstream of this area. The following paragraphs provide a summary of the springs location, landscape position, morphology and known ecological values of the main springs in this group.

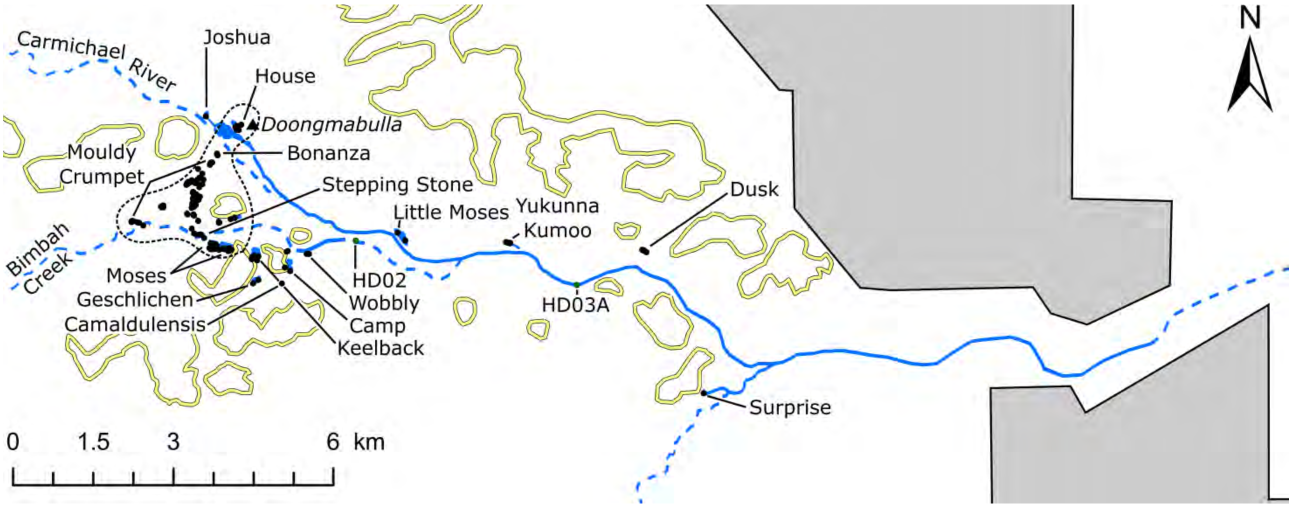


Figure 104. The Doongmabulla Springs at the small-scale; the location of two monitoring bores (HD02, HD03) and the approximate location of the proposed Carmichael Mine (Source: GHD, 2013a, p. 19). The permanent (solid) and impermanent (dashed) sections of the streams (blue lines) and the areas of outcropping sandstone (yellow lines) are identified. The dotted black line distinguishes springs with an unambiguous discharge character, i.e. discrete mounded vents on flat scalded ground not associated with sandstone outcrop.

Table 18. Summary of the status of the springs in the Doongmabulla springs at the complex, wetland and vent scale.

	Complex			Wetland		Vent	
	Active	Partially active	Inactive	Active	Inactive	Active	Inactive
Outcrop	1	0	0	11	0	13	0
Discharge	1	0	0	149	0	174	0

The House Springs comprise a cluster of small to medium-sized springs (64 to 6400 m^2) to the north of the junction of these streams just west of the Doongmabulla homestead. These are mounded vents in the middle of wetlands situated in flat topography.

Adjacent to the House Springs is the Joshua Spring. The area adjacent to the spring vent has been modified and a turkey nest dam with a pipe discharging a large flow of water through the dam wall (Figure 105). The outflow from Joshua Spring and the House Springs converge to provide the main discharge feeding the Carmichael River for a distance of approximately 20 km (Sam Cobb, pers. comm.). The vent of the massive Joshua Spring has not been located within the turkey nest where it occurs, and its precise character is difficult to determine. This spring excluded, the physical morphology of the vents and the topographic situation of the springs is variable and changes from the west to the east.

Figure 105. Joshua spring enclosed within a rectangular shaped 'turkey nest' in the foreground (left); the outflow pipe (right) is through the right-hand wall.

On the scalded plain between the Carmichael River and Bimbah Creek are a cluster of numerous small springs poignantly known as the Mouldy Crumpet group (Figure 106). These springs are mounded and occur on flat scalded ground, features typical of discharge springs. Despite their small size (generally less than < 100 m^2) these springs contain high concentrations of endemic species. The vents are mounded in the middle of the wetlands and are located on flat topography.

Figure 106. One of the large number of Mouldy Crumpet springs, north of Bimbah Creek.

South of these and amongst the channels of Bimbah Creek are the Stepping Stone Springs. The vents are mounded in the middle of the wetlands and are located on flat topography.

South of the confluence of the streams are small and large springs on a scalded area extending over 1.4 m, from the most westerly Moses Springs, to Keelback Springs, Geschlichen Spring (on a shallow side gully to the south) and Camp Spring (Figure 107). The large wetlands at Moses and Keelback Springs flow into permanent open ponds and channels within the bed of Bimbah Creek, but when evaporation reduces moisture in the regolith during drought times these channels do not discharge into the Carmichael River. A vent at the large Moses Spring was accurately measured at 0.5m above the edge of the wetland using a dumpy level in November 2014. This situation strongly suggests groundwater fed by artesian pressure through a vertical conduit, and all these features are characteristic of discharge springs elsewhere.

Figure 107. The main Camp Spring vent discharging from outcropping sandstone.

To the north of Camp Springs amidst the channels of Bimbah Creek is Bush Pig Trap Spring and to the south of Camp Spring on the edge of a belt of red-gums (Eucalyptus camaldulensis) is Camaldulensis Spring. On the side of a large water hole in Bimbah Creek are the Wobbly Springs, which contribute to the permanence of the water-hole.

On the bank of the Carmichael River south of Joshua Spring are the Bonanza Springs. Bonanza, Keelback, Geshlichen, Bush Pig Trap and Camaldulensis are not mounded but also occur in flat areas remote from outcrop, and are also almost certainly discharge springs with vertical conduits. Camp Spring has two vents, both emerging from sandstone rock (Figure 111) at the base of outcrop, but unlike other outcrop springs to the east the vents are very discrete, indicative of discharge springs fed by pressurised artesian water.

Figure 108. Camp Spring looking west towards Keelback Springs, visible as a stand of dark-green paperbarks. Note the scalded areas around the springs characteristic of discharge springs. The vents are at the base of a low rise (visible in the middle of the photograph).

North of the Carmichael River and 1 km downstream of the confluence of the streams is Little Moses Spring with its wetland at the base of a gentle slope but above the channels of the main stream (Figure 108).

Figure 109. Little Moses Spring with notable absence of scalded area

Heading downstream on the northern side of the Carmichael River and east of the Labona boundary fence is the large Yukunna Kumoo Spring, and then a cluster of small springs known as the Dusk Springs (Figure 109).

Figure 110. One of the Dusk Springs

Finally on the edge of Surprise Creek, which enters the Carmichael from the southwest, is Surprise Spring, which has formed a short gully from its ill-defined source in colluvial material (Figure 110).

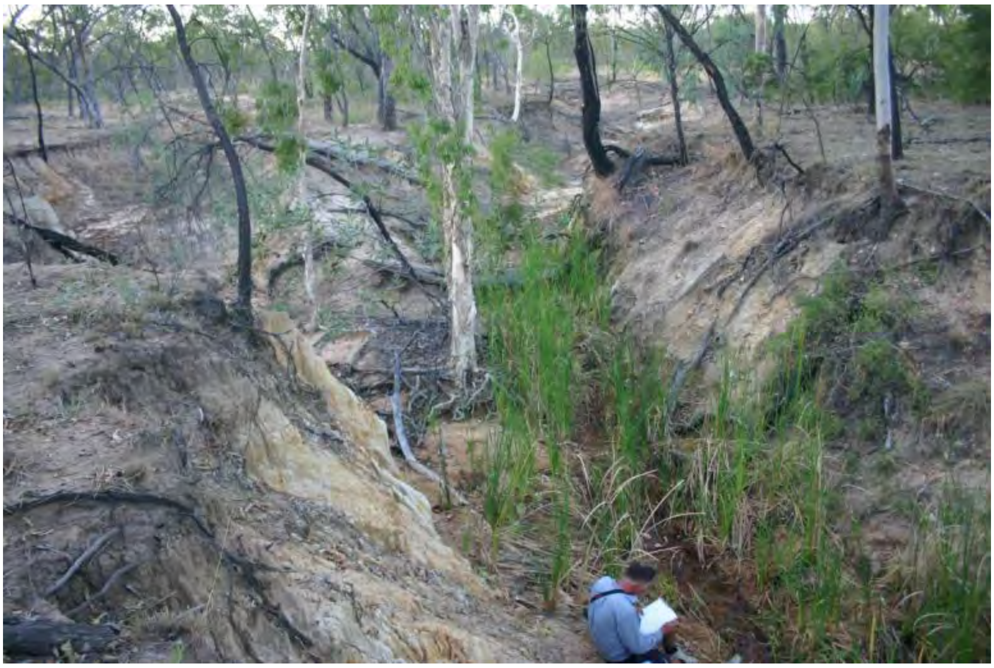


Figure 111. Head of Surprise Spring with discharge forming a channel in an incised gully within colluvial material.

The eastern springs, Little Moses, Yukunna Kumoo, Dusk and Surprise Spring have vents on the edge of wetlands at the base of gently sloping topography suggesting lateral discharge, a feature typical of outcrop springs.

The flat topography, mounded vents and absence of outcrop at the western springs (House, Mouldy Crumpet, Stepping Stone) is strongly suggestive of a vertical conduit through a confining bed typical of discharge springs. Whereas, the position of the vents of the eastern springs on sloping topography, and their association with outcropping sandstone, suggests a potentially horizontal discharge conduit through an unconfined aquifer typical of outcrop springs.

8.2 Hydrogeology

8.2.1 Geological setting

The geological sequence underlying this spring group includes the Rewan Formation, the Dunda Beds, the Clematis Sandstone and the Moolayember Formation (Figure 112). The existing geological mapping and available stratigraphic data indicates the Triassic Galilee Basin sediments dip to the west in the vicinity of the Doongmabulla Springs at less than 1° (Figure 112). Seismic data suggests that the dip near the base of the Triassic sequence is up to 5° in the east, but is almost flat lying 5km to the west (Velseis, 2012). The Rewan Formation forms the basal sedimentary unit and is overlain by the Dunda Beds, the Clematis Sandstone, and finally the Moolayember Formation. There are three bores in the vicinity of the springs which provide an understanding of the lithology of the underlying stratigraphy; C056C (GHD, 2013b, p. 99), C555 (QLD groundwater database) and Shoemaker 1 (ATP744P). A copy of the graphic log for Shoemaker 1 is attached as Appendix D

The Shoemaker bore suggests that the Rewan Formation is relatively fine-grained including 262m (94%) of fine grained siltstones and mudstones with two interbedded facies of sandstones. This is consistent with the available literature which suggests the Rewan Formation is dominated by fine-grained sediments which is generally characterised as an aquitard, separating the underlying Permian sediments (including the coal bearing Betts Creek Beds), and the overlying sandstones of the Dunda Beds and the Clematis Sandstone. A further stratigraphic bore C555P lies to east of Shoemaker 1. Here the Rewan has a thickness of 277m and comprises fine grain sediments similar to the Rewan Formation in Shoemaker 1.

The lithology recorded at C056C suggests that the Rewan Formation includes more sandstone than represented in the Shoemaker bore. It is represented as 89m (48%) of fine-grained sandstone, siltstones and mudstones, and the remaining 98m composed of sandstone in 11 interbedded facies.

The bores in the vicinity of the Doongmabulla Springs indicate that the Rewan Formation is between 187m and 280m thick (Table 19). The Rewan Formation is generally considered argillaceous (fine-grained) (Vine and Doutch, 1972), only rarely provides groundwater through pastoral bores (A. Bleakley pers. comm.), and is generally considered an aquitard.

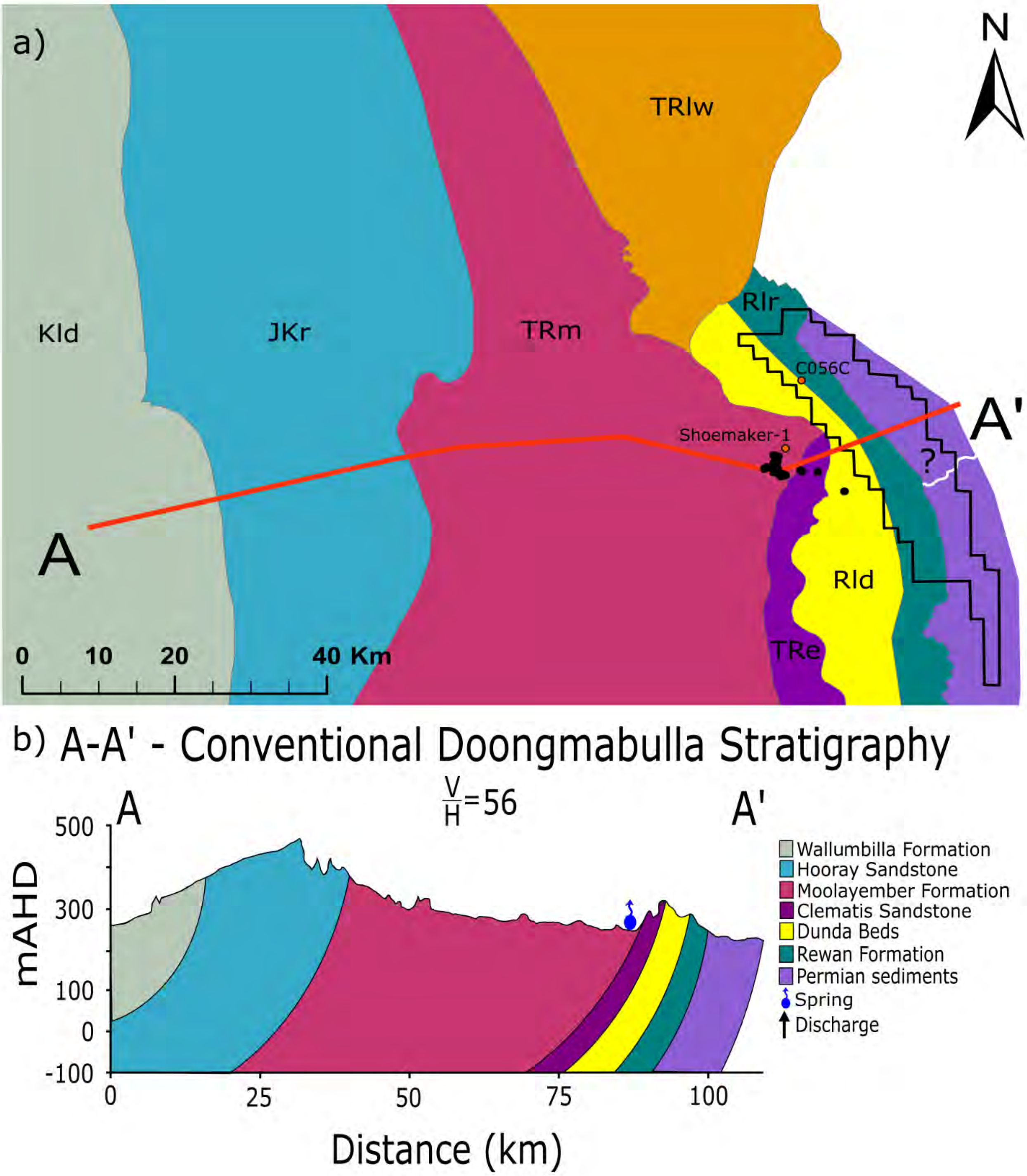


Figure 112. Representation of the regional geology (without Cainozoic) in the vicinity of the Doongmabulla Springs consistent with the existing geological mapping (Vine et al., 1972a). a) plan view with location of stratigraphy, the position of the Carmichael lease and the Doongmabulla Springs (black dots), and an area of uncertain geology north of the white line are also indicated. The location of two stratigraphic bores, Shoemaker and C056C, are indicated; b) Stratigraphic cross-section with discharge springs emanating under pressure through a thin layer of the Moolayember Formation; and outcrop springs in the Clematis Sandstone and Dunda Beds also indicated. The Permian sediments are buried beneath Cainozoic material and our interpretation here is consistent with Figure 90.

Table 19. The lithology of the Rewan Formation as described in two bore logs near the Doongmabulla Springs: Shoemaker 1 (-22.066°S, 146.241°E) and C056C (-22.976°S, 146.278°E); all measurements are in metres (see Figure 112).

(Shoemaker 1)				C056C			
Lithology	**Top**	**Bottom**	**Thickness**	**Lithology**	**Top**	**Bottom**	**Thickness**
Mudstone	250	260	10	Fine grain sandstone	90	95	5
Siltstone	260	288	28	Silt	95	99	4
Mudstone	288	296	8	Claystone	99	104	5
Siltstone	296	308	12	Sandstone	104	123	19
Mudstone	308	315	7	Claystone	123	126	3
Siltstone	315	383	68	Silt	126	127	1
Sandstone	383	392	9	Very fine grain sandstone	127	128	1
Siltstone	392	440	48	Fine grain sandstone	128	135	7
Siltstone	440	490	50	Siltstone	135	136	1
Sandstone	490	499	9	Claystone	136	139	3
Siltstone	499	518	19	Fine to medium grain sandstone	139	146	7
Very fine sandstone	518	530	12	Silt	146	149	3
Total	*250*	*530*	*280*	Sandstone	149	157	8
				Silt	157	158	1
				Sandstone	158	159	1
				Silt	159	161	2
				Sandstone	161	170	9
				Silt	170	172	2
				Sandstone	172	174	2
				Fine grain sandstone	174	176	2
				Fine to medium grain sandstone	176	177	1
				Siltstone	177	186	9
				Fine grain sandstone	186	187	1
				Siltstone	187	189	2
				Silt	189	192	3
				Fine grain sandstone	192	193	1
				Siltstone	193	200	7
				Fine grain sandstone	200	202	2
				Siltstone	202	203	1
				Very fine grain sandstone	203	204	1

(Shoemaker 1)				C056C			
Lithology	**Top**	**Bottom**	**Thickness**	**Lithology**	**Top**	**Bottom**	**Thickness**
				Siltstone	204	207	3
				Fine grain sandstone	207	209	2
				Sandstone	209	212	3
				Siltstone	212	213	1
				Sandstone	213	258	45
				Very fine grain sandstone	258	259	1
				Siltstone	259	265	6
				Fine grain sandstone	265	267	2
				Siltstone	267	268	1
				Fine to medium grain sandstone	268	270	2
				Fine grain sandstone	270	272	2
				Siltstone	272	274	2
				Fine grain sandstone	274	275	1
				Siltstone	275	276	1
				Sandstone	276	277	1
				Total	*90*	*277*	*187*

The Rewan Formation is overlain by the Dunda Beds and Clematis Sandstone (Figure 113). The Dunda Beds are ‘quartzose to lithic, commonly contain a kaolinitic matrix, and are generally fine-grained. Argillaceous interbeds are more common in the Dunda Beds than in the Clematis Sandstone’ (Vine and Doutch, 1972). The Clematis Sandstone is described as ‘quartzose, commonly porous and medium to very coarse-grained’. The Clematis Sandstone ‘forms bluffs and cliffs’, while the Dunda Beds form ‘rounded foothills’ (Vine and Doutch, 1972). There are pastoral bores providing groundwater from the Dunda Beds, although supplies are not as substantial and reliable as those from the Clematis Sandstone (A. Bleakley pers. comm.). Both units are generally considered as relatively sandy units compared to the Rewan Formation.

While there is some groundwater in the overlying Moolayember Formation, it is generally considered as an aquitard separating the Triassic sediments of the Galilee Basin from the Jurassic sediments of the Eromanga Basin (Habermehl and Lau, 1997). The only bore describing the full Triassic stratigraphic sequence is the Shoemaker 1 bore. At this location (Figure 112a) the Moolayember Formation occurs from 4 to 82 m depth and the Clematis Sandstone from 82 to 200 m depth. The depth of the Dunda Beds is unclear from the available information and is interpreted in combination with the Rewan Formation, and is expected to occur from 200-250 m depth (Appendix D). The Rewan Formation is interpreted to occur from 250 m depth (Table 19).

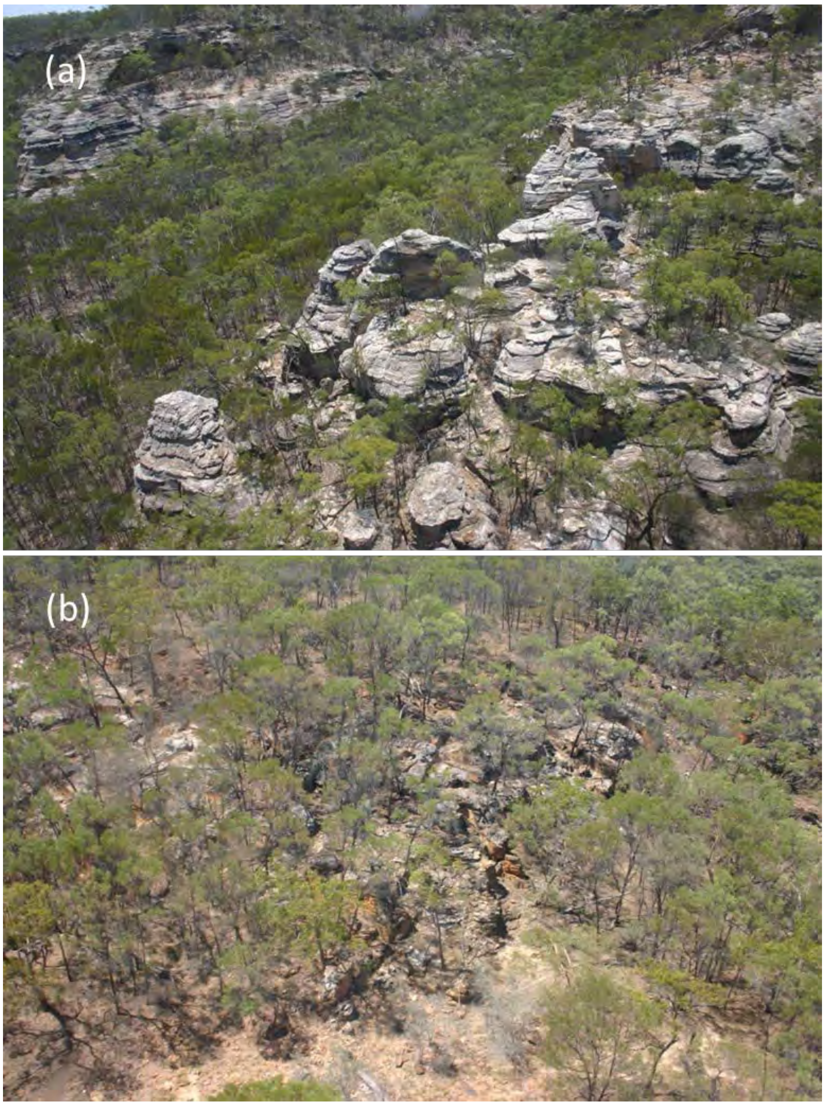


Figure 113. a) Outcrop of presumed Clematis Sandstone forming 'bluffs and cliffs' of pale quartz rich sandstone compared to b) presumed outcrop of Dunda Beds forming 'rounded foothills' of brownish sandstone (Source: Webb, 2015)

The variable thickness of the Rewan Formation interpreted from the Shoemaker 1, C056C, and C555P bores (279 m, 187 m and 277 m respectively) may be due to difficulty distinguishing between the Dunda Beds and the Rewan Formation. An alternative to the existing geological mapping of Triassic sediments around Doongmabulla was proposed by Dr John Webb (Webb, 2015) in evidence presented to the Queensland Land Court (Proceedings no. MRA428-14, EPA429-14, MRA430-14, EPA431-14, MRA432-14, EPA433-14). The Webb interpretation is based on aerial reconnaissance of the outcropping sediments (Figure 113), radiometric and seismic data. Generally, Webb suggested the dominant consolidated unit throughout the area of the Doongmabulla Springs is Dunda Beds. The divergent interpretations of the Triassic sedimentary sequence in the vicinity of the Dongmabulla Springs highlights that these units can be difficult to distinguish.

8.2.2 Hydrology of the springs

Two substantially different interpretations of the hydrology of the Doongmabulla Springs are presented in this section (Figure 112; Figure 114); the Triassic Scenario and the Permian Scenario. Both interpretations are consistent with the existing geological mapping in the area of Doongmabulla Springs (Vine and Doutch, 1972)(Figure 114a).

On the existing geological mapping the Surprise Spring is positioned within Dunda Beds. Little Moses, Yukunna Kumoo and Dusk Springs occur within Clematis Sandstone. The other springs to the west are located where there is a thin layer (<50 m) of Moolayember Formation overlying the Clematis Sandstone.

Under the 'Triassic scenario', the source aquifer for the springs is the Clematis sandstone. The springs within the outcropping sandstones (Little Moses, Yukunna Kumoo, Dusk, and Surprise) are interpreted as gravity-fed outcrop springs (Figure 114a). The Joshua, House, Bonanza, Moses, Stepping Stone and Mouldy Crumpet Springs are interpreted as discharge springs. Under this scenario sufficient artesian head in the Clematis Sandstone is required to provide discharge to the surface through a thin layer of the Moolayember Formation and/or surface alluvium thinned by erosion around the confluence of Carmichael Creek and Bimbah Creek (Figure 114a).

An alternative scenario, the Permian Scenario was suggested by Dr John Webb during the land court proceedings (Webb, 2015) (Figure 114b). Under this scenario, the source aquifer of the springs is the Permian sediments beneath the Rewan Formation and a fracture or fault and substantial potentiometric head is required to allow groundwater to discharge through the Rewan Formation and Dunda Beds to the springs at the surface (Figure 114b). This would require a conduit greater than 500m in length, and more importantly, it would also require a potentiometric surface in the Colinlea sandstone aquifer significantly above the natural surface of the springs, to overcome the potential headloss.

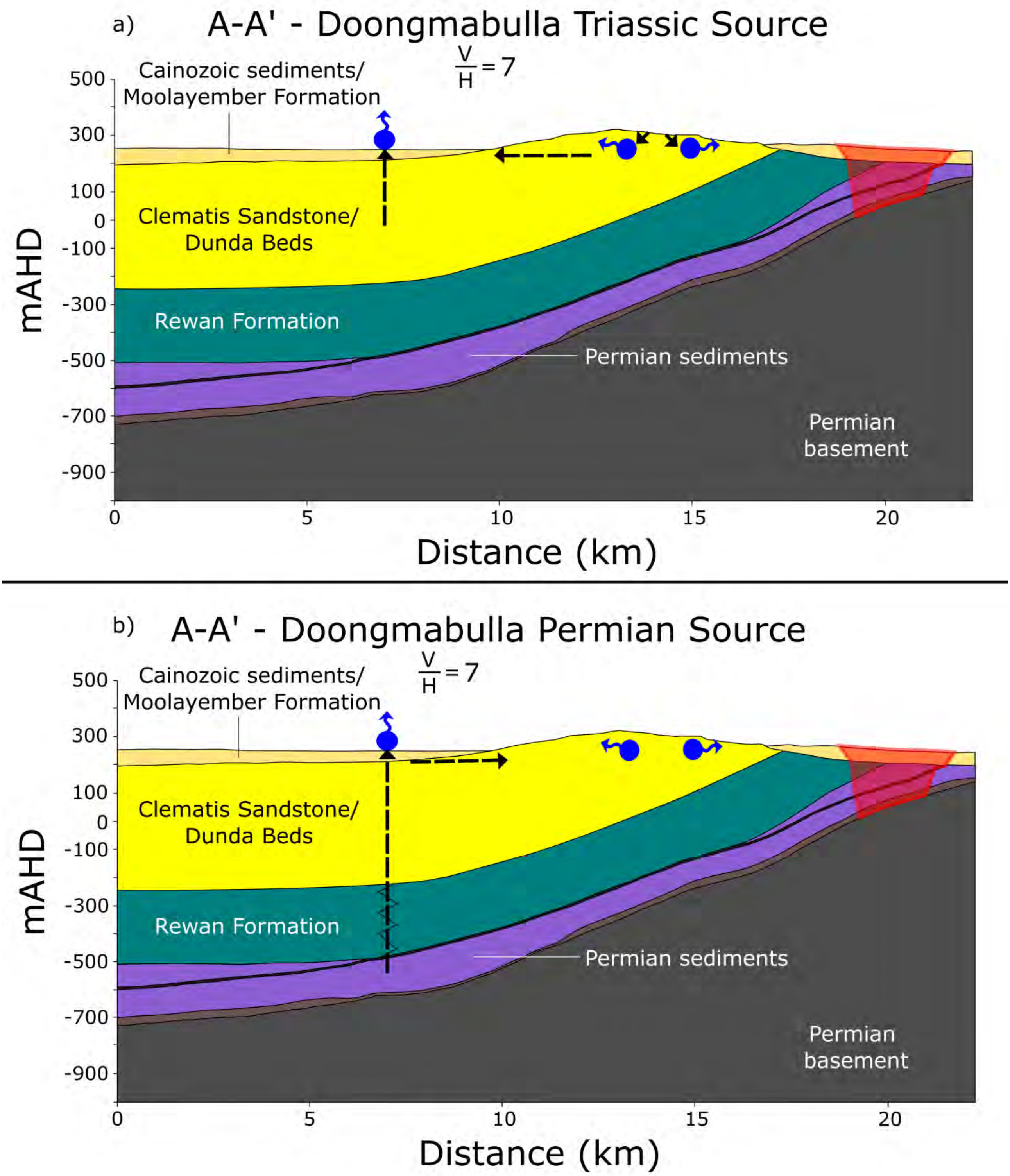


Figure 114. a) Hydrogeological conceptualisation of the springs at Doongmabulla (from the west-east) representing the Triassic Scenario with outcrop springs fed by gravity in the east and feeding an aquifer with sufficient head to supply artesian pressure to discharge springs in the west (Figure 112); b) Hydrogeological conceptualisation of the springs (from the west-east) representing the Permian Scenario whereby the source aquifer is in the Permian sediments emanating from a fracture through the aquitard (Rewan Formation) and some groundwater penetrating vertically to supply the mounded artesian springs and dispersing laterally to supplement an aquifer in the Triassic sediments that provides the source for outcrop springs to the east.

A key line of evidence to test these scenarios is the hydraulic head for the alternative source aquifers. Is there sufficient potentiometric head in the Triassic aquifer to supply water to the springs, or at least those western springs (House, Mouldy Crumpet, Stepping Stone and Moses; Figure 104) that are interpreted as discharge springs based on their morphology?

Data from relevant bores with reliable measurements of standing water level or pressure measurements were compiled to assess the potentiometric surface in a north-south direction in the vicinity of the springs (Figure 115). There is limited data available for interpretation. Data was sourced from the Queensland Groundwater Database and the position and data from those bores was also verified directly in the field and from landholders where possible. Unless otherwise stated, only those bores with adequate construction information and reliable water level measurements were included in the assessment.

The available data indicates a potential for horizontal flow in the Clematis Sandstone (Triassic Scenario) from both the north, west and south converging on the Carmichael River in the vicinity of the springs. This indicates that this area is a zone of groundwater discharge. It also suggests that there may be a marginal head at Surprise and Yukunna Kumoo springs within the Clematis Sandstone (Figure 116). With the caveat of considerable uncertainty, the north-south profile suggests marginal to insufficient head in the Clematis Sandstone to provide artesian flow to the springs in the western area, including House, Joshua, Mouldy Crumpet, Stepping Stone, Moses, Geschlichen, Keelback and Camp Springs (Figure 116).

The bore HD02 (RN158092) is 32 m deep (Clematis Sandstone) and HD03 (RN158036) is 37m deep (Dunda Beds) (GHD, 2013a) and represent Triassic aquifers above the Rewan Formation. These bores are located adjacent to Dyllingo Creek-Carmichael River and do not penetrate the full thickness of the formations and only tap the upper most aquifer. Furthermore since there is vertical flow of groundwater towards the spring vents and to the Carmichael River, it is feasible that the potentiometric head for the basal aquifer in the Clematis Sandstone and for the Dunda Beds would be higher than the potentiometric head observed in the bores (in the vicinity of the springs) shown on Figure 116F. This would place the potentiometric pressure (head) above the natural surface of the springs.

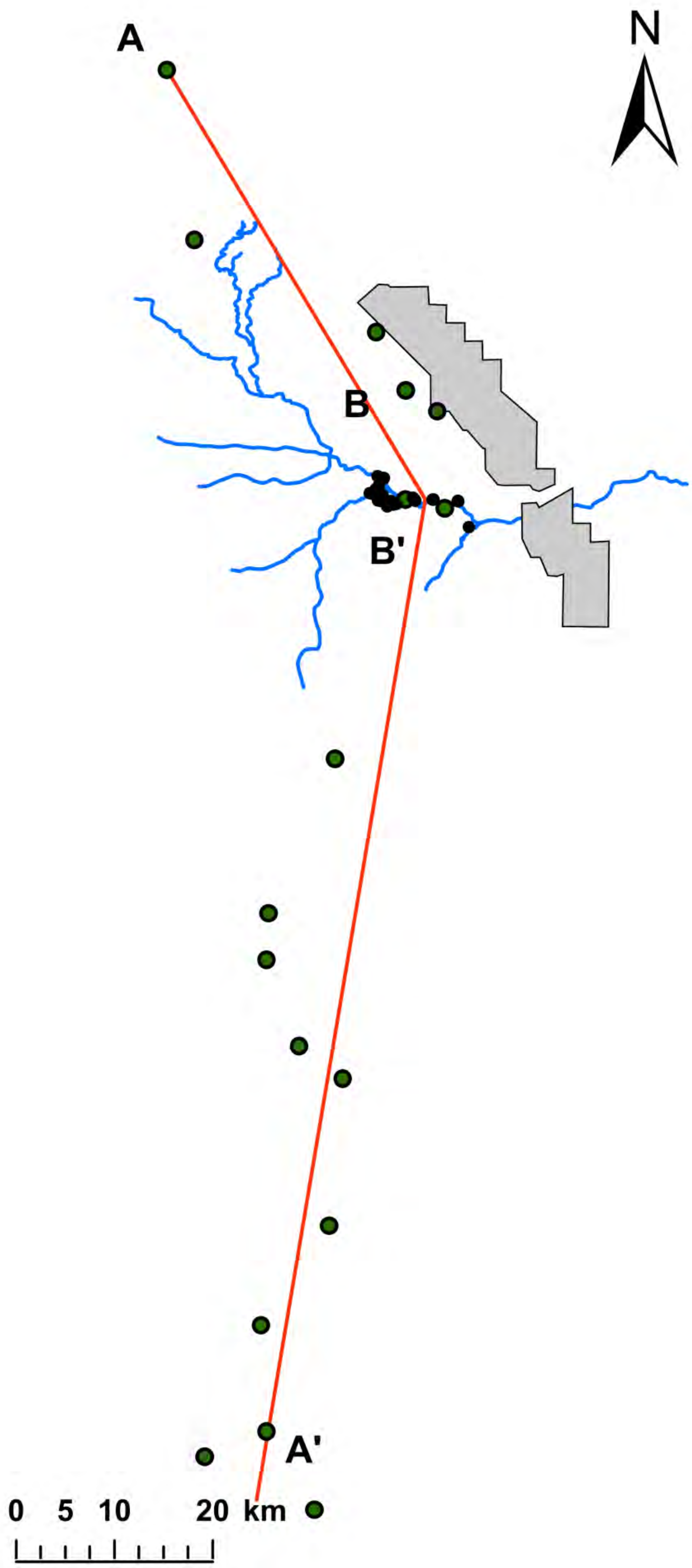


Figure 115: Location of the bores used to create the north-south stratigraphy (A-A') represented in Figure 116a and the fine-scale stratigraphy (B-B') represented in Figure 116b. Data was compiled by Ashley Bleakley (Department of Natural Resources and Mines) and where multiple water level records were available in some bores, an average water level was used. The black dots identify the location of the Doongmabulla Springs and the blue-line identifies the Carmichael River. The grey area identifies the location of the Carmichael Mine.

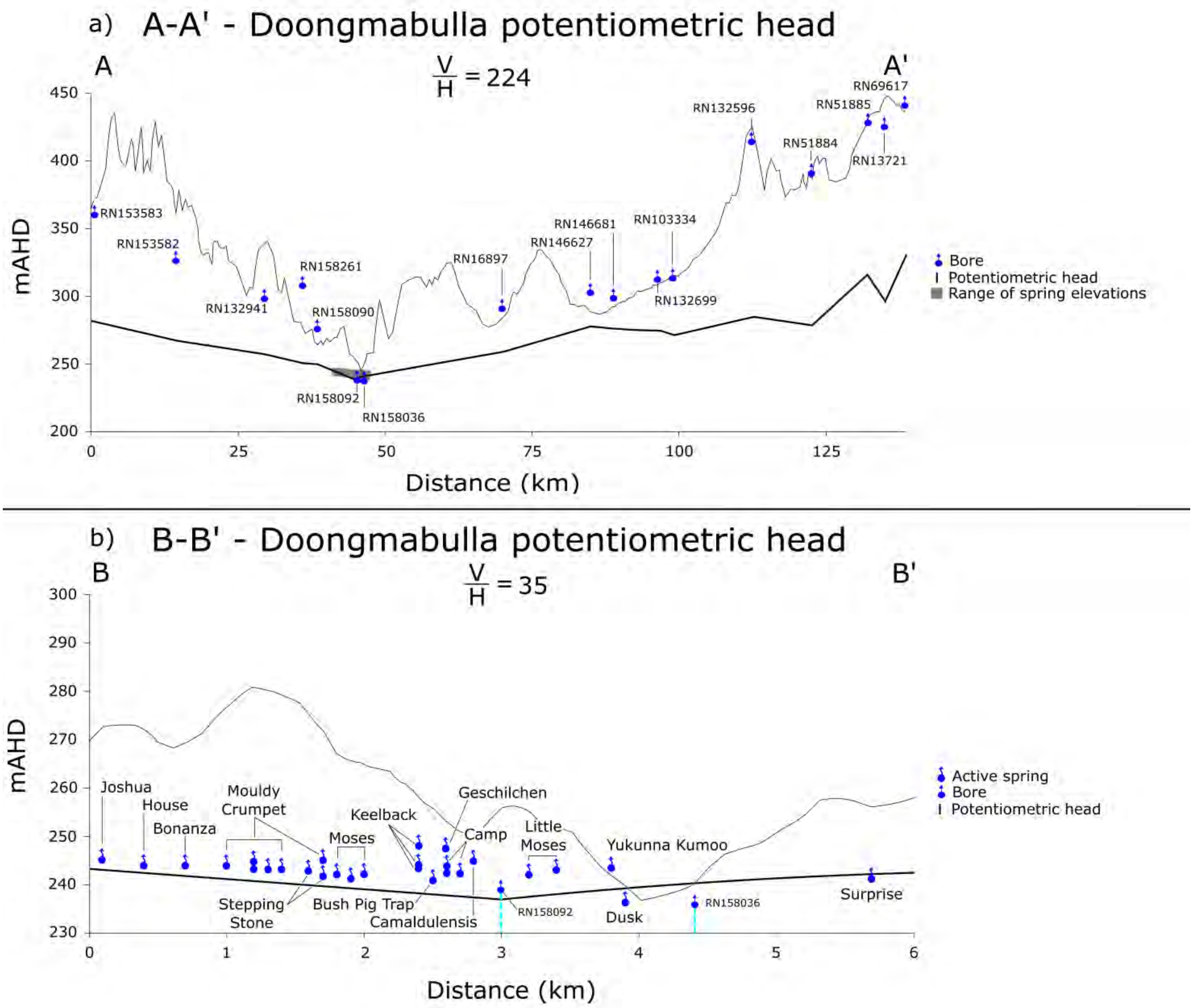


Figure 116. a) Ground surface (fine line) and potentiometric surface (coarse line) of the upper Triassic aquifer relative to the elevation of the springs at Doongmabulla. The position and elevation of the springs is identified by the grey box b) Fine-scale view of potentiometric surface in the vicinity of the springs. Elevations and standing water levels have been incorporated, so that the upper potentiometric head is represented relative to Digital Elevation Model employed here. Note the potentiometric head for the base of the Triassic aquifer may be several metres higher than the observed potentiometric surface of the upper aquifers.

Data from relevant bores (Figure 117a) were also compiled to assess the potentiometric groundwater surface in the Triassic sediments in the vicinity of the springs (Figure 117b) and to the north-west (Figure 117c), and south-west (Figure 117d) of the springs. Similar to the north to south sections, the data suggests the horizontal groundwater flow direction in the Clematis Sandstone is converging on the springs from the west, as well as the north and south. However, there are significant distances between the available data points. The potentiometric surface (Figure 117) suggests marginal to insufficient head to provide an artesian groundwater source to the springs from the Clematis Sandstone, but there is considerable uncertainty. As discussed above due to the shallow depth of HD02 and the potential for lowering of head in the vicinity of the springs, the potentiometric head for the base of the Triassic aquifer may be several metres higher than the observed potentiometric surface of the upper aquifers.

Additional local monitoring bores to the west, south or north of the springs would improve our understanding of the available pressure in the vicinity of these springs. A nest of deep bores to the base of each formation to the west of the springs would be a priority and the vicinity of -22.065, 146.218 is suggested.

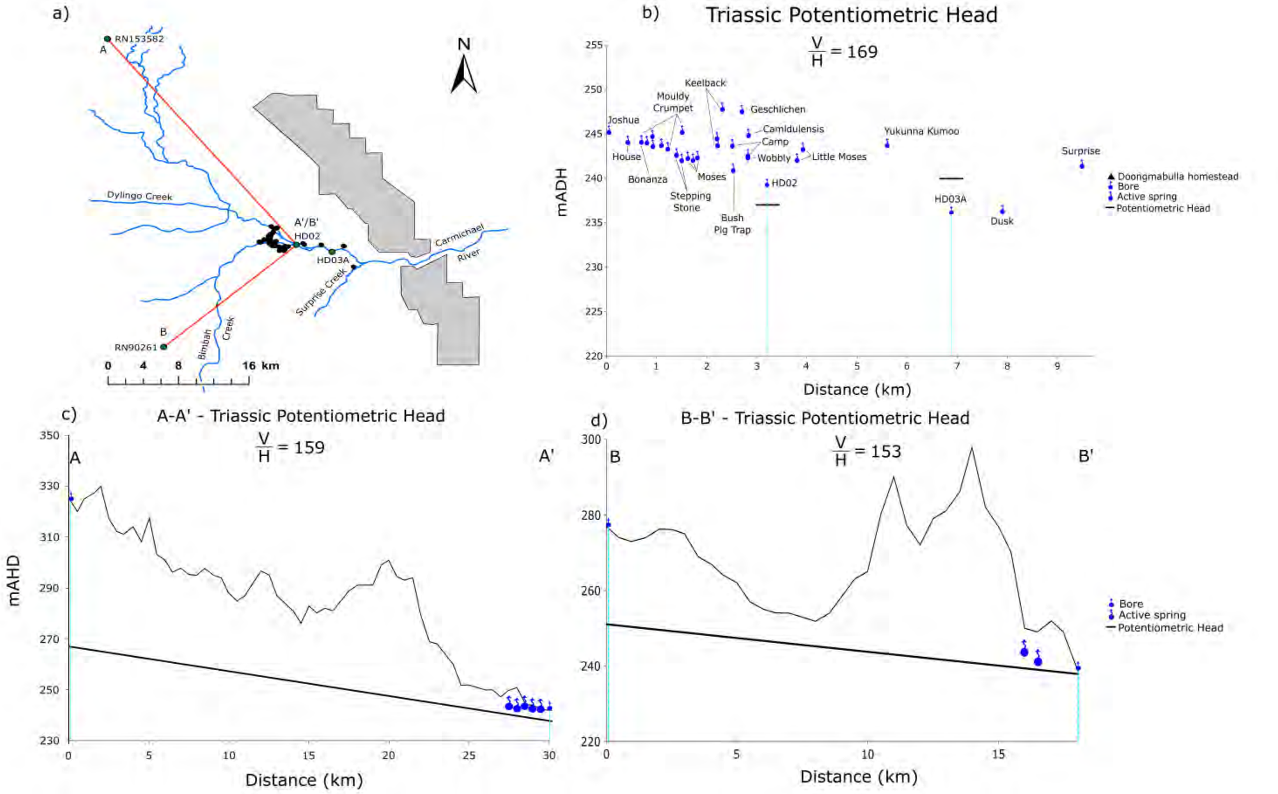


Figure 117. a) Location of the bores used to create the head profiles represented in b), c), and d); b) Potentiometric surface at HD02 (RN158092) and HD03 (RN158036) relative to the elevation of the springs at Doongmabulla; c) A-A' cross section of the inferred potentiometric surface in the Triassic Sandstone (attributed as Clematis Sandstone) and the elevation range of the springs along this cross-section; d) B-B' cross section of the inferred potentiometric surface in the Triassic Sandstone (attributed as Clematis Sandstone) and the elevation range of the springs along this cross-section. Elevations and standing water levels have been incorporated, so that the potentiometric head is represented relative to Digital Elevation Model employed here. Note the potentiometric head for the base of the Triassic aquifer may be higher than the potentiometric surface of the upper aquifers.

The potentiometric surface in the Permian Colinlea sandstone aquifer was compiled from the small number of available bores to provide an indication of the available pressure in the deeper sediments at this location. The interpretation suggests a horizontal flow direction in the Permian sequence from the west to east (Figure 118b) in addition to the main gradient with a south-north direction (Figure 92). A fine-scale view of this inferred surface (Figure 118c) suggests that the potentiometric surface in the Permian aquifer is slightly above the surface level of most of the Doongmabulla Springs except the Geschlichen, Camaldulensis, Yukunna Kumoo and Surprise Springs which have elevations above the inferred potentiometric surface. The band of potential head in the Permian aquifer at the left-hand side of Figure 118c results from two separate measures of head in the Shoemaker Bore with the uppermost measurement (590m depth) representing the higher measurement of head. The band of head at the right-hand side of Figure 118c results from differences in potentiometric head between bores. However, the inferred head in the Permian aquifer is marginal to insufficient. For the groundwater in this aquifer to rise through the aquitard of the Rewan Formation there would have to be exceptionally low resistance within the hypothetical fault/fracture.

A major source of imprecision is that the head in the Shoemaker Bore (Figure 118a, Appendix D) is inferred from two drill stem tests, an indirect measure of hydraulic head. There are also imprecision associated with determining hydraulic head at the site of the springs from the location of the bores informing the potentiometric surface (Figure 115; Figure 117, Figure 118a), and with the digital elevation model. The result is that all the inferred heads in both the Triassic and Permian aquifers can only be tentative. The possibility of reopening the Shoemaker bore to more accurately define the potentiometric surface in the Permian aquifer could be investigated.

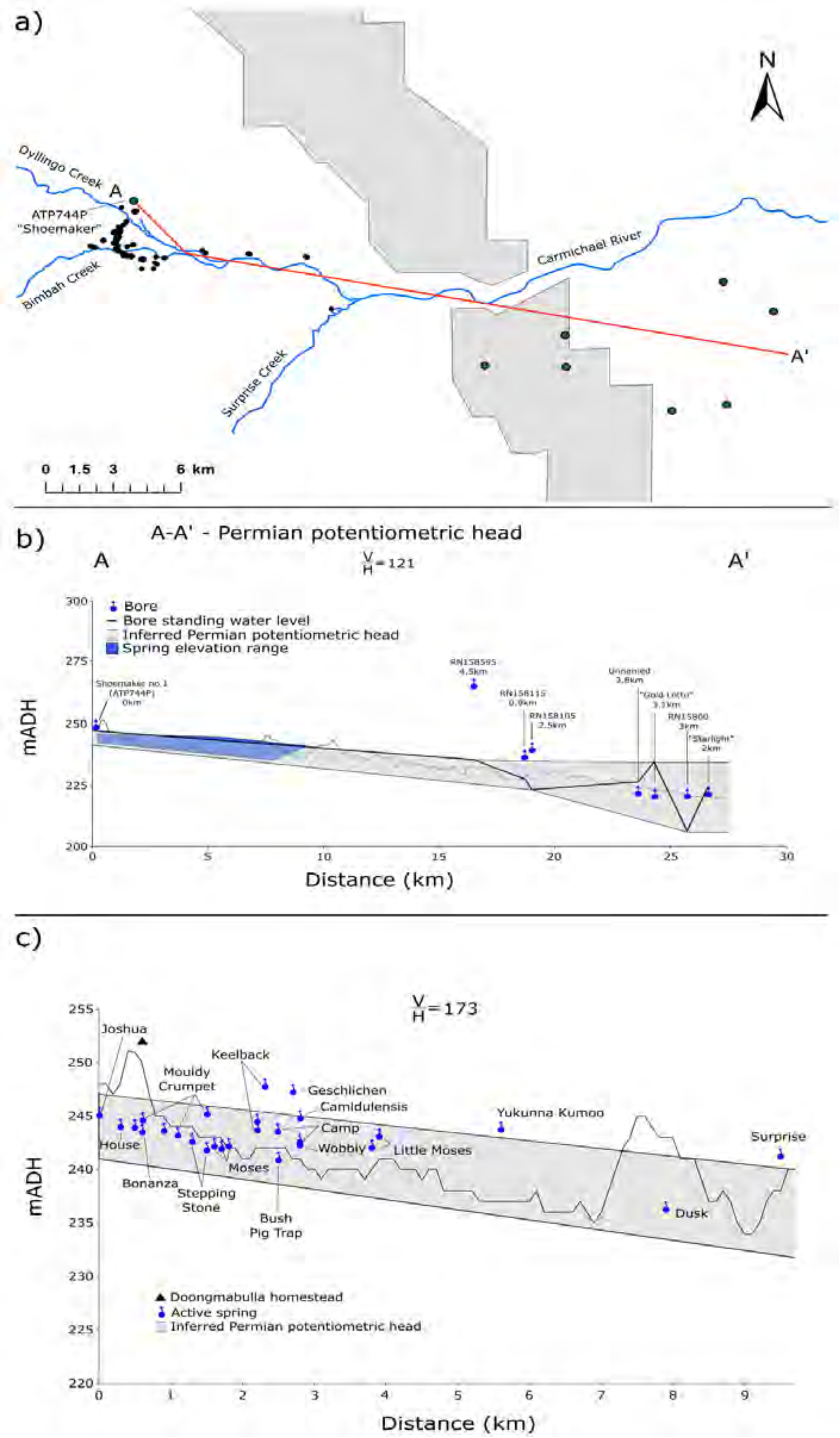


Figure 118. a) Location of springs (black dots) and the bores (green dots) used to create the potentiometric surface represented in b) and c); b) Inferred potentiometric surface (thick line) and topography (thin line) in an west-east cross section (A-A') of the Permian aquifer with bores identified (and the distance of their lateral displacement from the projection and the general position and elevation range of the springs (shaded blue); c) Close-up of the potentiometric head and the elevation of individual springs. The left hand end of the envelope of potentiometric head in the Permian aquifer on Figure 118c is a result of two pressure tests from the Shoemaker Bore with the uppermost head represented by a test from 590m and the lower from a test from 624 m deep.

While there is substantial uncertainty relating to the pressure surfaces in the Triassic and Permian aquifers, for the latter to provide a potential source for the springs, it is necessary to establish evidence of an open fracture or fault structure providing a conduit through the Rewan Formation. There has been some recent seismic survey in the vicinity of the Carmichael Mine 9km from the springs (Velseis, 2012) but there is no seismic data available in the vicinity of the springs. Thus no direct evidence of a fault structure in this location exists. Even if a fault should exist, the inferred head in the Permian aquifer may not be substantial enough to overcome the potential head loss.

The alignment of the western springs from Moses Spring in the south, arcing north through Stepping Stone and Mouldy Crumpet Springs, and then through Bonanza and House Springs (Figure 104) may be indicative of a structure potentially providing a conduit for vertical discharge. This would be consistent with the discharge character of these springs, including vertical conduits feeding discrete mounded vents (Figure 104, Figure 106). Fracturing in the vicinity of the Doongmabulla Springs could be the result of uplift to the west of the springs, and such a process has been invoked to explain the marked headward erosion of Dyllingo Creek (Figure 118) (Vine and Doutch, 1972).

A closed fault with displacement up to 100 m at the centre was recently identified from stratigraphic monitoring bores described in the Environmental Impact Assessment of the proposed China Stone coal mine (AGE, 2015) to the north of the Doongmabulla Springs (Figure 119). The fault is 30km from the Doongmabulla Springs, aligns with them, but its closure in the south is well-informed by stratigraphic information. It is possible that the geological forces creating the fault at China Stone had impacts elsewhere.

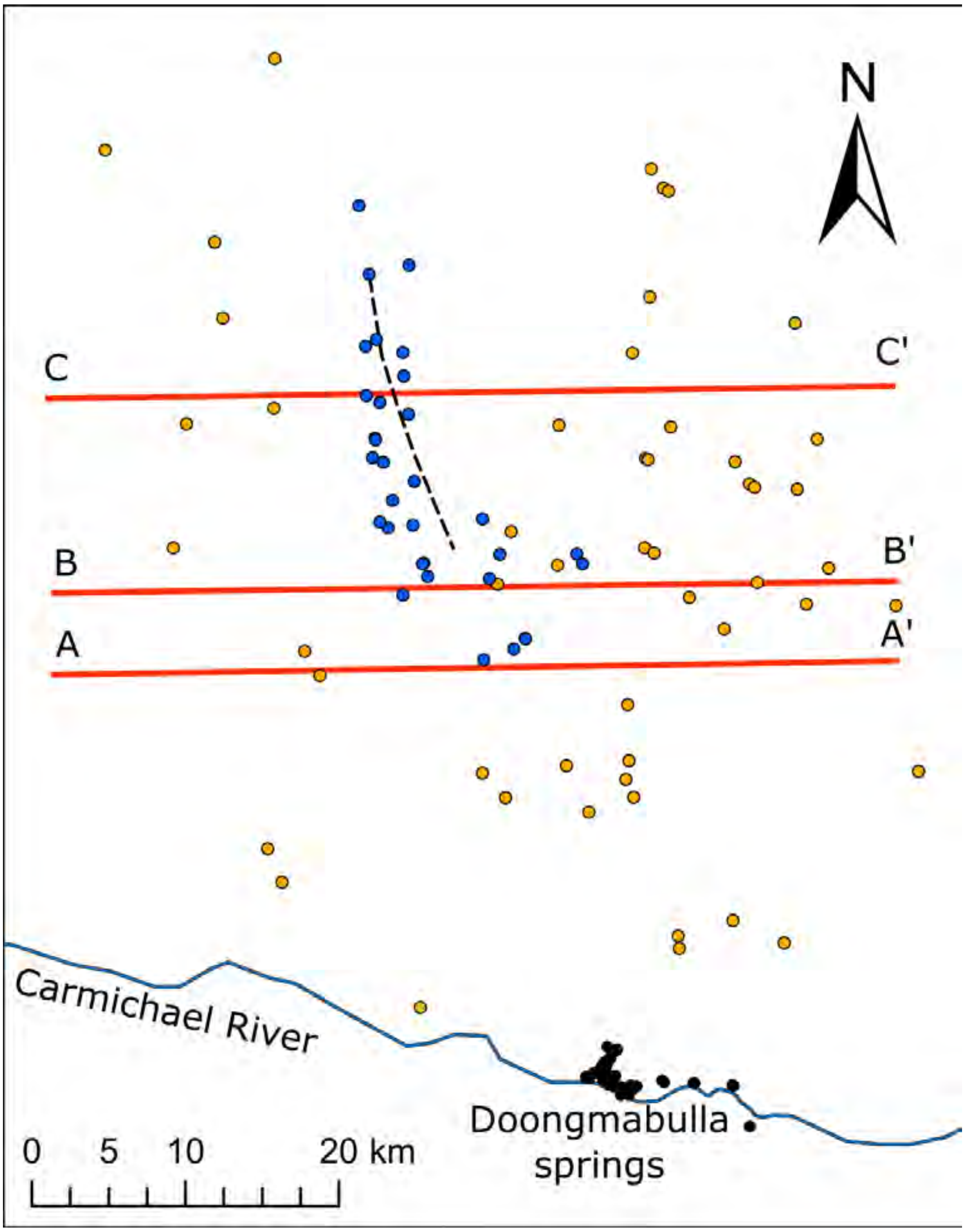


Figure 119. Fault structure at site of proposed China Stone mine (dashed line) with Doongmabulla Springs to the south. Stratigraphies informed by monitoring bores (blue dots) are also identified. While the information is not provided some pastoral bores (orange dots) may also have been included in the interpretation.

A local survey using high-resolution seismic reflection is an appropriate technique to reveal structural weakness within the Rewan Formation down to depths of about 500m (Steve Hearn pers. comm.). Such a survey should be conducted in the vicinity of the Mouldy Crumpet Springs where the location of the vents is suggestive of linear alignments (Figure 104) and there is excellent access for seismic equipment.

Analysis of isotopic signatures can be useful for determining source origins of aquifers. One of the tracers commonly applied is the $^{87}Sr/^{86}Sr$ ratios. Strontium ^{87}Sr is radiogenic; it is produced by decay from the radioactive alkali metal ^{87}Rb, which has a half-life of 4.88×10^{10} years. Thus, there are two sources of ^{87}Sr in any material: primordial that formed during nucleosynthesis along with other Sr isotopes, as well as that formed by radioactive decay of ^{87}Rb. The ratio $^{87}Sr/^{86}Sr$ is the parameter typically reported in geologic investigations and is partly controlled by water-rock interactions.

Preliminary results of strontium signatures from bores and springs in the vicinity of the Doongmabulla and Mellaluka Springs are not conclusive. There is considerable overlap in the radiogenic signatures from confirmed Permian and Triassic sources making it difficult to attribute the springs at Doongmabulla to aquifers of either origin.

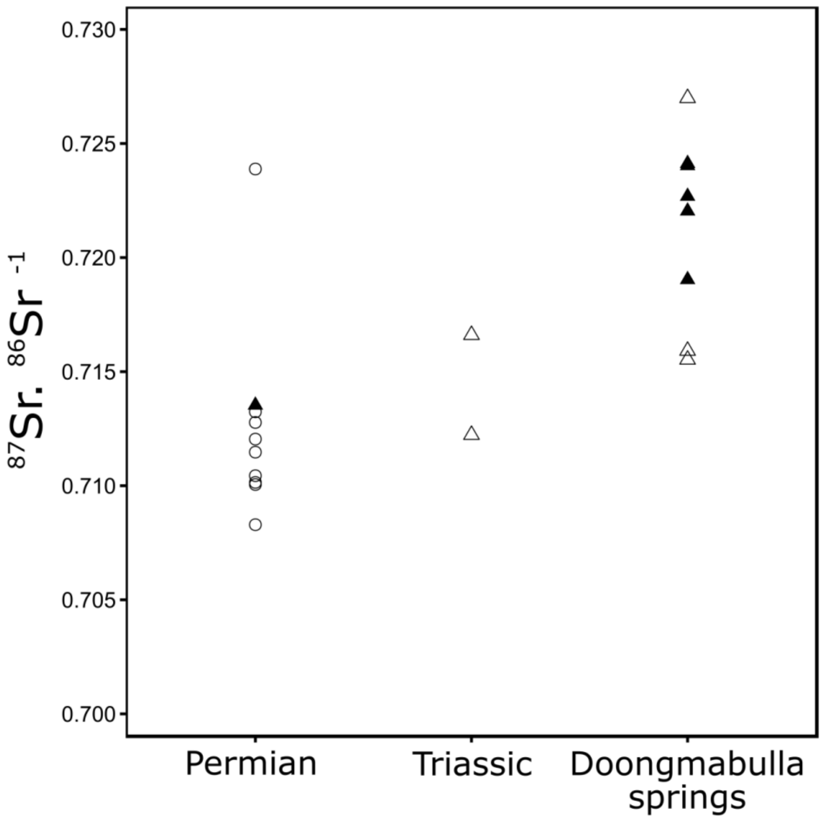


Figure 120. Strontium isotope signatures from bores and springs in the vicinity of Mellaluka and Doongmabulla. Circles are bores, triangles are springs with filled symbols representing springs with a discharge character; and open symbols represent springs with a recharge character.

8.3 Historical record

The springs at Doongmabulla are marked on an undated 19th century survey plan (Figure 121), and a newspaper article from 1890 demonstrates that they were well-known in the district, even if the location was not accurately reported:

> *A stream of water which runs 200 [?] miles north of Labona (Labona is a station on the Belyando) has plenty of feeders and causes the Carmichael to run in time of drought.*
> (The Maitland Mercury and Hunter River General Advertiser May 22, 1890, p. 6)

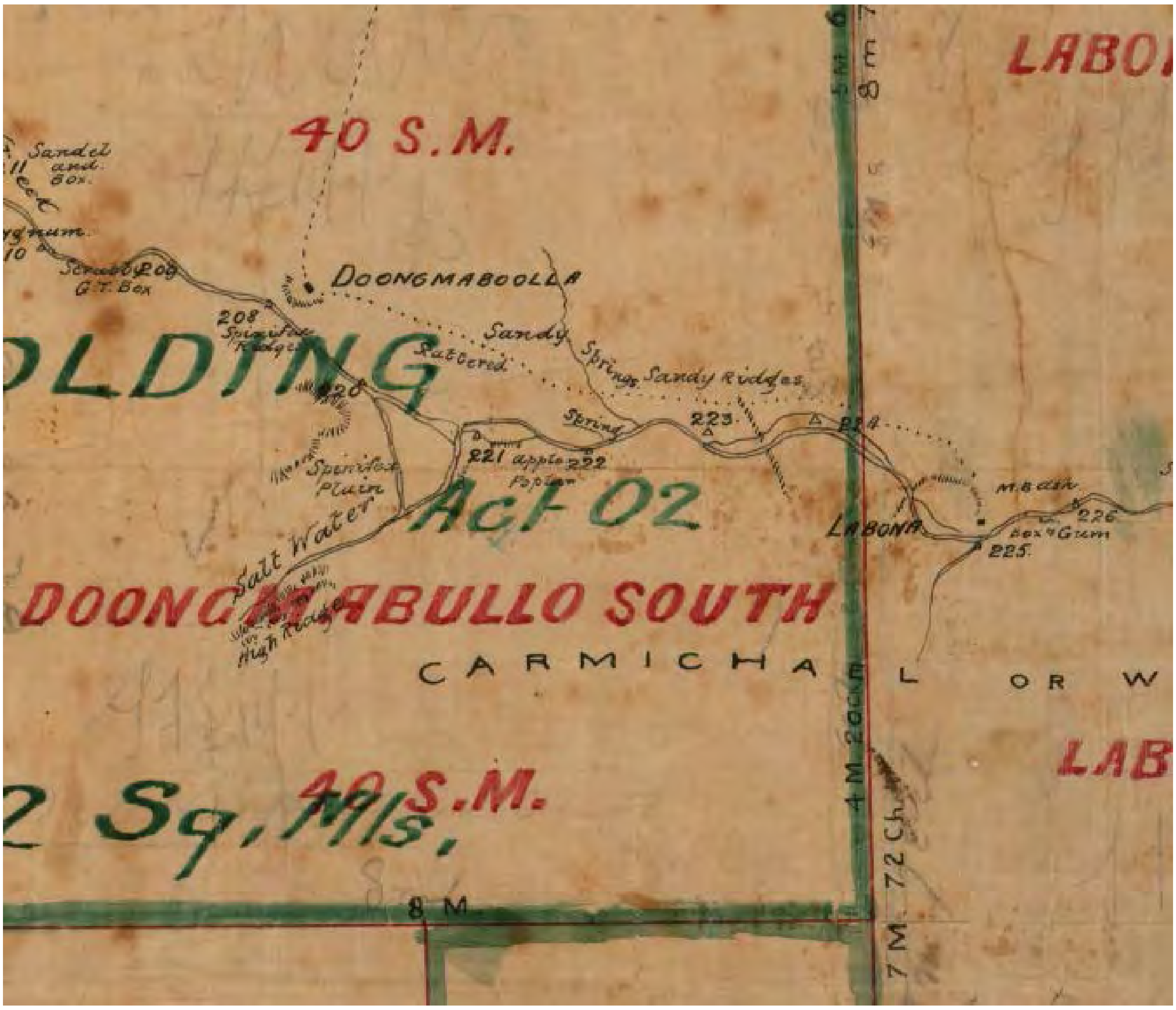


Figure 121. Section of survey plan K103.558. The springs are not quite accurately mapped in relation to the streams, and Doongmabulla homestead

Correspondent ‘Saltbush’, writing in The Queenslander 15 years later provided more detail, as well as a photograph that leaves much to the imagination, but is probably Joshua Spring:

> *After spending a pleasant week at Bowie I started to visit Doongmabulla. The track between the two places is in such bad repair that I decided to only take a light buggy and two horses. The journey was just a day's stage, about thirty miles, I found Mr. Frank North was at home, and was delighted to show me around. Doongmabulla has been rather badly served this year compared to the neighbours, as only 8in. of rainfall was registered here. Around the house the grass looks dry, but down the paddock, thanks to the springs, nice green couch and water grass are to be seen.*
>
> *Doongmabulla possesses the finest spring in the district in fact the one mentioned is nothing short of a natural artesian bore, as a stream a foot wide runs constantly to the garden. The water carries a percentage of soda, and all this country has salt in it, consequently it furnishes first-class water for stock. One of my pictures* [Figure 122] *shows the body of water from the spring, which is situated on the bank of the Carmichael River, famed for its bad crossing* (29 September 1906, p.29).

Figure 122. 'The Springs, Doongmabulla' as they appeared in The Queenslander on 29 September 1906, p. 21; this photo is probably of Joshua Spring that has now been extensively modified.

The 'stream a foot wide runs constantly to the garden' is evident on the aerial photograph from 1952 (Figure 123), taken prior to the modification of Joshua Spring undertaken during the 1990s (John Wilkinson pers. comm).

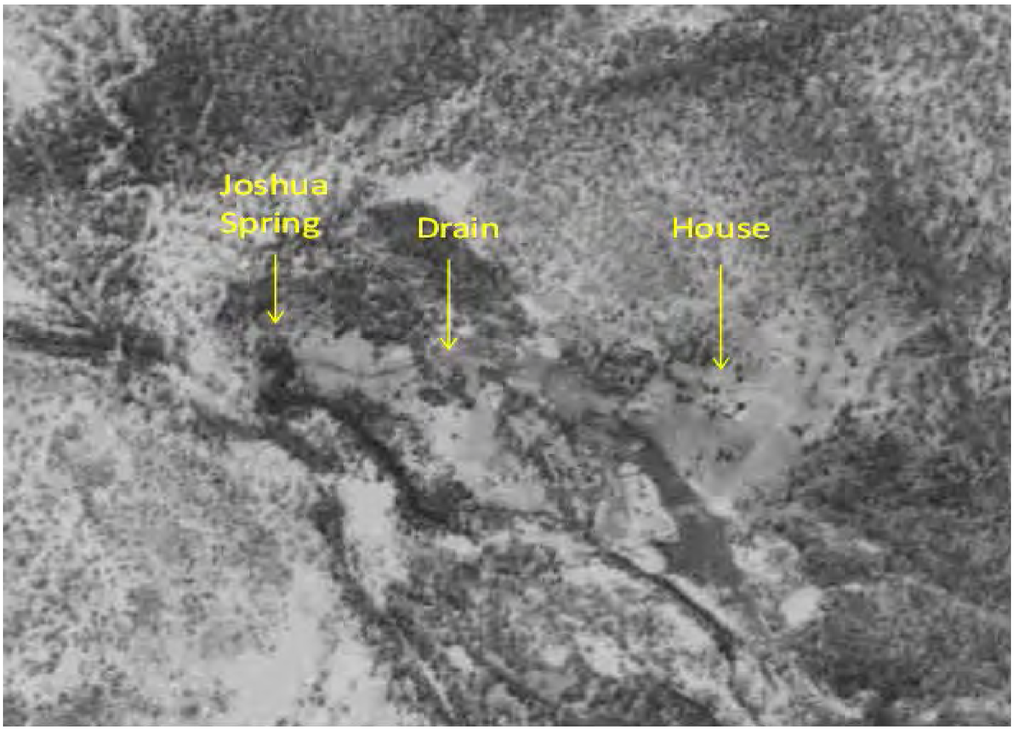


Figure 123. June 1952 aerial photograph showing the drain connecting Joshua Spring and the House and garden Doongmabulla.

The Doongmabulla springs were not mentioned by J. Alfred Griffiths in the late 1890s but were described by the geologist Danes who toured the region in the early 20th century,

> *…the biggest springs being near Doongmabulla about 3 miles east from the junction of Dyllingo and Carmichael Creek. They issue a permanent stream of water, whose capacity is estimated at least to 1,000,000 gallons daily flow…The water at the springs is cold, and very good for drinking purposes* (Danes 1909:92)

8.4 Cultural history

8.4.1 Aboriginal

The Wangan and Jagalingou people have a long and continuing connection with the country encompassing the Doongmabulla/Labona springs. A grindstone baseplate (Figure 124), an axe (Figure 125) and suspected hearths (Figure 126) as well as a sparse scatter of stone artefacts are apparent in the vicinity of the Doongmabulla Springs. Scar trees have been found along the Carmichael River.

Figure 124. Grindstone baseplate with worn groove on lower right in vicinity of Doongmabulla Springs

Figure 125. Stone axe found at Doongmabulla Springs

Figure 126. Suspected hearth at Doongmabulla Springs

8.4.2 European

The main track between the port at Bowen and Bowen Downs, one of the largest original sheep stations, established in the early 1860s, traversed a relatively low elevation crossing over the Great Dividing Range at the headwaters of Dyllingo Creek. Over time, other stations were established along this track. Doongmabulla Springs were valued as a rare source of reliable water:

> *This drive, or road, has been and still is known as the Bowen-Bowen Downs road and it should always be remembered was marked out by men who rode out on horses from Bowen and St. Lawrence to choose it. As far as I know, it still remains the only place where one can eventually cross over from the eastern waters to the fall that is called the western watershed (the upper waters of Cooper's Creek) without striking stony ground. The road was through fairly good country until they came to Bulliwallah. From there, they came across a high dry belt to Springs at Doongma Lagoon on Ulcanbah. Fred's Lagoon camp was followed by one at a soak or spring on the country now known as North Oakvale.*
>
> *…Going back along their route one is struck with the grand bushmanship of the men who opened this road, picking their way through ridges which spelt death to starving stock, picking out watering places which if missed would have meant miles of dry country on each side The ti-tree country on Corinda juts out in an easterly direction with miles of country on either side when they picked it. I am told one year a number of carriers came out with stores, tools, furniture, timber for the newly forming Uanda station. Coming to Wattle Soak, they found it dry and they had a bad time going back to Springs on Doongmabulla and camping until storms allowed the loading to proceed to its destination on the western side of Torrens Creek. Here, the original Corinda home stead was formed.*
>
> 'A Saga of the Old Station Hand – the story of the opening of the inland from Bowen' by 'C.F.B.', (The Longreach Leader 8 December 1948, p.58)

The transformation of Joshua Spring is viewed with wonder by the few people who have witnessed the outflow. Robbie Acton, the son of one of the previous owners of Doongmabulla, was correct when he observed that there is nowhere in country Queensland where you could see anything like that spring (pers comm. May 2015).

8.5 Biological values

Doongmabulla Springs are a large spring group providing habitat for many endemic species and great diversity of wetland vegetation types. They occur in a sub-humid environment (mean annual rainfall is about 516 mm) and are situated adjacent to the Carmichael River which flows into the Belyando River which then joins the Burdekin River that flows to the east coast near Ayr. The environmental setting contrasts with most of the other springs in the Great Artesian Basin which occur in the internal drainage of the Lake Eyre Basin in more arid environments. They represent a large complex of wetlands with many individual vents feeding about 160 wetlands varying in size from small clumps of wetland vegetation fed by miniscule discharge to a spring wetland of about 8.7 ha in size. A unique feature of the Doongmabulla Springs is the diversity of forms and vegetation types, with various levels of endemism.

The wetlands at Moses, Keelback, Geshlichen, Camp, Stepping Stone and Mouldy Crumpet Springs provide habitat for many spring wetland endemics and the sedge that characterises discharge springs elsewhere *Cyperus laevigatus*. Spring endemics include *Eriocaulon carsonii, Chloris* sp. (Edgbaston RJ Fensham 5694), *Eriocaulon carsonii*, *Eryngium fontanum*, *Hydrocotyle dipleura*, *Myriophyllum artesium*, *Panicum* sp. (Doongmabulla RJ Fensham 6555), *Sporobolus pamelae* and *Utricularia fenshamii. Panicum* sp. (Doongmabulla RJ Fensham 6555) is only known from one spring in the Mouldy Crumpet spring group, but was chewed down by cattle when it was recently discovered and may be more widespread. The macro-algae *Nitella tumida* occurs in the wetland of Moses Spring, and is previously only known from the type specimen collected by A.T. Vogan in 1889 from the Mulligan River where it was probably associated with the permanent springs in this vicinity. Non-endemics also occur in the spring wetlands with high concentrations of endemics including *Baumea rubiginosa, Eleocharis equisetina, Ischaemum australe, Leersia hexandra* and *Phragmites australis* which can be dominant in local areas. *Melaleuca leucadendra* forms dense forest thicket around the head of the main vents feeding Keelback Springs (Figure 127). *Myriophyllum artesium* occurs in the wetlands fed by the outflow pipe of Joshua Springs. *Fimbristylis blakei* is a spring wetland endemic typically found on outcrop springs in northern areas and also occurs at Joshua Springs. There are populations of the introduced ponded pasture grasses *Hymenachne amplexicaule* and *Echinochloa polystachyus* that has established on the outflow channel of Joshua Spring.

Figure 127. Keelback Spring with a dense thicket of *Melaleuca leucadendra* around the vent, Small vents in the foreground are rich in endemic species.

In the scalded areas around the Moses and Mouldy Crumpet Springs are other ‘scald endemics’ including *Trianthema* sp. (Coorabulka R.W. Purdie 1404), *Sporobolus partimpatens, Sclerolaena “dioceia”* and *Dissocarpus* sp. (Doongmabulla E.J. Thompson+GAL21). *Dactyloctenium buchananensis* and *Sphaeromorphaea major* are also very restricted species that occur in these scalded areas. There are some scalded areas around the House Springs and Camp Springs but *Trianthema* sp. (Coorabulka R.W. Purdie 1404) is the only scald endemic occurring in these areas.

Little Moses spring has a diverse assemblage of wetland species but none of the endemic species known from the Moses and Mouldy Crumpet spring groups. *Baumea rubiginosa, Eleocharis equisetina* and *Fimbristylis blakei* are typical dominants. The populations of this species at Doongmabulla are outlying southern populations. The spring wetlands of the Dusk, Yukunna Kumoo, and Surprise springs do not have any endemic species. The wetland of Yukunna Kumoo Spring is shaded under a canopy of *Eucalyptus camaldulensis and Melaleuca fluviatilis* with scattered individuals of the palm *Livistona lanuginosa* (listed as Vulnerable under the Nature Conservation Act 1992) (Figure 128).

Figure 128. Yukunna Kumoo spring wetland.

There are no confirmed spring endemics amongst the invertebrate community at Doongmabulla, although the taxonomic status of the fauna assemblage is incomplete. The molluscs, particularly those in the family Hydrobiidae, are often represented by endemic species in spring wetlands. At Doongmabulla there are no Hydrobiidae, although other families, Bythiniidae (*Gabbia fontana*) and Planorbidae (*Glyptophysa* sp. and *Gyraulus* sp.) are represented. A species of aquatic mite (*Mamersella* sp. AMS KS85341) is of unknown endemic status.

Because of the diversity of wetland vegetation, the Doongmabulla Springs is an ideal location to examine spring processes and chemistry as determinants of the biological community and the habitat conditions required for spring endemics.

An ordination of the wetland species was conducted using individual wetlands as the sampling unit to assess variations in the composition of the flora with water pH and conductivity (at the vent). The NMDS ordination separates sites in two-dimensional space such that the distance between sites best approximates their floristic similarity. Site pairs with very similar species composition will be represented near each other in the ordination space and sites with few species in common will be distant. The first axis of the ordination seems to be related to floristic diversity with diverse but non-endemic assemblages at one end and small springs with low species richness at the other (Figure 129). The second axis of the ordination is related to the proportion of species always associated with discharge springs (*Chloris* sp. (Edgbaston R.J.Fensham 5694), *Cyperus laevigatus, Eriocaulon carsonii, Eryngium fontanum*, *Fimbristylis ferruginea*, *Hydrocotyle dipleura*, *Myriophyllum artesium*, *Sporobolus pamelae, Utricularia fenshamii*). The vectors for water pH and conductivity at the discharge vent are non-significant through the ordination space, which suggests that these are not important determinants of the plant species composition over the wetland as a whole.

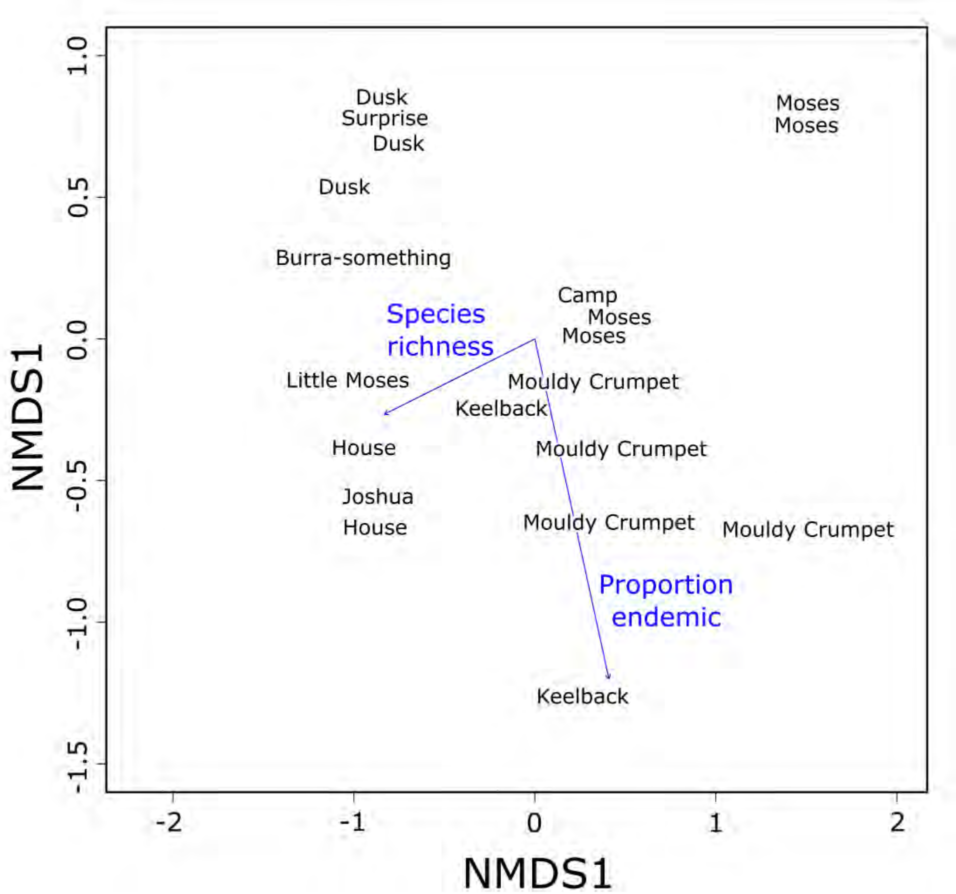


Figure 129. Non-metric multidimensional scaling ordination of wetlands of Doongmabulla Springs. Vectors providing the optimal direction of species richness and the proportion of endemics are also presented and labelled in blue.

Another preliminary analysis was conducted to examine these relationships at a finer scale. One m^2 quadrats were laid down throughout the wetlands of Camp, Geschlichen, Keelback and Moses Spring and all species were recorded. The water pH and conductivity was determined from the centre of these plots. An endemicity index was calculated based on the number of the ‘discharge endemics’ divided by the total number of species in the quadrat. There was no relationship between this endemism score and conductivity, but there was a weak relationship between endemism and alkalinity (Figure 130). This result suggests that the habitat conditions that suit the endemic species are partly a result of chemical changes that occur to spring water after leaving the vent. Alkalinity generally increases in the tails of springs with the degassing of carbonic acid, held in solution in groundwater, which converts to carbon dioxide under atmospheric conditions (Keppel et al., 2011). More work is required to understand the nature of chemical patterns in the spring environment and the habitat characteristics that favour the species endemic to discharge spring wetlands.

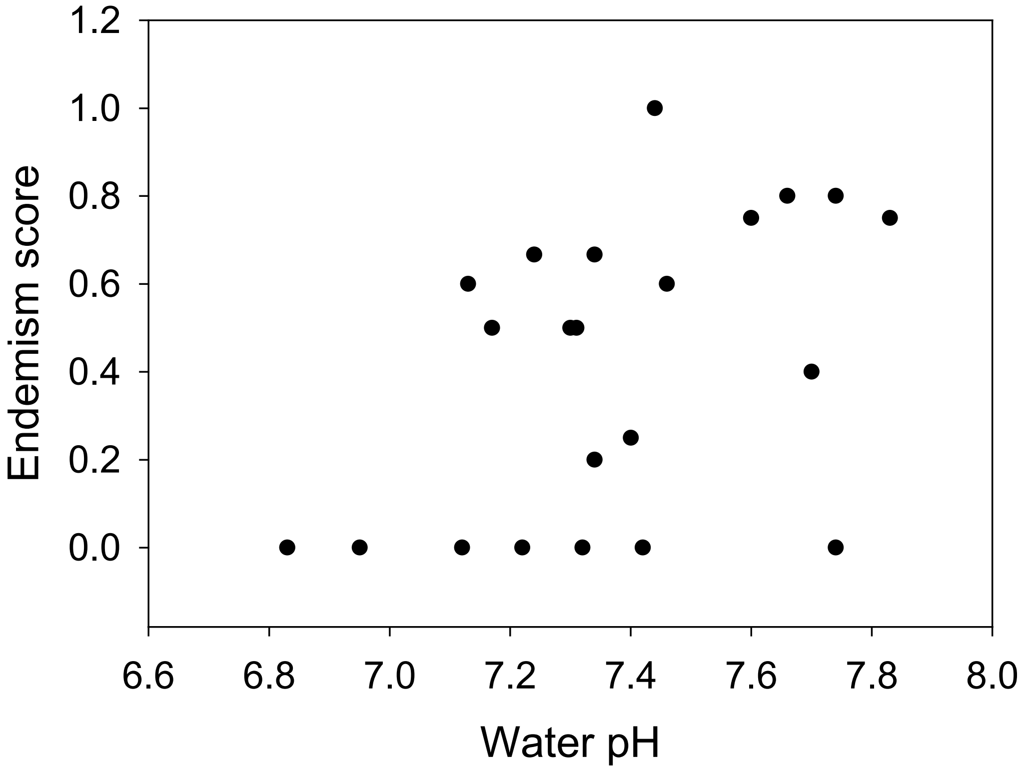


Figure 130. Preliminary results suggesting a positive relationship between water pH and endemicity in Camp, Moses and Keelback Springs (Spearman's Rank Correlation rho = 0.48, *P* = 0.024).

8.6 Key threats and management

The springs at Doongmabulla are protected under a Nature Refuge Conservation Agreement. This agreement was signed between the landholders and the State of Queensland and allows for continued production and land management activities such as sustainable grazing and water use, but prohibits further excavation, the introduction of exotic species to the springs and groundwater extraction that will impact on spring flows. The springs are currently within paddocks that are only irregularly grazed. After a bout of grazing the springs appear to be impacted around the edges with cropped herbage, pugging and fouling with dung. Cattle are regularly bogged in the vents of Moses Springs and perish if they are not located and extracted. However, these impacts are ephemeral and recovery is rapid when the livestock are excluded. It may be desirable to remove hymenachne (*Hymenachne amplexicaule*) and alamein grass (*Echinochloa polystachyus*) from the outflow of Joshua Spring, to ensure they do not spread into other spring wetlands. At the least, a baseline extent of the hymenachne and alamein grass populations should be established to determine if they are invasive.

The source aquifer of the springs is critical to considering any potential impact of the planned Carmichael Mine. The question of the source aquifer of the Doongmaulla Springs (DS) was addressed in the recent Queensland Land Court (Adani Mining Pty Ltd v Land Services of Coast and Country Inc & Ors [2015]QLC 48):

> *"[268] I concluded above, after considering the evidence as to the source aquifer of the DS, that I was concerned at the lack of direct investigation by the applicant of the area*

of the DS to determine the likelihood of faulting in the area. While I considered that on balance, it is unlikely that there was a continuous preferential pathway from the Colinlea Sandstone through the Rewan Formation, there was evidence to the contrary which raised some uncertainty as to the existence of faulting. There was also uncertainty as to the source aquifer of at least the Little Moses Spring and Dr Webb's evidence about the groundwater flow directions in the Colinlea Sandstone also raised further uncertainty as to the source aquifer of the DS. "

"[318] As discussed at length above, I concluded that, on balance, the DS are not fed by the Colinlea Sandstone. If that is correct, then Mr Wilson (who relied on Dr Merrick's calculations of loss of spring flow) said that the reduction in wetland would be no greater than about .7 ha, which was not substantial and no endemic species would be lost. Dr Fensham said that the persistence of viable populations would almost certainly be maintained. "

Whether the springs with discharge character at Doongmabulla emanate from a Triassic or Permian aquifer is unresolved without further data. Drilling of new monitoring bores in the vicinity of the springs, and appropriate seismic survey are required. A high-resolution survey of spring elevations would also improve the accuracy of predictions relating to spring flows and the potentiometric surface of potential aquifers. Water chemistry data for the Doongmabulla Springs is stored in the data-base and could serve as a baseline to assess potential future impacts of mining on the groundwater quality of the springs.

9 Western Queensland Tertiary Springs

9.1 Overview

The term ‘desert spring’ conjures images of exotic oases: bubbling crystal pools shaded by rustling date palms, creating welcome verdure amidst barren sandy wastes. The ‘oases’ of inland Australia are different. Often muddy and stagnant instead of clear and bubbling, dwindling to slimy green puddles towards the end of the dry; tiny and hidden instead of lush and flamboyant. Most subtle of all are the small water sources fed by localised aquifers – springs and native wells or *mikiri* – hidden deep within gorges in low stony ranges, guarded by waves of red desert dunes, or soaking into sandy flatlands.

In some areas these small oases provided the only reliable water source across hundreds of kilometres and dictated all human and animal activity during dry times. They were critical to the survival and movement of Aboriginal people over thousands of years. From the 1860s they were ardently sought and relied upon by early white settlers. Both Aboriginal people and the early pastoralists had an encyclopaedic knowledge, borne of necessity, of even the tiniest water sources. The importance of these waters is reflected in the rich mythology and varied testaments to human activity, indigenous and European, surrounding them.

With the advent of bore drilling and excavation of large dams, many of these small oases have slipped into obscurity. While they could provide sufficient water for a small family, a boundary rider’s hut or a flock of sheep, their flows are rarely sufficient for modern household needs or thirsty mobs of cattle. And with our faster mechanised mode of moving through country, they are no longer critical as camp spots, stopovers or change stations. Some have ceased flowing and are long forgotten. However even the more accessible springs which remain active are likely to be passed at speed with barely a backward glance. A few remain well-known by local townsfolk, opal miners and graziers, although are seldom relied upon as they were up until a century ago.

The focus of this chapter is those springs which emanate from local Tertiary sandstone aquifers in inland Queensland and northern New South Wales (Figure 128; Table 20). They may have flow paths restricted to a few hundred metres but often provide isolated and important sources of permanent water. While research over the past decade has documented the location, hydrogeology, biological values and cultural history of Great Artesian Basin (GAB) springs in inland Australia (Fensham et al., 2004; Silcock et al., 2014, this report; Powell et al., 2015), our knowledge of the location and activity status of non-GAB springs in the aridlands remains very patchy (Brim-Box et al., 2008).

Springs in recharge areas along the eastern edge of the GAB share many characteristics with non-GAB springs (Fensham et al., 2011), but are not considered here (See Fensham et al., 2011; and Silcock et al., 2014 for a discussion of these outcrop springs). After a succession of wet summers, water can seep out of saturated substrate, including sandstone ranges, sandy creekbeds and dunes or sandridges, for some months but then the same areas may be dry for years. Our focus here is those areas where water is, or was at the time of pastoral settlement, present for more than 70% of the time.

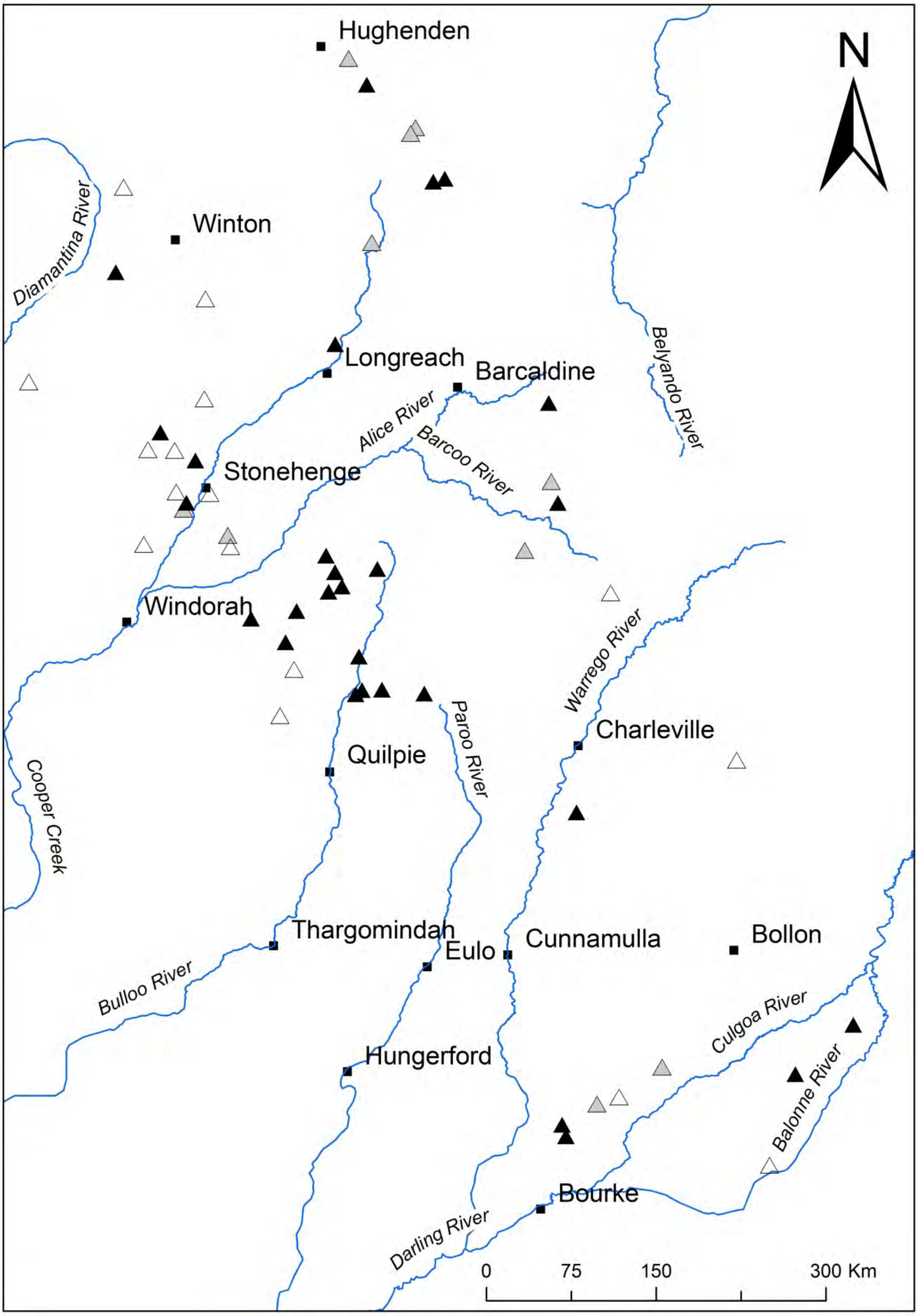


Figure 131. Spring complexes emanating from Tertiary (non-GAB) sandstone within the boundary of the GAB, western Queensland and northern New South Wales. Spring complexes with 100% active springs (solid triangles), partially active (grey triangles) and 100% inactive (open triangles) are identified.

Table 20. Summary of the status of the Tertiary springs at the complex, wetland and vent scale.

	Complex			Spring		Vent	
	Active	Partially active	Inactive	Active	Inactive	Active	Inactive
Outcrop	30	11	22	106	62	107	62
Discharge	0	0	0	0	0	0	0

9.2 Hydrogeology

The Tertiary included many periods of extensive deposition that blanketed inland Australia with sandstone. Since this time the sandstone has been eroded away leaving remnants of the former surface. The most extensive areas of these Tertiary sandstones occur at the heads of the major catchments, the Bulloo, Paroo, and Coopers Creek.

The sandstone has been extensively altered by weathering processes and indurated and clay-rich strata that are relatively non-porous predominate. The springs probably have their source with rainwater percolating through fissures in the impermeable material until it hits a zone of porous sandstone that has been relatively unaffected by weathering Figure 132. This recharges local aquifers which are confined by the impermeable sandstone and/or the underlying Cretaceous sediments of the Winton formation. Under this mechanism the lag between recharge and discharge is probably in the order of decades (Leblanc et al., 2015). These aquifers are exposed through erosion at the edge of the Tertiary land surface, and most springs (75%) occur at the base of escarpments in gorges or incised gullies (Figure 133). They are disconnected from the aquifers of the GAB, which are much deeper and below the Cretaceous sediments (Habermehl 1982). Some occur within or adjacent to streams in broad creek valleys or on sideslopes, but are still fed from surrounding Tertiary sandstone range. Water is generally slightly acidic and has low conductivity, reflecting its relatively short residence time (probably years to decades).

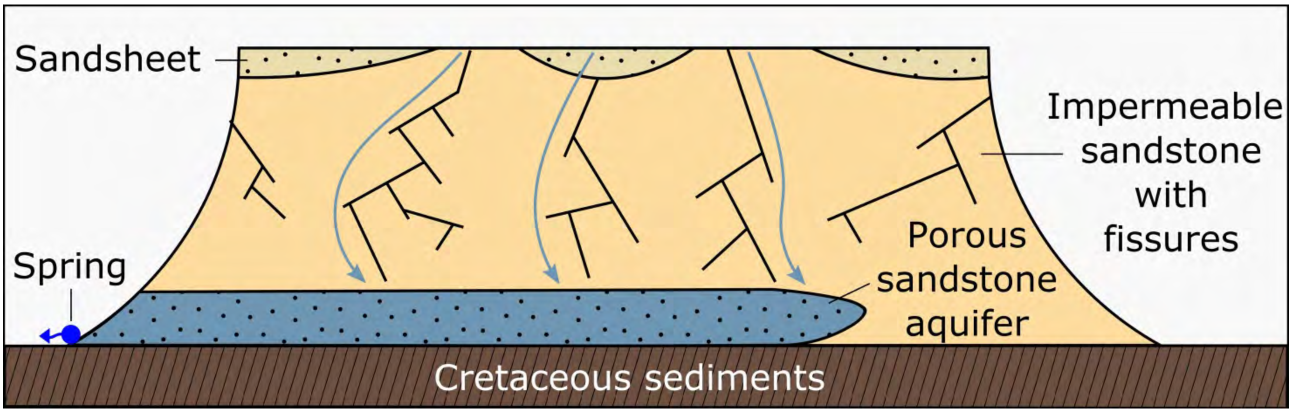


Figure 132. Conceptual diagram of a typical Tertiary sandstone spring at base of escarpment, where a porous sandstone aquifer is exposed by erosion of the plateau. This aquifer is confined by impermeable sandstone above and Cretaceous sediments of the Winton formation below. Unconnected GAB aquifers (not shown) occur at depth below these sediments. The aquifer is fed by local rainfall through fissures in the impermeable sandstone.

The Grey Range and associated range systems and the Goneaway Tablelands are the major areas of Tertiary sandstone in the study area. Springs are not distributed evenly, with some areas harbouring spring clusters while large expanses have no springs. The highest concentration of Tertiary springs occurs in the northern Grey and Gowan Ranges on the watershed separating the Bulloo-Barcoo catchment and in the Stonehenge district on both sides of the Thomson River (Figure 128). Idalia National Park/Highlands and two 'mother plateaux' on Budgerygar and Swan Vale (

Figure 133) are characterised by especially high concentrations of springs. There are also clusters of Tertiary springs in the Great Dividing Range along the eastern edge of the semi-arid zone, in the western Desert Uplands between Muttaburra and Hughenden, south-west of Winton and in the Charleville district.

There is a line of springs from Culgoa Floodplain to Lila Springs, many of which are unlikely to emanate from the GAB as discussed by Silcock et al. (2013). Three of these, including Nulty, Scrubber (

Figure 133) and Colless Springs, are associated with the Tertiary land surface which outcrops east of Enngonia. All seem to be permanent, although Nulty is the largest and its excavated pool maintains a constant water level (Brian Bambrick, pers.comm.). Colless and Scrubber are soaks emanating from rocky ground and both fluctuate with recent rainfall. To the east, Cowragil (

Figure 133) and Cumborah springs are both considered to be Tertiary rather than part of the GAB Bogan River supergroup. Colless differs from all other Tertiary springs visited in that it emanates from near the top of a ridge, rather than the footslope or drainage line, but seems to be permanent (

Figure 133).

Other non-GAB springs were documented across the study area in basalt. These are recorded in the Queensland Springs Database, but not considered in detail in the LEBSA report.

Figure 133. Tertiary springs of western Queensland and northern New South Wales: Black Spring, Budgerygar, the biggest Tertiary spring in the study area (top left); Harlow vent 2, on ironbark/poplar box flat, Idalia National Park (top right); Scrubber Spring atop a stony ridge, Stanbert, east of Enngonia (middle left); Cowragil Spring, The Springs, south of St George (middle right); and Goon Goon Spring, Evengy, west of Stonehenge (bottom).

9.3 Historical record

Only a couple of Tertiary springs are marked on the original survey run plans: two in the Enniskillen Range (Figure 134) and three on Highfields Holding (Figure 135). More than half are marked on 4 mile maps dating from the 1920s, and these are often the only records of these springs, particularly in the Quilpie-Yaraka area (Figure 136). The location of marked springs is often inaccurate, and in some cases there is doubt as to whether springs ever existed in the marked localities as they are not known to long-term landholders and no signs of springs were found on the ground.

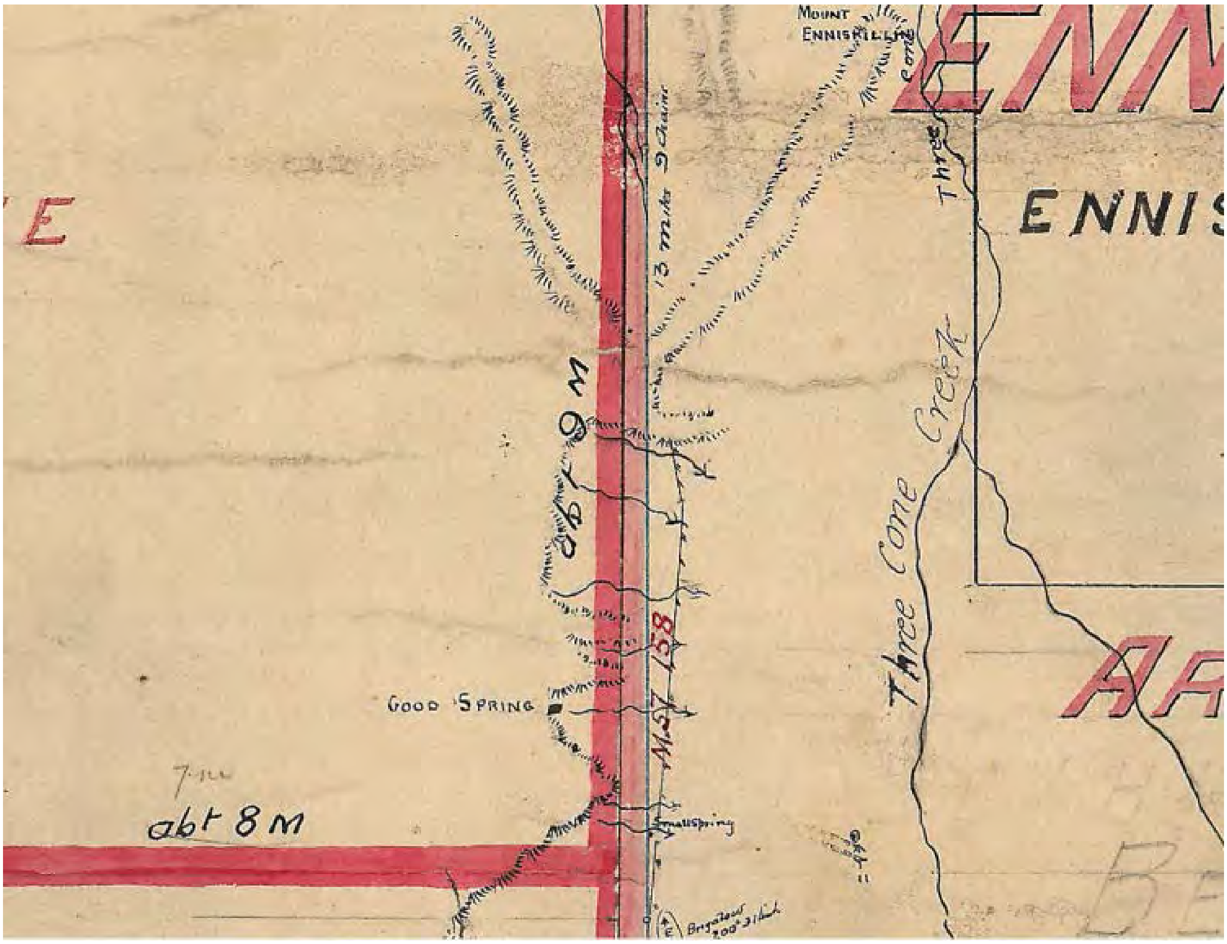


Figure 134. Survey Plan M57.146 (circa 1880s) showing 'good spring' and 'small spring' in Enniskillen Range south of Blackall, central Queensland

Figure 135. Survey plan M.57.161, showing three springs (faint text) on the edge of Highfields Holding south-west of Winton.

Figure 136. 4 mile series 1, 7C (1920), showing two springs on Stoneleigh Run, one on Yapunyah Creek and the other on Yarran Creek.

The main historical observations of non-GAB springs were made by J. Alfred Griffiths, who documented springs and bores in Queensland for the government in the late 1890s. His record has been invaluable in understanding the history and demise of GAB springs across the Basin (Fairfax and Fensham, 2002). Griffiths' recording of the non-GAB springs is more opportunistic and patchy. He describes springs around Charleville (Arabella Run springs), Stonehenge (Swan Vale and Warbreccan Runs) and in the Desert Uplands (Bromvil, Caledonia, Uanda) and an outlying spring south of Tambo (Clarke's) (Table 21). For the springs visited, Griffiths typically provides a brief description of its location and setting and an estimate of flow and number of stock able to be watered. J.M. Royle described Bexley and Springvale springs near Longreach in *Artesian Records vol. 14* (October 1912-March 1913), while Abbott described the 'Murillo Conglomerate' springs and wells in New South Wales in the 1880s (see section above).

Table 21: Non-GAB spring descriptions, J. Alfred Griffiths (1898-1900)

Spring	JAG description	Current status
Akers, Arabella Run, east of Charleville	'…are on GJs (?) 11 or 12V [refers to blocks] south of the railway; when cleared yield about 1000 g.p.d. and have stood the last three years drought.'	Inactive
Bald Hills, west of Stonehenge	'…are almost 12 miles east of Topham. There are 5 small unimproved springs, the best of which will supply about 100 horses in good seasons; but in the extreme drought of 1898 these springs failed.'	Inactive
Bimerah, Stonehenge	'There are several rather unimportant springs on Bimerah in the north end of the Johnstone Range, none of which known are utilised at present.'	Inactive
Caledonia Springs, north of Muttaburra	'…are on the road from H.S. to Uanda & 14 miles from the Station…The springs are in a clayey depression ? ¼ mile ? at the head of Boggy Creek, and any hole one or two feet deep is filled with pot able water in a few hours, A well 6 x 3 feet has been sunk 52 feet in the dry white clayey… The unprotected holes are soon trampled into bogs by the Uanda cattle…These springs are perennial, and did not fail in the 1892 drought. '	Active
Campbell's and Flockart's springs	'…are about 16 to 17 miles east from homestead near Curry's WH.'	Not found; assumed inactive
Clarke's, Nive River, Drensmaine	'…about 4 miles below the Government Bore site + opposite Cobb & Co's Darby Point Change House. It soaks out the east bank of the Nive River, has been logged and improved, and supplies about 300 head of large stock, including the mail horses. It has never been dry in the worst drought years.'	Inactive
Coctina Creek, south-west of Stonehenge	'…becomes brackish when low.'	Not found
Goon Goon Spring, south-west of Stonehenge	'…on Gum Creek percolates out…and supplies about 1500 sheep.'	Active but ephemeral
K.1.N. Spring, south-west of Stonehenge	'…on Flaggy Creek provides sufficient water for 3000 sheep.'	Active but diminished
Mason's Spring, south-west of Stonehenge	'…fills a waterhole 160 yards long. This group are in the Spring Paddock, and are marked by bullrush puddles(?) and the waterholes contain small(?) fish.'	Not found; assumed inactive

Spring	JAG description	Current status
Niagara Spring, south-west of Stonehenge	'…fills a rocky pond 15 feet across & 6 feet deep, with about ½ mile of a chain of waterholes.'	Not found; assumed inactive
Peglers, Arabella Run, east of Charleville	'…west of Akers and supply about 500 g.p.d. to the homestead.'	Inactive
Red, Arabella Run, east of Charleville	'…a desert spring in the north of a little rocky gully (about 2 miles east of the bore) on Back (?) Creek leading to Angellala Creek. The water is rather ochrey, flows about 2000 g.p.d. and is lost in the sand after running a few yards'	Active
Simpsons, Afflecks and Guthries	'…small ones on the heads of Frasers Creek.'	Not found; assumed inactive
Swan Vale Run, Jundah	'In the main body of the Johnstone Range on Swan Vale Run are many perennial desert springs which are the only water supply for the same during droughts.'	Some active but much-diminished
Topham Springs, Westerton	'…22 miles north from the Warbreccan Homestead on Vergemont Run; there are two shallow wells about ¾ mile apart on the east slope, and deep trenches are cut out of which the water flows 25 450 yards in the droughts, and each well waters about 150 horses.'	Inactive
Whitewell Creek Spring, south-west of Stonehenge	' runs ¾ mile south & fills small waterholes.'	Not found; assumed inactive
Wood's spring, Stonehenge	'…on Frasers Creek is about 12 miles south-west of Grange [Evengy?] O.S. A 12ft well supplies 3000 sheep by bailing, and even more in wet weather.'	Inactive

9.4 Cultural history

9.4.1 Aboriginal history

Each spring documented here was almost certainly part of a story, mythology or song-line formulated and passed down over thousands of years. Coorigul or Cowragil Spring features in Aboriginal mythology as the start of a dreaming track following the Bogan River, and is the only non-GAB spring for which an individual story was found. It has been documented by anthropologists and is painted as a mural at a Lightning Ridge service station. There is a stone arrangement on the slope above the spring, consisting of large stones arranged in wavy lines. Traditional owners continue to visit the site.

There is a story from the pastoral frontier era which has been passed down through generations at Ray Station west of Quilpie (Mark Tully, pers.comm., June 2015). Tippo was a Boontamurra man who lived on Canaway Downs, and told a story about Patsy Tully riding into the ranges to peg out his land claims. A group of Aboriginal people were camped at the spring and were very surprised to see a white man on a horse. They debated whether to attack him, but decided against it due to Patsy's clearly-visible pistol. Apparently if they had known what a bad shot Patsy was, they wouldn't have been so hesitant! From this first encounter, Aboriginal people enjoyed a good relationship with the Tullys at Ray. The last Aboriginal man to live at Ray was Tiger, Tippo's grandson, who died in 1970 on a trip to Brisbane. The paddock where he last mustered still bears his name.

At other springs, the archaeological record provides mute testament to their mythological significance and importance as water sources in otherwise dry areas. Stone arrangements, mostly consisting of rings or circles and associated pathways, on plateaux through the northern Grey Range and southern Goneaway Tablelands (Knuckey, 1992; Jenkins, 2001) suggest the ceremonial importance of these areas (Figure 137). The network of small permanent springs and rockholes would have provided vital water for ceremonial gatherings (Simmons, 2007). On a low plateau west of Longreach stones are arranged to form an arrow pointing towards a formerly permanent spring. There are carvings, stencils and/or freehand paintings on rock walls above or close to springs in the stony mountain ranges throughout western Queensland, including at Cutzies Spring north of Blackall, Springvale west of the Thomson River, Swan Vale near Jundah, and Carisbrooke and Ayrshire Hills west of Winton. Common motifs include rainbow serpents, emu and kangaroo feet, handprints, boomerangs, cross-hatching, and circles and horseshoes of various shapes, sizes and configurations (Figure 137). There are also extensive carvings in a creekbed on Stoneleigh in the Cheviot Range, midway between two permanent springs.

As well as being intrinsically sacred, springs were of vital importance in an arid land, as campsites and nodes in trade and communication routes (Boyd, 1990; Harris, 2002). The concentration of artefacts in the vicinity of Tertiary springs, combined with their often considerable distance from other reliable sources of water, hints at the significance of these isolated waters. Some spring clusters are especially notable for their high concentration of artefacts, especially around Stonehenge (Figure 137), north of Blackall and north of Adavale. Quarries are dotted throughout the ranges, often near springs, where the combination of a ready source material of stone and permanent water allowed people to stay in these areas to manufacture tools.

Springs are not isolated entities in the ‘cultural landscape’ (Holdaway et al., 2000; Armstrong, 2001), and the proximity to other reliable water supplies would have been the principal factor in determining patterns of use of certain springs and regions. Springs 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 springs, rockholes and ‘native wells’ would not have supported large numbers of people on a permanent basis. It is believed that the sandstone ranges were visited only during good seasons, for ceremonial and meeting purposes, with little permanent occupation. This interpretation is supported by the archaeological record, with hearths and grindstones rarely found in the ranges but usually clustered along the major creeklines bisecting or on the edge of the range country.

Unsurprisingly, these small but precious sources of water were protected, and even enhanced, over thousands of years. People were required to be extremely circumspect in their behaviour towards 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 edge (Duncan-Kemp; cited in Watson 1998). ‘Water people’ saw that suitable corroborees were performed to maintain water supplies, and water spirits were honoured with gifts and offerings. 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), with ownership conferring responsibility for maintenance.

In central Australia, rockholes and springs were crucial water sources 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. 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 (Margarey, 1894). They sometimes covered smaller openings or pools with stone slabs and vegetation to minimise evaporation and exclude wild animals, which often fell in and drowned (Carnegie, 1898). While such physical cleaning and augmentation is not documented for western Queensland, it seems unlikely that vital water sources were not maintained or enhanced in some way. This raises the possibility that some springs, particularly smaller ones, were more permanent in the past than today and that their permanence at the time of pastoral settlement was dependent upon human intervention, as discussed in the final section of this report.

Figure 137: Examples of aboriginal cultural artefacts associate with Tertiary Springs: Rock art (top left), carvings on rock wall (top right), a serpent painting in a cave (middle left); a grindstone (middle centre); Aboriginal stone tools and cores (middle right); bora ring on a barren plateau (bottom left) and portion of an extensive ceremonial ground (bottom right).

9.4.2 European history

Unlike GAB springs, which provided critical nodes for exploration and settlement especially in areas with a paucity of other surface waters (see Harris 1990; Powell et al. 2013), Tertiary springs provide only small water supplies at scattered localities usually in rough country, which limited their role in early pastoral settlement. Tertiary springs do not feature in Queensland's exploration history as they do in the Northern Territory and Western Australian deserts, due to the comparative abundance of reliable waterholes along the major rivers (Silcock, 2009). These rivers provided natural corridors facilitating exploration, while ranges were viewed not as potential sources of vital water as in the western sandy deserts but as obstacles to be crossed, for example Burke and Wills in the Selwyn Range (Murgatroyd, 2002) or small blips barely worthy of a passing mention in an explorer's journal, for example William Landsborough crossing the Enniskillen Range (Landsborough, 1862).

Once the country was split up into pastoral runs, however, early settlers actively sought out and utilised the springs as important sources of water for both humans and stock. This importance is reflected in the fact that Tertiary springs are marked on old survey plans dating from 1860-1900 (Figure 134, Figure 135) and particularly the 4 mile map series from the 1920s (Figure 136). Properties were commonly named after the springs, for example Springvale, Spring Plains and Spring Hill in western Queensland. There are also numerous Spring Creeks dotted across western Queensland, however it seems that some of these were 'discovered' and erroneously named in good seasons when the quantity and quality of water present suggested a spring-fed origin.

Huts and homesteads were often built near springs, especially on runs without river frontage. Remnants of huts or camps are found at Old Idalia, Collabara, Old Morestone Downs, Wingara, Tooloomi (Figure 138), Scrubber, Colless, Hideaway/Two Mile, Cowragil, Billabong, Barcoorah, Clarke's, Westerton, Glencoe, Riverside, Old Swan Vale, Mt Windsor (Figure 138) and Highfields (Figure 135) springs. Other homesteads, such as those at Nulty Springs, have only been abandoned in the past decade, while some homseteads remain in the same location near springs or ex-springs but are now supplied by bores or dams. Springvale near Longreach is the only homestead which still relies on Tertiary spring water. The now-dry Stonehenge spring (Figure 139) used to supply water for the town during drought, as described by Griffiths:

> *'The Stonehenge Spring is about 3 miles SE from the town of Stonehenge, at the foot of the NW end of the Johnstone Range. An area of 160 acres around it has been recently resumed and gazetted. A well (6' x 3') was sunk about 16 feet, by the Bimerah Lease about 1890; it is entirely in rock and the water fills it & overflows slightly when not bailed. The capacity of the spring has only been tested by removal water carts [indecipherable] & 1000 gall per day could be bailed. The water is said to be of excellent quality, and supplies domestic drinking water to the town during drought'.*

Figure 138: Stone foundations and lone kurrajong near Tooloomi Spring, Glenora (top left); ruins of the original Mt Windsor homestead, built near a now-extinct spring (top right) and dry tank and windlass which used to supply Highfields house, south-west of Winton (bottom).

Figure 139: Rectangular depression marking the site of Stonehenge spring and well, with bucket hanging from log in background.

The Swan Vale Run springs east of Jundah played an important role in early pastoral settlement. James ‘Hungry’ Tyson bought Swan Vale in the 1880s. By 1898 his pastoral empire covered over two million hectares, including Glenormiston, Meteor Downs, Albinia Downs, Babbiloora, Carnarvon, Felton, Mt Russell, Wyobie, Tully and Tinnenburra in Queensland. He would bring stock from his properties to the east and hold them at Swan Vale, watering on the springs, until the first decent storm rains opened a safe passage to the west. He would then travel to Glenormiston via Vergemont Creek, the Mayne River, King Creek, Hamilton River and finally the Georgina. In this way, the Swan Vale springs, now shrunk to tiny puddles and some all but forgotten, were a key link in the early stocking of western Queensland.

Cattle continued to be watered on the Swan Vale springs and at springs to the south in what was formerly part of Jedburgh. According to Len McKay, a former Jedburgh manager, the cattle on this block were watered solely on the springs until they declined post-World War II (Lester Cain, pers.comm., November 2014). After this time, the ‘Springstead’ block was something of a ‘No Man’s Land’, and men such as Claude Griffiths built makeshift yards and trapped cattle on the remaining springs. Lester Cain’s cattle from Swan Vale used to walk onto the springs sometimes through the 1980s and 1990s, but only one (Russel) still had a tiny pool of permanent water.

There are remains of old yards, fences and troughs at most larger springs, while over a quarter of those visited have wells sunk near or in them (Figure 140). Even where such structures are absent, old bottles (often purple pickle bottles), wire, tin and assorted contraptions testify to an early pastoral presence. Springs were also used as sites to muster stock during dry seasons, both legally and illegally, as evidenced by the remnants of fencing around some springs and ex-springs. At Cheviot Spring, in the north-western corner of Stoneleigh, ash heaps and burnt stumps can be seen where musterers used to light fires around the spring to discourage cattle from watering there and move them back to the other waters. There have been attempts to fence the spring in the past, with old wire and marks around the trees. Even at Bernard’s Spring, a small soak in a mulga gully on Culgoa National Park which is not marked on any historical maps and was ‘discovered’ by the son of the landholders in the 1950s, a poplar box stump has been cut with an axe and there are old horse yards nearby. Where springs are no longer active, relics of European industry remain isolated discords in an arid landscape; a reminder of past human activity once nourished by groundwater.

Figure 140: Old stake yards at Goon Goon Spring, Evengy (top left), and well marking site of Topham Springs, Westerton (top right); remains of old makeshift fence at the now-forgotten and dry ‘Uncle Claude’s Spring’ on Welford National Park, and remnants of substantial wooden yards built at Eight Mile Spring on Swan Vale in the 1970s (bottom right).

Unsurprisingly, given their occurrence in rough and inaccessible country, only a couple of Tertiary springs were used as change stations for horses and stop-overs for thirsty travellers. Fig Tree Rockhole (Figure 141) remains a designated camping and water reserve, although the spring no longer flows and only holds water for a few weeks after rain. Wingara or Five Mile springs on Uanda were used to water stock teams travelling between Aramac and Torrens Creek, but the main spring no longer flows. Two springs along Bostock Creek on Arno were on the old stock route between Stonehenge and the railhead at Yaraka. Clarke's Spring on the Nive River near Tambo and Jack in the Rocks (JD Springs) west of Adavale were change stations. J. Alfred Griffiths described the long-inactive Clarke's Spring:

> *… is about 4 miles below the Government Bore site + opposite Cobb & Co's Darby Point Change House. It soaks out the east bank of the Nive River, has been logged and improved, and supplies about 300 head of large stock, including the mail horses. It has never been dry in the worst drought years.*

JD Springs was the second horse change station on the Cobb and Co route between Adavale and Windorah, and a hotel known as 'Jack in the Rocks' was built at the site (Figure 141). The spring rose to the surface and ran above ground for 15-25 feet before going back underground (Jenkins, 2001). A shallow well was dug on the spring, which was used as the water supply. 'The Overlander', in an article titled 'A Trip to the Far West' published in the Brisbane Courier in 1886 described the scene:

> *Passing over splendidly-grassed country, and a couple of stony ridges which played pretty roughly with the buggy, we arrived at the J. D. Springs, so called, it is said, because Mr. Jeremiah Durack discovered the springs and engraved his initials upon a tree in the vicinity. At this place there is an hotel kept by a merry-eyed little Irishman named John Cummins, but he generally goes by the sobriquet of "Jack-on-the-rocks", a title of which he appears to be proud. He is an amusing character, possessing quite a fund of anecdote, the telling of which makes everybody laugh, but nobody longer or more heartily than Jack himself…* (Brisbane Courier, 7 June 1886, p.3).

A town was gazetted with two streets (Corona and Mulga Streets), but was never built. Mary Durack in *Kings in Grass Castles* (Durack, 1959) wrote that miners and travellers would say they were off to see old Jack in the Rocks when they were going for a sly drink. This euphemism became gruesomely literal when Jack died, according to an article related by 'Plumbob' to a correspondent of The Wingham Chronicle and Manning River Observer in 1928:

> *Wanderers who have been out Adavale way remember a place called the J.D. Springs. It is about 40 miles west of Adavale, and is sometimes referred to as 'Jack in the Rocks.' A bush shanty used to stand nearby, and at one time it was a mail change for Cobb and Co. One of Cobb's grooms, who was stationed there, was a heavy rum drinker, and at last the booze killed him. When he was about to be buried it was discovered there wasn't enough wood to make a coffin. Some handy individual suggested hewing a hole in a rock, but when this was done it was found that the corpse would not fit into it. As the weather was very hot and the rock was very hard, the burial party secured an axe and lopped the dead groom's legs off below the knees. Then there was no trouble putting him in the rocky excavation. The grave can still be seen, and although the lower part of his legs lie beside him I don't suppose it worries him very much* (Wingham Chronicle and Manning River Observer, 3 August 1928, p.3).

Jack was no longer on the rocks but in them, literally. There may be cause for some scepticism when a story is related by a character called 'Plumbob' in a column titled 'Life Outback – Heard in the Barber's', published in an obscure local paper. However this is also the story passed down through the Duff family, former long-term owners of Canaway Downs. According to Darryl Duff (pers.comm., Charleville, May 2015), there was a mound of rocks marking Jack's grave but its location is no longer known.

Constance Ellis travelled from Brisbane to Kyabra in May 1889 and describes 'Jack in the Rocks' as being 'some distance from a watercourse, but there was a constant supply – a spring – in some rocks there' (Ellis, 1981,p.8). She had breakfast and met her next coach. At that time, Denis (Dinny) and Mary Skeahan and their four sons were living at Canaway Downs, which was half a day's travel further on. Mary was the oldest sister of the Durack brothers and was known as 'Poor Mary', apparently in response to her choice of husband and the lifestyle she was subjected to after the marriage: Dinny was a drinker, gambler and opal miner ten years Mary's junior, with little to offer in the way of comfort or stability (Lehane, 1996) . Patsy Durack took up two runs for Mary and Dinny in 1877. Constance Ellis remembered the Canaway homestead and the Skeahan family, particularly Mary:

> *We reached the homestead about noon, a white-washed place built of Egyptian brick, that is, brick made of clay, no straw or grass in them. Very bare and clean. A clean girl ushered us into the 'dining room' with a slab table and benches down each side. Presently, an old man, and his grown sons all in spotless white shirts and moleskins walked in. Mr Skene (sic) and his entire family. They were painfully shy ...We were on the road again by one a 'clock. About 2.30 we came across an old woman loading firewood - great boughs of trees- on to a bullock wagon. 'There's Mrs Skene' said the driver. This dirty and ragged old woman doing this heavy work and driving four bullocks, the mother of those spotless young men. I felt quite dazed!*

Dinny, Mary and their family moved to JD Springs in the mid-1890s from Canaway Downs, some 20 km to the south. The Cobb & Co would arrive on Mondays at midday with a rum supply for Dinny Skeahan. Once he had consumed the rum, which might take up to a week, he would take the mail from 'The Rocks' to Ray, Terrachie and Thylungra, where the residents of those isolated stations were no doubt waiting anxiously (Jenkins 2001). There are many stories from these times, as related in Jenkins (2001). One concerns the management of the pub by two of the Skeahan sons while their parents were absent. Instructed not to serve too much free grog, they took turns to serve each other, passing one shilling over the bar to the acting bartender on the other side. They managed to drink the pub dry.

Mary Skeahan died in 1913, after being confined to her rocking chair for some years. Her death was reported in the Brisbane Courier (19 August 1913, p.9), where she was remembered as a generous host and entertainer. Her body was collected in the cool of evening by her niece Mary Tully and station workers, who were horrified to find her legs had fused together (Lehane 1996). At least Poor Mary was afforded more dignity than Jack the original publican, and was taken to Ray station for burial (Jenkins, 2001). The last coach passed through in 1932 and the site has been abandoned since.

Apparently there were rumours that a cache of opals or gold coins were buried beneath the spring, and a couple of blokes decided to use gelignite to exhume the treasures in the 1950s. No treasure was found, but the gelignite caused the spring to cease flowing (Darryl Duff, pers.comm., Charleville, May 2015). An old wire fence and a well mark the site of the spring, while old timber lying nearby is the remains of the 10-room public house. To the south-east, you can still see the Cobb & Co wagon tracks.

Figure 141. JD Springs depression, dug out to form a well but inactive since it was gelignited in the 1950s (top left) and the now-abandoned Adavale-Windorah road east of Jack in the Rocks (top right); Tryeata Spring, an important site for opal miners on the Jundah fields from 1900 (bottom left), and Bell & Black matchbox found beside old road that passed Tryeata spring (bottom right)

The Tryeata spring west of Jundah was an important source of water for opal miners on the opal fields around the turn of the century. Apart from some small native wells, this was the only natural water between Farrars Creek and the Thomson, and was declared a stock route as a thoroughfare for opal miners travelling from the fields to Jundah. There are old bottles, cans, tins and old Bell & Black matchboxes lying around (Figure 138), but it seems the main camp was in a declared reserve just to the north. It is mentioned in an article in the Western Champion in a ‘Jundah Jottings’ column written by ‘Nemo’ in 1900:

> *…things are "humming" at the opal mines, and further good "finds" are going to prove the undoubted richness of the gems to be won…There are two camps of miners on the field, one about four miles south of a point about eighteen miles along the rabbit fence, which runs out west from the Thompson River near Jundah, the other one being some eight miles from the first, on the head of Stewart's Creek. At the first camp there are about fifty men, and at the second one from thirty to forty…In view of the undoubted permanency of the field, the miners are making an effort to get an unfailing spring of pure water some little distance away from the first-mentioned camp reserved, that they may fence it in…* (Western Champion, 20 March 1900, p.8).

Bertie Rayment also mentions this spring in his memoirs *My Towri*, written in 1956. He was on the fields at the turn of the century, and describes the competition between opal miners and graziers for the precious water.

> *In 1900 there were several hundred men idle in Jundah, during the drought. They had the area proclaimed an opalfield and with no other prospects started gouging. The land was an undeveloped part of the cattle section of a large station. The livestock, as well as the miners, had to get their water from a spring five miles away from the actual mine. The spring was a good one and trickled about half a mile. The miners carted the water – the most up-to-date in drums on bicycles and neither tyres nor tubes. Some of the men carried the water chinaman fashion, on yokes, some used home-made wheel barrows. But the station also flocked thousands of cattle on the spring. The miners took it in turn to camp at certain pools to protect the water…* (Rayment, 1956,p.8)

The spring could no longer be described as an 'unfailing spring of pure water' (Figure 138), but this could be simply due to having silted up over the century since it was regularly used. When gravel was scooped out by hand in June 2015, the holes immediately filled with water.

In comparison to bigger, more accessible water sources such as waterholes and GAB discharge springs, the history of non-GAB springs is a sketchy and poorly documented one, although rich in intrigue and mythology. Tales of outlaws, rebels, loners, misfits and strange happenings abound. The small, hidden, isolated nature of springs in rocky ranges make them a haven for people wanting to retreat or hide from the world. The ruins of a cypress pine hut lie near the Tertiary Colless Spring and well east of Enngonia (Figure 142). It is uncertain who lived in the hut or what it was used for, but there were apparently rifle slots in the walls, giving rise to its local name of the 'bushranger's hut' (Brian Bambrick, pers.comm.). A World War I digger lived a solitary life at a small spring on the eastern fall of the Enniskillen Range near Blackall for years, at a hut locally known as 'Madman's Hut' (Figure 142).

Emmet's sole resident John Avery remembers an old-timer who would travel to Old Idalia spring to get water for his whiskey, claiming it to be the best water around, while the local name of 'Marijuana Spring' reveals a more illicit use for one spring. To the growers, who lived in makeshift huts hidden beneath dense tea-tree beside the spring a 20 km walk from the nearest habitation, the site became known as Magic Mountain (Figure 142). Lion sightings and tales of a lost tribe dating from this time remain unverified.

Figure 142: Outlaw history: Ruins of the 'bushranger's hut' at Colless Spring (top); Stanbert; likely site of Madman's Hut Spring in the Enniskillen Range, Macfarlane Downs (right); Steve's hut (Wayne's is to the right of the frame) at Magic Mountain west of Jundah (bottom).

9.5 Biological values

Unlike GAB discharge springs, which are permanent, unusual and ancient, outcrop springs including Tertiary springs, tend to be more dynamic and less unusual as a habitat type (Fensham et al., 2011). Although overall diversity is higher for non-GAB springs than rockholes, no endemic species have been recorded at any non-GAB springs in the study area. Non-GAB springs are, in general, not floristically distinct from GAB outcrop springs (Fensham et al., 2004) and were grouped as 'outcrop springs' by Fensham et al. (2011).

Despite the lack of endemism, some geographically isolated populations of more mesic species of plants were recorded (Figure 140). The fern *Cyclocorus interruptus* is only known from one arid-zone population, at Alice Spring on New Haven in the Grey Range. The fork fern *Psilotum nudum* is recorded from two arid-zone springs (Boundary on Purtora north of Blackall and William on Carisbrook south-west of Winton), the latter representing an especially disjunct population. A third fern, *Lindsaea ensifolia* subsp.*ensifolia*, is also known from only two arid-zone populations in Queensland, William Spring (Figure 143) and Dripping Spring on Highlands in the Grey Range.

The Endangered *Microcarpaea agonis* occurs in the wetland at Bore Spring on Idalia. This is only the second known population, the other record being from a seasonal swamp west of Millmerran in 1996. Black tea-tree (*Melaleuca bracteata*) is common further east but is restricted to springs in more arid areas and characterises Tertiary springs from Budgerygar to Stonehenge (Figure 143).

Larger springs support fish populations, including rainbow fish, glassfish, gudgeons and spangled perch. Their ecological significance also lies in providing sources of water in areas that otherwise have little permanent water. Koalas have been observed in the vicinity of some Tertiary springs, including on Stoneleigh which represents the western edge of koala's distribution. Yellow-footed rock wallabies and numerous species of water-dependent birds drink from these small water sources.

Figure 143. *Lindsaea ensifolia* subsp. *ensifolia* at William Spring, Carisbrooke (left), and black tea-tree forest at Arno Spring, north-west of Yaraka

9.6 Key threats and management

Like GAB springs, which have fared catastrophically due to groundwater extraction and aquifer decline (Fairfax & Fensham 2002; Powell et al. 2013), non-GAB springs are less numerous and permanent than in the past, although for different and more mysterious reasons. Some spring groups have experienced little change in permanence since pastoral settlement, notably the limestone and sandstone springs of north-western Queensland. However, all other groups have experienced some spring extinctions. These have been particularly pronounced for the Tertiary springs (Table 22).

Table 22: Tertiary springs that have become inactive or with much-diminished flows

Spring	Summary of flow status/trend
Direct human disturbance	
Bexley	Used to be quite permanent, but dynamited years ago and now tend to only flow for 6 months or so after wet season
Fig Tree Rockhole, Ayrshire Hills reserve	Apparently used to be quite permanent spring and overflow as far as road, but now has filled in with gravel and only holds water for 2-3 months after rain, but can still obtain water by digging in gravel. Some local stories suggest it was dynamited many years ago, others believe it has naturally silted up.
Jack in the Rocks, Canaway Downs	Used to provide water for change station on old Adavale-Windorah road. Dynamited by opal miners searching for treasure that was allegedly buried beneath spring and has not flowed since.

Spring	Summary of flow status/trend
Madman's Hut,	When WWI digger left in the 1940s, attempts were made to improve the spring, possibly involving gelignite, and it has not flowed since.
Spring Plains	Permanent until it was dynamited 20 years ago and has not flowed since
Westerton	Dynamited in the 1980s in an attempt to increase its supply, and has never flowed since.
Unexplained flow reduction	
Bernards, Culgoa Floodplain NP	Seems to come and go, but general trend over past few years is declining, as prior to that it would run the creek for 25-30m.
Billabong, Budgerygar	Tiny surface moisture in 2009 - excavated 10 x 10m hole and has flowed since; past permanence indicated by Outstation adjacent to spring
Blue (9 Mile) 1, Uanda	Used to run gully for >200m but has been dry for years, although other springs nearby continue to flow
Brennans, Thrungli	Pipes used to fill a tank and spring could water 200-300 sheep. Cleaned out in 1950s but only yielded a couple of hundred gallons per day. There has not been sufficient water to fill the tanks in the past 60 years, but until about 30 years ago you could fill a quart pot and kangaroos could get a drink from small puddles in the gully and water dribbling out of the pipe. Both vents are still moist for a tiny area (20 x 10cm soaks) but there is no free water.
Clarke's, Drensmaine	Boxed well sunk on spring at old change station now sanded over; all wells in area now dry
Collabara, Idalia NP	Excavated but apparently with water in 2002; no water in past few years despite good seasons
Colless, Stanbert	Well adjacent to spring suggests spring never supplied enough water for hut, but is now dry + spring a mere puddle
Cumborah	Well still with water, but springs extinct
Deadman, Culgoa Floodplain NP	The name suggests it was never permanent; excavated hole has not contained water in recent decades
Eight-Mile, Swan Vale	20 x 20m sturdy wooden fence + pipe suggests formerly large flow at gully head; now dry and spring reduced to tiny (<1m^2) shallow puddle in gravelly creekbed 30m downstream
Gilmore, Gilmore	Tiny puddle; used to be cleaned out and ran water down gully
Koala Spring, Idalia NP	Tiny pool on slope of gorge above gully; fenced; has apparently contracted in recent years
Old Mt Windsor, Mt Windsor	No sign of spring near old homestead; has not flowed in living memory
Riverside, Riverside	Permanent spring until 1915 (used to water 10 000 sheep twice a week during dry times in early 1900s); started flowing again in 2000 for a few months after big wet
Tin, Culgoa Floodplain NP	Dug out in the past to increase flow, but now a tiny soak/damp area. Moisture can be obtained by digging.
Tooloomi, Glenora	Apparently permanent in past, but has not flowed for decades
Topham Springs, Westerton	Described by Griffiths as two shallow wells with deep trenches cut flowing water 25 450 yards in the droughts, each watering 150 horses. Still used for house water up until the 1950s; has been dry for decades, although there is an ephemeral soak that comes and goes below a dam which has been dug on the site of the southern well.
Wingara (5 Mile) springs, Uanda	Both main springs described by Griffiths (1898) have been dry for decades; one of the nearby 'unimportant' springs still flows intermittently
Woods, Evengy	Griffiths described a 12ft well sunk on a spring on Frasers Creek which supplied 3000 sheep by bailing; spring probably located near old bore, and now inactive.

Inferring the activity status or flow trends of non-GAB springs is difficult due to natural dynamism of some springs. The name Deadman Spring on Culgoa Floodplain National Park predates its excavation in the 1960s, and suggests that the spring was naturally dynamic or intermittent (i.e. you could miss out on a drink with dire consequences). Old Idalia spring was inactive for decades but began flowing again following wet summers from 2009-2011. Smaller springs around the base of the Enniskillen Range go dry occasionally after long droughts, but macropods can still dig for water. There is the possibility that some springs marked on historical maps but without historical descriptions were never permanent, especially given the variable definitions of what constitutes a ‘spring’ that are evident even today. However, the record of Griffiths, knowledge of long-term landholders and signs of regular human activity, all indicate a general declining trend in spring flow and permanence.

At least five springs have been excavated and/or dynamited in an attempt to increase their flow. The latter treatment has usually achieved the opposite effect, and most springs that have been blown up no longer flow at all (Figure 144) . However, many more springs across western Queensland and New South Wales, including Tooloomi, Tin, Bernards, Collabara, Riverside, Eight Mile, Koala and Topham Springs, have stopped flowing or have much reduced flow without obvious causes. These seem to be smaller Tertiary springs in the ranges and those reliant on shallow groundwater such as along the Nive River and Mungallala Creek.

Figure 144: Examples of inactive Tertiary springs: ‘Ex-spring’, Spring Plains, February 2009 (water present after recent rainfall) (top left); Tooloomi spring depression east of Enngonia (top right); dry well, Topham Spring north, Westerton (bottom left); Wingara (Five-Mile) main spring, Uanda.

There are only scattered shallow bores in these localised aquifers, so aquifer pressure decline does not explain these reduced spring flows. It is possible that less water is getting into the streams to recharge them due to some large dams on tributaries, particularly of the Nive River. In the Swan Vale area, decline of springs may be related to the sinking of sub-artesian bores tapping the shallow Tertiary aquifer.

The numerous accounts of Aboriginal people ‘husbanding’ natural rockholes and springs raises the possibility that water was more widespread and permanent in the ranges prior to pastoral settlement. In the early days of pastoralism, settlers would have also maintained and cleaned out many of these water sources as they were critical for both stock and humans. 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.

Springs that have stopped flowing for reasons that are unclear could be dug out to test this hypothesis. In the early 2000s, Stonehenge locals Glen and Amanda dug out the gravel in the Stonehenge Spring to a depth of about 1.5m and it had a beautiful pool of water for months. Bill Scott excavated a spring beside the ruins of Billabong Outstation, surmising that it must have been more permanent in the past. The spring has not been dry since and now supports a permanent wetland >100m long. Clayton Dolgner did the same thing on a smaller scale at Needle Creek, and there is now a small permanent hole. If this pattern is repeated across numerous springs, it will support the hypothesis that the permanence of some springs, particularly smaller ones, was primarily due to human excavation/maintenance. This would place the database field ‘excavation damage’ in an interesting light, if long-term excavation (over millennia) was actually responsible for creating and/or maintaining some springs.

The exact location of some springs is not known, even by long-term residents. Some unlocated springs 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 National Park; Charlie Prow, pers. comm., February 2009). It is extremely difficult to locate such springs, due to the rugged and inaccessible country and often clandestine nature of the springs themselves. They are included in the database with a low precision on their location. Some springs have been ‘discovered’ and continue to be found by chance, by landholders, musterers, helicopter pilots and Queensland Parks & Wildlife staff. It is certain that some active springs remain hidden in rocky recesses, perhaps never to be re-discovered, while many have ceased to flow and seem unlikely to be relocated. They have indeed become the most obscure of oases.

10 Conclusion

This report builds on previous reports that provide a systematic methodology for understanding the historical, cultural, geographic, hydrochemical, biological and hydrogeological attributes of springs. This systematic and comprehensive understanding of springs is now available for the Springsure, Bogan River, Bourke, Eulo, Barcaldine, Springvale and Flinders supergroup in the GAB, the springs in the Galilee Basin and also the Tertiary Springs of western Queensland. The South Australian component of the LEBSA project should deliver compatible information. In Queensland there is an obvious need to complete these assessments for the remaining areas of the GAB, including the Mulligan River, Mitchell-Staaten and Cape York supergroups. There is also an imperative to complete compatible assessments in other areas with significant spring ecosystems such as the Kimberley in Western Australia and the Einasleigh Uplands in Queensland.

Identification of the source aquifer and the mechanism of release from the aquifer can usually be interpreted after developing an understanding of the stratigraphy from bore logs, evidence of faulting from seismic data and potentiometric heads. Attribution of the hydrogeology of the springs improves when there is reliable data from nearby bores. In some cases, such as for the Doongmabulla Springs, the source aquifer and mechanism of groundwater release can be ambiguous.

While many wetlands, populations and most likely some species have been lost as a result of artesian aquifer pressure drawdown and local disturbances, the active springs continue to provide habitat for endemic species and disjunct populations. It is critically important to preserve the springs that remain. Preservation and conservation effort must be directed to the spring wetlands which still support endemic species. The remaining active springs may be candidates for rehabilitation in the future, but are not a priority for action until the high value springs have been secured.

The recovery efforts for the Critically Endangered red-finned blue-eye at the Pelican Creek Springs require ongoing support for an achievable outcome. Nature Refuge agreements should be pursued over remaining high value spring wetlands. Other management actions such as fencing, feral animal control, exotic plant control and endangered species recovery must be undertaken on a case-by-case basis. Fencing springs has often been a ‘knee-jerk’ recovery action for springs, but needs to be considered for each spring. Natural values of some springs can be diminished by a complete lack of disturbance, and fencing may compromise biological, cultural and aesthetic values. Maintaining fences in the face of pig and goat pressure during dry times, and flooding and run-off after rains in some situations, represents a significant and ongoing challenge.

11 References

AGE (2015) Report on Project China Stone. Groiundwater report Appendix I. Australasian Gourndwater and Environmental Consultants Pty Ltd. Prepared for Hansen Bailey,

Ah Chee, D. (2002) Kwatye (water) in the Great Artesian Basin. Environment South Australia, 9**,** 20-21.

Allen, G.R., Midgley, S.H. & Allen, M. (2002) Field Guide to the Freshwater Fishes of Australia. Western Australian Museum.

Aramac Shire Council (n.d.) History of Aramac, Qld. Available online at http://lineage.tilbury.net.au/history-aramac-qld [accessed 15 May 2015].

Armstrong, N. (2001) Desert gobies Chlamydogobius. Fishes of Sahul, 15**,** 740-749.

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 floodplain river, Cooper Creek, Australia. Marine and Freshwater Research, 56**,** 25-35.

Bailey, J. (2006) Mr Stuart's Track : the forgotten life of Australia's greatest explorer. Pan Macmillan, Sydney.

Bandler, H. (1995) Water resources exploitation in Australian prehistory environment. The Environmentalist, 15**,** 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, 82**,** 17-25.

Bean, A.R. (2013a) Reinstatement and revision of Sphaeromorphaea DC. and Ethuliopsis F.Muell (Asteraceae: Plucheinae). Austrobaileya, 9**,** 30-59.

Bean, A.R. (2013b) Three new species of *Pluchea* Cass. (Asteraceae: Inuleae-Plucheinae) from northern Australia. Austrobaileya, 9**,** 66-74.

Bedford, C.T. (1886) Reminiscences of a surveying trip from Boulia to the South Australian Border. Royal Geographical Society of Queensland, 2**,** 99-113.

Blake, T. (2001) A Dumping Ground : a history of the Cherbourg settlement. University of Queensland Press, St Lucia.

Bode, A.M. (1929) Pioneers Went These Ways. James Ferguson Pty Ltd, Brisbane.

Bottoms, T. (2013) A conspiracy of silence. Allen & Unwin, Sydney.

Boyd, W.E. (1990) Mound Springs. Natural History on the North East Deserts (eds M.J. Tyler, C.R. Twindale, M. Davies & C.B. Wells), pp. 107-118. Royal Society of South Australia, Adelaide.

Brim-Box, J., Duguid, A., Read, R.E., Kimber, R.G., Knapton, A., Davis, J.A. & Bowland, A.E. (2008) Central Australian waterbodies: The importance of permanence in a desert landscape. Journal of Arid Environments, 72**,** 1395-1413.

Burger, D. & Senior, B.R. (1979) A revision of the sedimentary and palynological history of the northeastern Eromanga Basin, Queensland. Journal of the Geological Society of Australa, 26**,** 121–132.

Carnegie, D.W. (1898) Spinifex and sand: A narrative of five years' pioneering and exploring in Western Australia. Hesperian Press, Perth.

Casey, J.N.R., M.A., Dow, G.B., Pritchard, P.W., Vine, R.R. & Paten, R. (1967) Boulia Sheet SF 54-10. 1:250 000 Geological Series. Bureau of Mineral Resources, Canberra.

Cathcart, M. (2009) The Water Dreamers: the remarkable history of our dry continent. Text Publishing, Melbourne.

Clarke, L.J., Whalen, M.A. & Mackay, D.A. (2013) Cutting grass on desert islands: genetic structure of disjunct coastal and central Australian populations of Gahnia trifida (Cyperaceae). Journal of Biogeography, 40**,** 1071-1081.

Clement, C. (2002) 'Quilty, Thomas John (1887–1979)'. Australian Dictionary of Biography, National Centre of Biography, Australian National University.

Clifford, S.E., Steward, A.L., Negus, P.M., Blessing, J.J. & Marshall, J.C. (2013) Do cane toads (*Rhinella marina*) impact desert spring ecosystems? Proceedings of the Royal Society of Queensland, 118**,** 17-25.

Cooper, J. (2013) Crossing the divide: a history of Alpha and Jericho districts Barcaldine Regional Councill, Barcaldine.

David, T.W.E. (1950) The geology of the Commonwealth of Australia. Edward Arnold and Co., London.

Davies, R.J.-P., Craigie, A.I., Mackay, D.A., Whalen, M.A., Cheong, J.P.-E. & Leach, G.J. (2007) Resolution of the taxonomy of *Eriocaulon* (Eriocaulaceae) taxa endemic to the Australian mound springs, using morphometrics and AFLP markers. Australian Systematic Botany, 20**,** 428-447.

Davis, J.A., Harrington, S.A. & Friend, J.A. (1993) Invertebrate communities of relict streams in the arid zone: the George Gill Range, central Australia. Australian Journal of Marine and Freshwater Research, 44**,** 483-505.

De Deckker, P. (1986) What happened to the Australian aquatic biota 18 000 years ago? Limnology in Australia (eds P. De Deckker & W.D. Williams), pp. 487-496. CSIRO.

Department of National Parks Recreation Sport and Racing (2013) Cudmore (Limited Depth) National Park Management Statement. Available online at http://www.nprsr.qld.gov.au/managing/plans-strategies/statements/pdf/cudmore.pdf [accessed 15 May 2015].

Duncan-Kemp, A.M. (1934) Our sandhill country: man and nature in south-western Queensland, 2nd edn. Angus & Robertson, Sydney.

Durack, M. (1959) Kings in grass castles. Transworld Publishers, Milsons Point, Sydney.

Ellis, C.J. (1981) I seek adventure: an autobiographical account of pioneering experiences in outback Queensland from 1889 to 1904. Alternative Publishing Cooperative Ltd, Sydney.

Exon, N.F., Casey, D.J. & Kirkegaard, A.G. (1969) Tambo SG 55-2. 1: 250 000 Geological Series. Bureau of Mineral Resources, Geology and Geophysics, Department of National Development, Canberra.

Fairfax, R., Fensham, R., Wager, R., Brooks, 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, 34**,** 156-166.

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

Fatchen, T. (2000) Mound springs management planning. Management issues, strategies and prescriptions for mound springs in far north South Australia. South Australia Department of Environment and Heritage,

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

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, 52, 583-595.

Fensham, R.J., Ponder, W.F. & Fairfax, R.J. (2010) Recovery plan for the community of native species dependent on natural discharge of groundwater from the Great Artesian Basin. Department of the Environment, Water, Heritage and the Arts, Canberra. Queensland Department of Environment and Resource Management, Brisbane.

Fensham, R.J., Silcock, J.L., Kerezsy, A. & Ponder, W. (2011) Four desert waters: Setting arid zone wetland conservation priorities through understanding patterns of endemism. Biological Conservation, 144, 2459-2467.

Fensham, R.J., Silcock, J.L., Powell, O.C. & Habermehl, M.A. (In press) In search of lost springs: A protocol for locating active and inactive springs. Groundwater.

Fisher, N.H. & Hahn, G.W. (1963) Review of available groundwater data on the Great Artesian Basin. Bureau of Mineral Resources, Geology and Geophysics, Record 1963/128, Canberra,

GABCC (2000) Great Artesian Basin Strategic Management Plan. Great Artesian Basin Consultative Council, Canberra,

Gallant, J.C., Dowling, T.I., Read, A.M., Wilson, N., Tickle, P. & Inskeep, C. (2011) 1 second SRTM Derived Digital Elevation Models User Guide. Geoscience Australia. October 2011., Canberra,

GHD (2013a) Carmichael Coal Mine and Rail Project SEIS Report for Mine Hydrogeology Report.

GHD (2013b) Carmichael Coal Mine and Rail Project SEIS V4.K6. Mine Hydrogeology Report Addendum.

Gibbs, L.M. (2006) Valuing water: variability and the Lake Eyre Basin, central Australia. Australian Geographer, 37, 73-85.

Gilliat, H.A. (1885) Royal Commission of Water: Notes on the mud springs and some shafts and borings of underground supply on the road between Ford's Bridge (on the Warrego River) and Hungerford (on the Paroo River). Votes and Proceedings of the Legislative Council, 6, 827-828.

Glover, C.J.M. (1989) Fishes. Natural History of Dalhousie Springs (eds W. Zeidler & W.F. Ponder). South Australian Museum, Adelaide.

Gorecki, P., Grant, M. & Salmon, M. (1992) The 1992 archaeological surveys on Esmeralda station, Gulf of Carpentaria: preliminary results. Queensland Archaeological Research, 9, 54-58.

Gow, G. (n.d.) 'Reminiscences of George Gow', compiled by Crowley A. Unpublished memoirs obtained from Woodhouse family, 2012. .

Griffiths, J.A. (1896) Unpublished field notes of James Alfred Griffiths. Queensland State Archive. RSI 3037-1-1 to RSI 3037-1-4.

Grimes, K.G. & McLaren, M.A. (1972) Millungera SE 54-15. Bureau of Mineral Resources Geology and Geophysics, Canberra.

Habermehl, M.A. (1982) Springs in the Great Artesian Basin, Australia - their origin and nature. Bureau of Mineral Resources, Geology and Geophysics, Canberra, Report 235.

Habermehl, M.A. & Lau, J.E. (1997) Hydrogeology of the Great Artesian Basin, Australia. 1:2 500 000 map. Australian Geological Survey Organisation, Canberra.

Harris, C. (2002) Culture and geography: South Australia's mound springs as trade and communication routes. Historic Environment, 18**,** 8-11.

Hercus, L. & Clarke, P. (1986) Nine Simpson Desert wells. Archaeology in Oceania, 21**,** 51-62.

Hodgkinson, W.O. (1877) North-West Explorations. Report to Parliament, Brisbane.

Holdaway, S.J., Fanning, P.C., Jones, M., Shiner, J., Witter, D.C. & Nicholls, G. (2000) Variability in the Chronology of Late Holocene Aboriginal occupation on the Arid Margin of Southeastern Australia. Journal of Archaeological Science, 2002**,** 351-363.

Horwitz, P., Rogan, R., Halse, S., Davis, J. & Sommer, B. (2009) Wetland invertebrate richness and endemism on the Swan Coastal Plain, Western Australia. Marine and Freshwater Research, 60**,** 1006-1020.

Jack, R.L. (1900) Artesian water in the state of Queensland, Australia. Harrison and Sons, London.

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

Jobson, R.W. (2013) Five new species of *Utricularia* (Lentibulariaceae) from Australia. Telopea, 15**,** 127-142.

Junk, W.J. (2006) The comparative biodiversity of seven globally important wetlands. Aquatic Sciences, 68**,** 239-239.

Kanso, S. & Patel, B. (2003) *Microvirga* subterranean gen. nov., sp. mov., a moderate thermophile from a deep subsurface Australian thermal aquifer. International Journal of Systematic and Evolutionary Microbiology**,** 401-406.

Keith, D.A. (2000) Sampling designs, field techniques and analytical methods for systematic plant population surveys. Ecological Management and Restoration, 1**,** 125-139.

Kelley, J.E. (1882) Well sinking, water storing, and irrigation in the interior. 1 May 1882. 1 May 1882.

Keppel, M., Clarke, J.D.A., Halihan, T., Love, A.J. & Werner, A.D. (2011) Mound springs in the arid Lake Eyre South region of South Australia: A new depositional tufa mode; and its controls Sedimentary Geology, 240**,** 55-70.

Kerezsy, A. (2009) Gambusia control in spring wetlands. South Australian Arid Lands Natural Resources Management Board, unpublished,

Kerezsy, A. (2014a) Bore drain survey, Aramac District. Desert Channels Queensland, unpublished, Kerezsy, A. (2014b) Distribution of Edgbaston goby in the Aramac Shire (excluding Edgbaston Reserve) and recommendations on standardised sampling techniques for detecting the species. Bush Heritage Australia, unpublished,

Kerezsy, A. (2014c) Fish survey of the Edgbaston spring complex with an emphasis on the distribution of the endangered Edgbaston goby, *Chlamydogobius squamigenus*. Bush Heritage Australia, unpublished,

Kerezsy, A. (2015) Report on fish recovery work at Edgbaston, February 2015., Dr Fish Contracting, Clontarf, Queensland.,

Kerezsy, A., Balcombe, S.R., Tischler, M. & Arthington, A.H. (2013) Fish movement strategies in an ephemeral river in the Simpson Desert, Australia. Austral Ecology, 38**,** 798-808.

Kerezsy, A. & Fensham, R. (2013) Conservation of the endangered red-finned blue-eye, *Scaturiginichthys vermeilipinnis*, and control of alien eastern gambusia, *Gambusia holbrooki*, in a spring wetland complex. Marine and Freshwater Research, 64**,** 851-863.

Kinhill–Stearns (1984) Olympic Dam Project supplementary environmental studies, Mound Springs. Roxby Management Services Pty Ltd, Adelaide.

Knuckey, G.K., K. (1992) The archaeology of Stonehenge – a preliminary survey. Queensland Archaeological Review, 9**,** 17-25.

Landsborough, W. (1862) Journal of Landsborough’s Expedition from Carpentaria in Search of Burke and Wills. F.F. Bailliere, Melbourne.

Laurie, A. (1951) History of the Croydon goldfields. Journal of the Royal Historical Society of Queensland, 4**,** 524-534.

Leblanc, M., Tweed, S., Lyon, B.J., Bailey, J., Franklin, C.E., Harrington, G. & Suckow, A. (2015) On the hydrology of the bauxite oases, Cape York Peninsula, Australia. Journal of Hydrology, 528**,** 668-682.

Lehane, F. (1996) Heartbreak corner: a story of the Tully, Durack and other pioneer families of South-West Queensland. Fleur Lehane, Beaudesert.

Macgillivray, A. (1886) The Flinders and Cloncurry Rivers. The Australian Race: Its origins, languages, customs, place of landing in Australia and the routes by which it spread itself over that continent (eds E.M. Curr), pp. 340-345. John Ferres, Government Printer, Melbourne.

Margarey, A.T. (1894) Aboriginal water quest. Royal Geographical Society of Australasia (South Australian Branch), Session 1894 - B.

McBryde, I. (2000) Travellers in storied landscapes: a case study in exchange and heritage. Aboriginal History, 24**,** 152-174.

McDonald, E., Coldrick, B. & Villiers, L. (2005) Study of Groundwater-Related Aboriginal cultural values of the Gnangara Mound, Western Australia. Department of Environment, Estill & Associates, Perth.

McRae, P.D. (2004) Ecology of the Greater Bilby, *Macrotis lagotis*, in western Queensland. University of Sydney.

Meston, A. (1923) Lakes, mineral springs, and artesian bores. 28 April 1923. 28 April 1923.

Mitchell, T.L. (1847) Journal of an expedition into tropical Australia in search of a route from Sydney to the Gulf of Carpentaria. Electronic book, Adelaide, University of Adelaide

Morwood, M.J. (1990) The prehistory of Aboriginal landuse on the upper Flinders River, North Queensland Highlands. Queensland Archaeological Research, 7, 56.

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

Murphy, N.P., Breed, M.F., Guzik, M.T., Cooper, S.J.B. & Austin, A.D. (2012) Trapped in desert springs: phylogeography of Australian desert spring snails. Journal of Biogeography, 39, 1573-1582.

Murphy, N.P., Guzik, M.T. & Worthington Wilmer, J. (2010) The influence of landscape on population structure of four invertebrates in groundwater springs. Freshwater Biology, 2499-2509.

Newton, E. (1971) Unpublished memoirs. cited in Rolfe, J.C., Blamey, R.K. & Bennett, J.W. 1997, Remnant Vegetation and Broadscale Clearing in the Desert Uplands Region of Queensland, Choice Modelling Research Reports, School of Economics and Management, University of New South Wales, Canberra; available online at https://crawford.anu.edu.au/pdf/staff/jeff_bennett/chmdrr03.pdf [accessed 18 May 2015]. .

Niejalke, D. (1998) Proceedings to the 2nd Mound spring researchers forum and spring management workshop. Mound spring researchers group, Adelaide.

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. The Rangeland Journal, 20, 275-300.

Noble, J.C. & Tongway, D.J. (1983) Pastoral settlement in arid and semi-arid rangelands. Australian Soils: the human impact (eds J.S. Russell & R.F. Isbell), pp. 217-242. University of Queensland Press, St Lucia.

Nolan, C. (2003) Sandhills and channel country. Diamantina Shire Council, Bedourie.

Palmer, E. (1884a) Hot springs and mud eruptions on the lower Flinders River. Proceedings of the Royal Society of Queensland, 1, 19-23.

Palmer, E. (1884b) Notes on some Australian tribes. Journal of the Anthropological Institute of Great Britain and Ireland, 13, 310-325.

Pennay, C., Drimer, J. & Fensham, R.J. (2012) Ecological and botanical survey of springs in the Surat-Cumulative Management Area. Report prepared for Queensland Water Commission, Brisbane,

Percy, A. (1906) The drought antidote for the north-west: or, the utilisation of the artesian resources of New South Wales. Sydney,

Pettigrew, J.D. (2003) The Min Min light and the Fata Morgana: an optical account of a mysterious Australian phenomenon. Clinical & Experimental Optometry, 86, 109-120.

Ponder, W., Vial, M. & Jefferys, E. (2010) The aquatic macroinvertebrates in the springs on Edgbaston Station, Queensland. Bush Heritage Australia, unpublished,

Ponder, W.F. (1995) Mound spring snails of the Great Artesian Basin. The conservation biology of molluscs (eds K.E. Alison), pp. 13-18.

Ponder, W.F. & Clark, G.A. (1990) A radiation of hydrobiid snails in threatened atresian springs in western Queensland. Records of the Australian Museum, 42, 301-363.

Ponder, W.F., Hershler, R. & Jenkins, B. (1989) An endemic radiation of Hydrobiidae from artesian springs in northern South Australia: their taxonomy, physiology, distribution and anatomy. Malacologia, 31**,** 1-140.

Potezny, V. (1989) The perentie and the women - a mythology from Dalhousie Springs. Natural history of Dalhousie Springs (eds W. Zeidler & W.F. Ponder), pp. 5-6. South Australia Museum, Adelaide.

Powell, O. (2012) Song of the artesian water: aridity, drought and disputation along Queensland’s pastoral frontier in Australia. Rangeland Journal, 34**,** 305-317.

Powell, O., Silcock, J. & Fensham, R. (2015) Oases to oblivion: The rapid demise of springs in the south-eastern Great Artesian Basin, Australia. Groundwater, 53**,** 171-178.

Pyke, G.H. (2008) Plague Minnow or Mosquito Fish? A Review of the Biology and Impacts of Introduced Gambusia Species. Annual Review of Ecology, Evolution and Systematics, 39**,** 171-191.

Rayment, B.J. (1956) My Towri and fireside chats. Tabra Press, Jundah.

Reyenga, P.J., Habermehl, M.A. & Howden, S.M. (1998) The Great Artesian Basin – Bore rehabilitation, rangelands and groundwater management. Bureau of Resource Sciences, Canberra,

Richards, J. (2008) The secret war: A true history Of Queensland's Native Police. University of Queensland Press, St Lucia.

Robins, R. (1998) Archaeological investigations at Youlain Springs, southwest Queensland. Memoirs of the Queensland Museum, Cultural Heritage Series, 1**,** 57-74.

Roth, W.E. (1897) Ethnological studies among the north-west-central Queensland Aborigines. Government Printer, Brisbane.

Schlumberger Water Services (2012) BHP Billiton Fifth Cannington Borefield Performance Report. BHP Billiton Cannington, Perth, 52298/R1.

Schmiechen, J.I. (2004) Lake Eyre Basin heritage tourism: Future directions. Lake Eyre Basin Coordinating Group, http://www.lakeeyrebasin.org.au,

Silcock, J. (2009) Identification of permanent refuge waterbodies in the Cooper Creek & Georgina-Diamantina catchments. South Australia Arid Lands Natural Resource Management Board, Adelaide,

Silcock, J., Powell, O., Drimer, J. & Fensham, R. (2013) Ecological and hydrogeological survey of the Great Artesian Basin Springs - Springsure, Eulo, Bourke and Bogan River supergroups - Volume 1: history, ecology and hydrogeology. Report commissioned by the Department of the Environment on the advice of the Interim Independent Expert Scientific Committee on Coal Seam Gas and Coal Mining.,

Silcock, J.L., Healy, A.J. & Fensham, R.J. (2014) Lost in time and space: re-assessment of conservation status in an arid-zone flora through targeted field survey. Australian Journal of Botany, 62**,** 674-688.

Silcock, J.L., Tischler, M. & Smith, M.A. (2012) Quantifying the Mulligan River pituri, *Duboisia hopwoodii* F.Muell. (Solanaceae) trade of central Australia Ethnobotany Research and Applications, 10**,** 37-44.

Simmons, A. (2007) “Life in a Corridor”: An Archaeological Investigation of the Diamantina Channel Country – A Western Queensland Corridor. PhD, University of Queensland, St Lucia.

Stuart, J.M. (1865) The journals of John McDouall Stuart 1858, 1859, 1860, 1861 & 1862. William Hardman, Saunders, Ottley, London.

The Vagabond (1885) A winter tour in Queensland. 19 September 1885. 19 September 1885.

Tolcher, H.M. (1986) Drought or deluge: Man in the Cooper's Creek region. Melbourne University Press, Carlton.

Towner, A.C. (1962) An outline of the history of western Queensland. Proceedings of Royal Society of Queensland, 6**,** 779-816.

Unmack, P.J. & Dowling, T.E. (2010) Biogeography of the genus *Craterocephalus* (Teleostei: Atherinidae) in Australia. Molecular Phylogenetics and Evolution, 55**,** 968-984.

Velseis (2012) 2011 Adani 2D seismic survey, Galilee Basin, Queensland. Final report. Velseis Processing Pty Ltd, Brisbane,

Vine, R.R., Casey, D.J. & Doutch, H.F. (1972a) Galilee SF 55-10. 1:250 000 Geological Series. Bureau of Mineral Resources , Geology and Geophysics, Department of National Development, Canberra.

Vine, R.R. & Doutch, H.F. (1972) Galilee 1:250 000 Geological Series Explanatory Notes. Canberra,

Vine, R.R., Jauncey, W. & Chertok, I. (1961) Julia Creek SF 54-3. 1:250 000 Geological Series. Bureau of Mineral Resources, Canberra.

Vine, R.R., Jauncey, W., Galloway, M.C., Casey, D.J., Olgers, F., Doutch, H.F., Eftekharnezhad, J. & Senior, D.A. (1972b) Jericho SF 55-14. 1:250 000 Geological Series. Bureau of Mineral Resources , Geology and Geophysics, Department of National Development, Canberra.

Wade, V., Wallis, L.A. & Woolgar Valley Aboriginal Corporation (2011) Aboriginal rock art sites on Middle Park Station, inland northwest Queensland. Australian Archaeology, 72**,** 23-34.

Wager, R. (1995) Elizabeth Springs goby and Edgbaston goby: distribution and status. Queensland Department of Primary Industries, unpublished,

Wager, R. (1999) The distribution of two endangered fish in Queensland. Endangered Species Unit Canberra,

Wager, R. & Unmack, P.J. (2000) Fishes of the Lake Eyre catchment of central Australia. Department of Primary Industries, Queensland Fisheries Service, Brisbane.

Wallis, L.A. & Collins, S.J. (2013) Just passing through: Archaeological investigations of a late Holocene open site in the Mitchell Grass Downs, inland northwest Queensland. Queensland Archaeological Research, 16**,** 45-54.

Wallis, L.A., Keys, B., Moffat, I. & Fallon, S. (2009) Gledswood Shelter 1: Initial radiocarbon dates from a Pleistocene aged rockshelter site in northwest Queensland. Australian Archaeology, 69**,** 71-74.

Wallis, L.A., Smith, H. & Smith, D. (2004) Recent archaeological surveys on Middle Park Station, northwest Queensland. Australian Archaeology, 59**,** 43-50.

Watson, P. (1983) This precious foliage. A study of the Aboriginal psycho-active drug *pituri*. Oceania Monograph 26. University of Sydney.

Watson, P.L. (1998) Frontier Lands & Pioneer Legends: how pastoralists gained Karuwali land. Allen & Unwin, St Leonards.

Webb, J. (2015) Expert report on groundwater impacts to the Land Court. Land Services of Coast and Country Inc. & Ors ats Adani Mining Pty Ltd. Land Court proceedings no. MRA428-14, EPA429-14, MRA430-14, EPA431-14, MRA432-14, EPA433-14. Objection to Mining lease and Environmental Authority for Carmichael Coal Mine.

Werner, A.D. (2015) Analysis of Carmichael coal mine assessment Adani Mining Pty Ltd v Land Services of Coast and Country Inc. & Ors. Report for the Queensland Land Court.

Whitehouse, F.W. (1954) Appendix G. The geology of the Queensland portion of the Great Australian Artesian Basin. Department of the Co-ordinator General of Public Works,

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, 21**,** 687-695.

Worthington-Wilmer, J.W., Elkin, C., Wilcox, C., Murray, L., Niejalke, D. & Possingham, H. (2008) The influence of multiple dispersal mechanisms and landscape structure on population clustering and connectivity in fragmented artesian spring snail populations. Molecular Ecology Notes, 17**,** 3733-3751.

Yu, S. (2002) Ngapa kunangkul (living water): an Indigenous view of groundwater. Country: Visions of Land and People in Western Australia (eds A. Gaynor, M. Trinca & A. Haebich). Western Australian Museum, Perth.

Zeidler, W. (1997) A new species of freshwater amphipod, *Austrochiltonia dalhousiensis* sp. nov., (Crustacea: Amphipoda: Hyalellidae) from Dalhousie Springs, South Australia. Transactions of the Royal Society of South Australia, 121**,** 29-42.

12 Appendices

12.1 Appendix A

Assessment of elevation accuracy

Ground control points from the Queensland state survey database (supplied by Peter Todd, Senior Survey Advisor, Geodesy & Positioning, Department of Natural Resources and Mines, 22/8/2014) were obtained. Points within a rectangle defined by -21° latitude, 145° longitude; 25° latitude, 147° longitude.

Only points identified meeting the following criteria (Peter Todd pers. Comm.) were accepted as accurate:

AHDFIX_DE: 1 way levelling, 2 way levelling, gps, intertial, tidal transfer, trig

AHDACC_DE: 1-4 order

AHDCLS_DE: ClassA-D

In addition control sites with greater than 6m discrepancy were deleted from the dataset if they are in areas that have been mined of quarried or the field GDAFIX_DE is 'scaled'.

The total number of points in the area is 204 and the analysis is presented in the histogram below. The difference between the DEM and the survey control points is the Absolute difference. All differences are positive, i.e. the DEM is always higher than the survey points. The difference between the DEM and the survey control points is the Absolute difference. The mean Absolute difference is 4.22m. This value of the mean Absolute differences was subtracted from the Absolute difference to generate a Relative difference. The mean of the Relative difference is 2.10m.

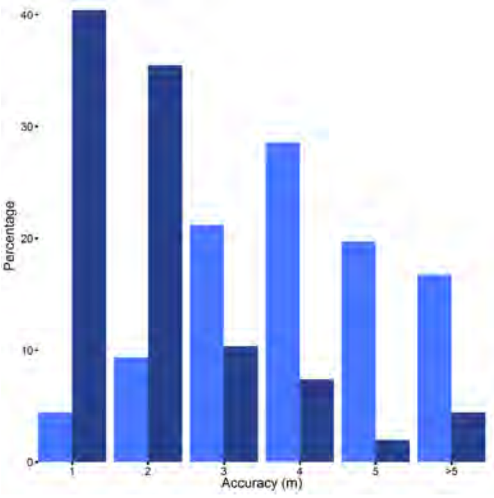


Figure. Histogram presenting the percentage of locations according to the categories of the difference in elevation between the ground control points and the Digital Elevation Model for an area of central Queensland. The values on the x axis represent the upper limit of each category.

12.2 Appendix B

Metadata for Spring Database

Dataset COMPILERS

Chris Pennay, Jeremy Drimer, Owen Powell, Rod Fensham, Renee Rossini, Boris Laffineur, Russel Fairfax, Jen Silcock, Danny Brock, Travis Gotch, Lloyd Sampson, Ellen Krahnert

Dataset DATE

July 2015

Dataset CUSTODIAN

Queensland Herbarium, Department of Science, Information Technology, And Innovation

South Australian Department of Environment, Water & Natural Resources; South Australian EPA; South Australian Department of Manufacturing, Innovation, Trade, Resources and Energy

Dataset JURISDICTION

Queensland, South Australia, Northern Territory and New South Wales

Description ABSTRACT

A spring is a hydrogeological feature by which groundwater discharges naturally to the land or cave surface. This includes springs with permanent and non-permanent (i.e. intermittent or ephemeral) saturation regimes, dynamic or static geographic locations, and diffuse or point source geographic locations. The LEBSA springs dataset provides a comprehensive catalogue of springs with a permanently saturated saturation regime that have fixed locations in the LEBSA study area and any associated surface expression groundwater dependent ecosystems. This precludes soaks that are not permanent, bores (because they are not natural), wells that do not have a surface expression of groundwater, and groundwater discharge along a stream-bed that is not in a fixed location. The LEBSA springs dataset also includes other types of springs (e.g. springs with a non-permanent or unsaturated saturation regime), however, information on these types of springs may be limited. The LEBSA springs dataset includes comprehensive information on spring location, status (active/inactive), and grouping (complex) for all springs included in the dataset. Where available, information is also provided on physical properties, general morphology, water chemistry, floristic composition, disturbance, faunal composition, survey effort, photographic documentation, and historical descriptions. Where sufficient information was available, springs have also been given a conservation ranking at both the individual spring and complex levels.

Description SEARCH WORD(S)

Spring, spring wetland, wetland, Australia

Description GEOGRAPHIC EXTENT NAMES(S)

10°S 136°E, 32°S 155°E

Access STORED DATASET FORMAT(S)

Point locations

DATUM: Geocentric Datum of Australia (GDA94)

ACCESS AVAILABLE FORMAT TYPE(S)

ArcGIS shapefile (Site Details Table only), Microsoft Access database

Data Quality LINEAGE

Original field data collected from 1995 to present checked, tested and compiled by the Queensland Herbarium. The water chemistry tests were performed by the Water Laboratory, Chemistry Centre, EcoScience Prescinct.

DEFINITION

In this document, the following terms describe:

LUT: a look-up table, list of available values that can be entered in a field.

South Australia Only Field: A field that has not been used by Queensland but may have been populated when data was available.

Queenskland Only Field: A field that has only been used by Queensland and is not populated in South Australia.

A Site Details Table

Field Name		Description	Allowed Values
1	Vent ID	Unique identifier for an individual spring vent. Multiple vents from the same wetland are differentiated using underscore and a number.	Primary Key, Text
2	Site Number	Numerical identifier for spring wetland.Springs physically close from each other are often numbered with a decimal (i.e. 75, 75.1)	Primary key, Number
3	Preliminary Site Number	Preliminary unique identifier given to spring wetlands during field survey.	Text, Blank
4	Spring Status	Description of the water regime in the spring as 1. Permanent: the spring is permanently active or was permanently active and is now inactive. 2. Ephemeral: the spring is ephemeral and there is no evidence that it was ever permanent. 3. Not Sure: Final assessment of the status of the spring has not been made. 4. Rejected: Assessment of a previous record has been conducted and the spring status is rejected	LUT, Permanent, Ephemeral, Not Sure, Rejected, Blank
5	Name	Assigned name	Text, Blank
6	Aboriginal Name	Aboriginal name	Text, Blank
7	Synonym	Other names for the spring.	Text, Blank
8	Property Name	Name of property/pastoral station/national park on which spring wetland is located	LUT, Text, Blank
9	Group Number	South Australia Only Field. Spring group code in SA this is the same as the three letter code at the beginning of the vent id i.e. HWF in HWF003. Springs are naturally grouped and derive water from a similar fault or fracture and largely have similar water chemistry	Number, Blank
10	Group Name	South Australia Only Field. Spring group name	Text, Blank
11	Complex Number	Unique numerical identifier for spring complex	LUT, Number, Blank

Field Name		Description	Allowed Values
12	Complex Name	Name of spring complex to which spring wetland belongs. Complexes can contain both active and inactive springs. Slight variations on how this is derived exist between states. In Queensland a complex represents a group of springs or spring-groups such that no adjacent pair of springs or spring-groups is more than about 6km distant and all springs within the spring-complex are in a similar geomorphic setting. South Australia has no distance criteria, Complexes are naturally clustered Spring Groups located in a similar geomorphological setting. Geomorphic setting includes geological unit, landform, landscape position or soil type.	LUT, Text, Blank
13	Supergroup Name	Name of spring supergroup to which spring wetland belongs. A supergroup represents a major regional cluster of spring-complexes with some consistent hydrogeological characteristics as defined by Habermehl (1982) Ponder (1986) GABCC (1998) and Fensham and Fairfax (2003).	LUT, Text, Blank
14	Source Aquifer	Source aquifer where the water is coming from. More details are available in the hydrogeology reports.	LUT, Text, Blank
15	Discharge	Discharge springs emanate from a confined aquifer under artesian pressure, as opposed to outcrop springs that emanate by gravity where the water-bearing sediments are outcropping. An outcrop spring in the GAB has been referred to as a ‘recharge’ spring or ‘recharge-rejection’ spring.	LUT, True/False
16	Active	The spring vent is permanently active. The location of some inactive springs is approximate (see additional reports), and some inactive springs may have been permanent but are currently only active under some seasonal conditions (see additional reports).	LUT, True/False
17	Inactivity Rationale	The different reasons why a spring can become inactive are listed in this field.	LUT, Draw down, Explosives, Silting up, Unknown, Not applicable.
18	Region	This field sometimes relate to a broad basin such as the GAB or fragmented aquifers such as the tertiary sandstones in Central Queensland or may include unrelated aquifers in a particular region (e.g. SEQ). These regions have been surveyed with varying degrees of comprehensiveness described in Table 1.	LUT, Text, Blank

Field Name		Description	Allowed Values
19	Exposed by Excavation	Spring that have free water only because they have been excavated (i.e. The aquifer level is below the surface of the ground)	LUT, True/False
20	Latitude	Latitude, recorded as decimal degrees to 7 decimal places (0.01m accuracy). Negative values indicate location in southern hemisphere	(mandatory), Number
21	Longitude	Longitude, recorded as decimal degrees to 7 decimal places (0.01m accuracy). Positive values indicate location East of the prime meridian.	(mandatory), Number
22	Horizontal Coordinate System	Coordinate system used for horizontal location. 1. Australian Geodetic Datum of 1984 (AGD84), 2. Geocentric Datum of Australia 1994 (GDA94)	LUT, AGD84, GDA94
23	Horizontal Precision	South Australia Only Field. Meters to 3 decimal places. Given by the device.	Number, Blank
24	Vertical Precision	South Australia Only Field. Meters to 3 decimal places. Given by the device.	Number, Blank
25	Vertical Coordinate System	Australian Height Datum (AHD)	Australian Height Datum (AHD), Blank
26	Elevation - AHD (metres)	Mean elevation referenced to Australian Height Datum (AHD). Recorded in metres to 2 decimal places (0.1m accuracy).	Number, Blank
27	Elevation Source	The elevation data can come from two different sources. A differential GPS that measured the elevation in the field or the Digital Elevation Model (DEM) from which elevation information for any spring in Queensland was extracted. The DEM used is 1 second SRTM derived DEM-H v1.0 (i.e. DEM with smoothing and hydrological correction) (Wilson et al (2011)).	LUT, DEM, Differential GPS.

	Field Name	Description	Allowed Values
28	Survey Device (accuracy)	Indication of the precision (accuracy) of location data (horizontal coordinates, latitude and longitude). 1. RTK (Real Time Kinematic) has a mean elevation error of 5cm. 2. Omnistar Differential GPS has a mean horizontal positional error of ± 0.1m. 3. Handheld GPS units have a mean horizontal positional error of ± 10m. 4. Other measures of location have been given a horizontal positional error range from 0.1-10km. 5. Some spring wetland locations have had their location masked to protect populations of endangered species, these have been given a horizontal positional error of >10km. In some cases springs have been assigned the same location as nearby springs. This is usually inactive springs where the precise location of old vents was difficult to determine, or awaits further field survey. The actual location of inactive springs is sometimes uncertain despite the accuracy of measurement.	LUT, RTK ~ 0.5cm; Omni-star Differential ~ 0.1m accuracy, Garmin handheld ~10m accuracy, Other 0.1-10km accuracy, Masked >10km accuracy LUT
29	Adjacent Environment RE	Queensland Only Field. Field description of vegetation adjoining spring wetland including regional ecosystem (RE) code(s). For a full description of regional ecosystem codes refer to Queensland Herbarium (2014)	LUT, Text, Blank
30	Spring RE	Queensland Only Field. Regional ecosystem (RE) code for the spring wetland. For a full description of regional ecosystem codes refer to Queensland Herbarium (2014).	LUT, Text, Blank
31	Morphological Type (landscape situation)	Field description of the landscape situation of the spring wetland using Morphological types as defined by J.G. Speight in Australian Soil and Land Survey Field Handbook 3rd Edition (CSIRO 2009).	LUT, refer to (CSIRO 2009)
32	Landform (landscape) element	Field description of Landform element (landform with 20m radius) of the spring wetland using landform element types described & defined by J.G. Speight in Australian Soil and Land Survey Field Handbook 3rd Edition (CSIRO 2009). Page 34-35.	LUT, refer to (CSIRO 2009)
33	Erosional Landform Pattern	Field description of Erosional pattern (landform with 300m radius) of the spring wetland using erosional landform pattern classes described by J.G. Speight in Australian Soil and Land Survey Field Handbook 3rd Edition (CSIRO 2009). Page 47-48.	LUT, refer to (CSIRO 2009)

Field Name		Description	Allowed Values
34	Landform Pattern	Field description of Landform pattern (landform with 300m radius) of the spring wetland using landform pattern types described & defined by J.G. Speight in Australian Soil and Land Survey Field Handbook 3rd Edition (CSIRO 2009). Page 49. Previously Landform Pattern2.	LUT, refer to (CSIRO 2009)
35	Surface Geology	Reference to 1:250,000 Geology mapping units unless the field observation improve accuracy.	Text, Blank
36	Location Notes	Additional information including information on spring location	Text, Blank
37	References	Directory path to the folder containing all additional information regarding this spring.	Text, Blank
38	Hydrogeology Report	Directory path to the folder containing the hydrogeology report regarding this spring.	Text, Blank

B Spring Table

Field Name		Description	Allowed Values
1	Site Number	Numerical identifier for spring wetland.	Primary key, Number
2	Visit Number	Unique date for each visit.	Primary key, Date
3	Spring Wetland Length	Visual estimate of the length (metres) of the saturated spring wetland assuming the shape is a rectangle.	Number, Blank
4	Spring Wetland Width	Visual estimate of the width (metres) of the saturated spring wetland assuming the shape is a rectangle.	Number, Blank
5	Spring Wetland Area	Area (square metres) covered by ≥50% spring wetland vegetation (refer to Fensham and Fairfax (2009))	Number, Blank
6	% Connectivity	Visual estimate of the percentage of spring vents connected by shared wetland vegetation.	0-100, Blank
7	Area Derivation	Method used to calculate Spring wetland area. (a) *Differential GPS - GIS polygon*- field traverse of the spring wetland boundary (defined as having >= 50% cover of perennial wetland plant species) using Differential GPS to generate a GIS polygon feature for which an area could be calculated using Albers equal areas projection; (b) manually digitised from imagery; (c) mapped from Quickbird; (d) remote sensed image classification; (e) *Visual estimate* - multiplication of values recorded for spring wetland length and width; (f) digitised from Google Earth; (g) Using a tape to measure Width and Length; (h) Using GPS point and visual estimate; (i) Using the tracklog function on handheld GPS to walk around the spring; (j) Manually adjusting the track recorded using the differential GPS on a GIS; (k) Not applicable (i.e. Historical record, usually include information in "Notes")	LUT, Differential GPS - GIS polygon, From Imagery, From Quickbird, Remote sensed classification, Visual estimate, Google Earth, Tape measure, GPS + Visual Estimate, GPS Tracklog, Manually modified Differential GPS_GIS track, Not applicable, Blank
8	Estimated Spring Flow	Estimated discharge rate (Litres per minute) of water from spring wetland.	Number, Blank
9	Flow Derivation	Method used to calculate Estimated spring flow. (a) Fatchen - Model based on vegetated area (spring wetland area), for detail refer to Fatchen (2001). (b) White & Lewis (2011) and Petus et al. (2013) (c) Visual estimate - Field estimate of visible flow rate. (d) Expert estimate.	LUT, Fatchen, White & Lewis, Visual estimate, Expert, Blank
10	Notes	Additional information	Text, Blank

C Condition Table

Field Name		Description	Allowed Values
1	Vent ID	Unique identifier for an individual spring vent. Multiple vents from the same wetland are differentiated using underscore and a number.	Primary key, Text
2	Visit Number	Unique date for each visit.	Primary key, Date
3	Date	Dates of visit	Text, Blank
4	Flow	South Australia Only Field. Flow data collected. Default value for QLD is "False"	LUT, True/False
5	Excavation Damage (proportion)	Visual estimate of excavation damage recorded as one of five classes based on proportion of wetland area affected. 0 = none; 1 = adjacent to spring wetland; 2 = spring wetland less than 50% affected; 3 = spring wetland more than 50% affected, but not totally eradicated; 4 = spring wetland totally eradicated; Blank = No data	LUT, 0, 1, 2, 3, 4, Blank
6	Excavation Damage (type)	Description of excavation damage to site. 1= Bored; 2= Milled; 3= Dammed; 4= Drained; 5= Boxed well; 6= Pumped; 7= Other; 8=Gelignite; 9=Dugout	LUT, 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, Blank
7	Pig Damage	Visual estimate of pig damage recorded as one of four classes based on proportion of wetland area affected. 0 = absent; 1 = <10% affected; 2 = 10-50% affected; 3 = >50% affected; Blank= No data	LUT, 0 , 1, 2, 3, Blank
8	Stock Damage	Visual estimate of stock damage recorded as one of four classes based on proportion of wetland area affected. 0 = absent; 1 = <10% affected; 2 = 10-50% affected; 3 = >50% affected; Blank= No data	LUT, 0 , 1, 2, 3, Blank
9	Sulphate Status	South Australia Only Field. Sulphate or sulphides present at spring	LUT, True/False
10	Bore Casing	South Australia Only Field. Presence or absence of bore casing in spring vent to improve flow (default value "False")	LUT, True/False
11	Dominant Surface Composition (vent level)	Field description of the dominant surface composition of the vent. 1. Peat, 2. Mud (exuded), 3. Rocky seep (fractured), 4. Sand/Silt, 5. Carbonate (travertine), 6. Water/soak, 7. Other, 8. Blank (No data)	LUT, Peat, Mud, Rocky Seep, Sand/Silt, Carbonate, Water/soak, Other, Blank

Field Name		Description	Allowed Values
12	General Morphology (vent level)	Field description of the general morphology of the vent: Mound, Flat, Closed depression (concave), Open depression (watercourse) bed, Open depression (watercourse) bank, Terraced, Other, Blank (No data)	LUT, Mound, Flat, Closed Depression (concave), Open Depression (watercourse) bank, Open Depression (watercourse) bed, Terraced, Other, Blank
13	Mound length	Visual estimate of the length (metres) of mound.	Number, Blank
14	Mound width	Visual estimate of the width (metres) of mound.	Number, Blank
15	Relative mound height	Visual estimate of the relative height (metres) of mound to the adjoining non-mounded area.	Number, Blank
16	Surface expression (Saturation)	Known or inferred moisture status, based on information from landholders and floristic composition of spring wetland (perennial obligate wetland species). The surface expression of some excavated springs with sub-surface water levels is uncertain. The ‘Ephemeral’ springs have only been surveyed in a haphazard way. 'Not applicable' applies to 'Rejected spring'.	Assumed permanent; Ephemeral; Inactive; Not permanent; Permanent; Unknown; Not applicable
17	Stromatolites	South Australia Only Field. Presence or absence of stromatolites.	LUT, True/False
18	Notes	Additional information about the visit.	Text, Blank

D Observers Table

	Field Name	Description	Allowed Values
1	Vent ID	Unique identifier for an individual spring vent. Multiple vents from the same wetland are differentiated using underscore and a number.	Primary key, Text
2	Visit Number	Unique date for each visit.	Primary key, Date
3	Observer Number	Unique identifier for each observer	Primary Key, Number
4	Observer Name	Name of observer associated with unique number	Text
5	Observer Sequence	South Australia Only Field. Observer Sequence	Text, Blank
6	Notes	Additional information about the observer	Text, Blank

E Photos Table

Field Name		Description	Allowed Values
1	Vent ID	Unique identifier for an individual spring vent. Multiple vents from the same wetland are differentiated using underscore and a number.	Primary key, Text
2	Visit Number	Unique date for each visit	Primary key, Date
3	Description	Caption describing photo (keep short, less than 100 characters)	Text, Blank
4	File Name	Unique identifier for site photo, Full file name including extension (e.g. BAR_1044.jpg).	Primary Key, Text
5	Locality	Brief text describing locality (e.g. property name)	Text, Blank
6	Direction	Azimuth of photo direction measured clockwise in degrees from magnetic north (e.g. 270)	0-360, Blank
7	Latitude	Latitude at point photo taken, recorded as decimal degrees to 7decimal places. Negative values indicate location in southern hemisphere	Number, Blank
8	Longitude	Longitude at point photo taken, recorded as decimal degrees to 7 decimal places. Positive values indicate location in eastern hemisphere	Number, Blank
9	Bioregion	Queensland Only Field. 3 letter code indicating Bioregion as per Sattler and Williams (1999).	LUT, BBN, BBS, CYP, CHC, CQC, DEU, EIU, GUP,MGD, NWH, MUL, NET, SEQ, WET, Blank
10	Name	Name of photographer	Text, Blank
11	Notes	Additional information	Text, Blank

F Flora Record Table

Field Name		Description	Allowed Values
1	Vent ID	Unique identifier for an individual spring vent. Multiple vents from the same wetland are differentiated using underscore and a number.	Primary Key, Text
2	Visit Number	Unique date for each visit	Primary Key, Date
3	Taxon ID	Unique identifier for Floristic taxa - equivalent to BC_NR in Queensland Herbarium HERBRECS database.	Primary Key, Number
4	Taxon Name	Accepted Taxon Name, without Author details	Text
5	Method	Method used to record the flora. Standard Queensland survey: complete survey of plants in the spring.	LUT, Standard Queensland Survey, Blank
6	Abundance	Approximate number of a species encountered in the spring (if only the presence was recorded, Abundance=1)	Number, Blank
7	Genetically Distinct populations	Occurrence of populations of plant taxa that are genetically different from any other known population.	LUT, True/False
8	Disjunct/isolated population	Occurrence of populations of plant taxa not known from habitat other than spring wetlands within 250km. Based on confirmed species records held in the Queensland Herbarium HERBRECS database.	LUT, True/False
9	DNA	A DNA sample of the Flora specimen has been taken.	LUT, True/False
10	Notes	Additional information	Text, Blank

F Flora Taxa Table (Storage Table for QLD)

Field Name		Description	Allowed Values
1	Taxon ID	Unique identifier for Floristic taxa - equivalent to BC_NR in Queensland Herbarium HERBRECS database. Very few taxon have not been assessed yet and do not yet have a BC_NR, there are flagged in the “Notes” field and sometimes have a collection number (AQ_NR).	Primary Key, Number
2	Taxon Name Including Author	Accepted Full Taxon name including Author(s)	Text, Blank
3	Taxon Name	Accepted Full Taxon name excluding Author(s)	Text
4	Common Name	Common name of the plant taxa	Text, Blank
5	Species Type	Species type is always equal to “Plant” in this table. Default Value is plant. This column is hidden in the datasheet view.	Plant
6	Spring Endemic	Taxon endemic to GAB springs.	LUT, True/False
7	Scald Endemic	Taxon Endemic to scalds associated with springs.	LUT, True/False
8	NCA	Taxon Listed under Queensland’s Nature Conservation Act.	LUT, True/False
9	EPBC	Taxon Listed as Threatened under the Environment Protection and Biodiversity Conservation Act 1999.	LUT, True/False
10	Naturalised	Taxon recognised by Queensland Herbarium as Naturalised.	LUT, True/False
11	Widespread colonisers	Taxon recognised as common and widespread in a broad range of wetland habitats (cosmopolitan wetland taxa).	LUT, True/False
12	Non-wetland Incidental Taxa	Taxon not normally associated with wetland habitats.	LUT, True/False
13	Invasive Taxa	Naturalised taxon recognised as potentially invasive in wetland habitats e.g. 'Ponded Pasture' taxa.	LUT, True/False
14	Notes	Additional information	Text, Blank

G Fauna Record Table

Field Name		Description	Allowed Values
1	Vent ID	Unique identifier for an individual spring vent. Multiple vents from the same wetland are differentiated using underscore and a number.	Primary Key, Text
2	Visit Number	Unique date for each visit.	Primary Key, Date
3	Taxon ID	Unique identifier for Fauna Taxa. Some taxon names have been assigned to every spring in a complex in order to protect their exact location.	Primary Key, Number
4	Taxon Name	Accepted Taxon Name, without Author details.	Text
5	Method	Description of the method used to sample Fauna. 1. Unknown survey: there are no records of the method or search effort. 2. Winston Ponder survey: Sweeping the wetland with a 1mm sieve and ID the inverts in the field. 3. Standard field survey: 10 netting or sieving with 1mm mesh across a small area sampling both water and mud. 4. Intensive survey: Multiple standard or non-standard sampling across the whole wetland.	LUT, Unknown Survey, Winston Ponder survey, Standard field survey, Intensive survey, Blank
6	Abundance	Abundance of a species encountered in the spring.	Number , Blank
7	Genetically Distinct populations	Occurrence of populations of animal taxa that are genetically different from any other known population.	LUT, True/False
8	Disjunct/isolated population	Occurrence of populations of animal taxa not known from habitat other than spring wetlands within 250km.	LUT, True/False
9	DNA	A DNA sample of the Fauna specimen has been taken.	LUT, True/False
10	Notes	Additional information	Text, Blank

G Fauna Taxa Table (Storage Table for QLD)

Field Name		Description	Allowed Values
1	Taxon ID	Unique identifier for Fauna Taxa	Primary Key, Number
2	Taxon Name Including Author	Accepted Full Taxon name including Author(s)	Text, Blank
3	Taxon Name	Accepted Full Taxon name excluding Author(s)	Text
4	Common name	Common name of the fauna taxa	Text, Blank
5	Species Type	For South Australia, in BDSA, Species can be: F= fish, B= Bird, R = reptiles, A= Amphibious, Amphibious, and others to be determined. For Queensland, Species type can be : Absence of fish, Absence of mollusc, Amphibian, Beetle, Crustacea, Fish, Invertebrate, Mammal, Mollusc, No species found, Spider, Worm	LUT, Text, Blank
6	Spring Endemic	Taxon endemic to GAB springs or very likely to be endemic.	LUT, True/False
7	Scald Endemic	Taxon Endemic to scalds associated with springs. Always False in this table. Default value is False. This field is hidden in datasheet view.	LUT, True/False
8	NCA	Taxon Listed under Queensland's Nature Conservation Act	LUT, True/False
9	EPBC	Taxon Listed as Threatened under the Environment Protection and Biodiversity Conservation Act 1999	LUT, True/False
10	Naturalised	Taxon recognised by Queensland Herbarium as Naturalised. Always False in this table. Default value is False. This field is hidden in datasheet view. This field is not used.	LUT, True/False

11	Widespread colonisers	Taxon recognised as common and widespread in a broad range of wetland habitats (cosmopolitan wetland taxa).	Widespread colonisers
12	Non-wetland Incidental Taxa	Taxon not normally associated with wetland habitats. Always False in this table. Default value is False. This field is hidden in datasheet view. This field is not used.	LUT, True/False
13	Invasive Taxa	Naturalised taxon recognised as potentially invasive in wetland habitats. Always False in this table. Default value is False. This field is hidden in datasheet view. This field is not used.	LUT, True/False
14	Notes	Additional information	Text, Blank

H Water Table

Field Name		Description	Allowed Values
1	Vent ID	Unique identifier for an individual spring vent. Multiple vents from the same wetland are differentiated using underscore and a number.	Primary Key, Text
2	Visit Number	Unique date for each visit	Primary Key, Date
3	Distance from vent	The distance (metres) from main spring vent to the point at which water chemistry data was collected	Primary Key, Number
4	Latitude	Latitude, recorded as decimal degrees to 7 decimal places (0.01m accuracy). Negative values indicate location in southern hemisphere	Number
5	Longitude	Longitude, recorded as decimal degrees to 7 decimal places (0.01m accuracy). Positive values indicate location in eastern hemisphere	Number
6	Measured Spring Flow	South Australia Only Field. Estimated discharge rate (Litres per minute) of water from spring wetland.	Number, Blank
7	Flow Measurement Method	South Australia Only Field. Method used to measure spring flow: (a) Salt dilution. (b) Weir gauge. (c) Timed volume measurement. (d) Colorimetric method.	Salt Dilution, Weir Gauge, Timed volume measurement, Colorimetric method, Blank
8	Quantitative flow	South Australia Only Field. To be described by South Australia	Number, Blank
9	Qualitative flow	South Australia Only Field. Description of flow: FW+T= Free water and tail. F= Free water. S= Soak. D= Damp. Dry= Dry. Extinct= Extinct	Text, Blank
10	pH	Hydrogen ion potential of field water sample, recorded to 2 decimal places.	0-14, Blank
11	Temperature	Water temperature in degrees Celsius, recorded to 1 decimal place.	Number, Blank
12	Conductivity	Measure of electrical conductivity in micro siemens by centimetre, recorded as 1 decimal place.	Number, Blank
13	Alkalinity	Field Measure of Alkalinity as total dissolved $CaCO_3$ using a Hach© digital titrator.	Number, Blank
14	Hydrogeological Report Exists	A hydrogeological report exists for the spring or an associated bore	LUT, True/False

Field Name		Description	Allowed Values
15	Detailed water chemistry	1. Detailed water chemistry not available; 2. Detailed water in hydrogeological report; 3. Detailed water chemistry exists in Chemistry table	NA, Hydrogeological Report, Chemistry Table
16	Method of recording	Water chemistry methods used to sample the water. 1. Field Recording; 2. Laboratory Sample	LUT, Field Recording, Laboratory Sample
17	Notes	Additional information	Text, Blank

I Chemistry Table

Field Name		Description	Allowed Values
1	Vent ID	Unique identifier for an individual spring vent. Multiple vents from the same wetland are differentiated using underscore and a number.	Primary Key, Text
2	Visit Number	Unique date for each visit	Primary Key, Date
3	Distance from Vent (in m)	Distance from vent at which the sample was taken	Number
4	Sample ID	Unique identifier for water sample (must be the same ID as the ID on the results sheet coming from the Laboratory which analysed the water)	Primary Key, Text
5	Parameters	In a look up table, list of chemical elements analysed by a laboratory. Each parameter is associated with its value in the next field.	Primary Key, LUT, Text
6	Value	Value found by the laboratory for the parameter in the previous field.	Number
7	Notes	Additional information	Text, Blank

K GDE - ATLAS Table

Field Name		Description	Allowed Values
1	Vent ID	Unique identifier for an individual spring vent. Multiple vents from the same wetland are differentiated using underscore and a number.	Text, Primary Key
2	Aquifer name	Name of source aquifer	LUT, Sandstone (Great Artesian Basin), Carnarvon Basalt, Sandstone
3	Aquifer geology	Broad geology type of the source aquifer	LUT, Fractured and consolidated sedimentary, Fractured rock
4	Aquifer confinement	Source aquifer confinement	LUT, Confined, Unconfined
5	Aquifer porosity	Source aquifer porosity	Primary and secondary
5	Aquifer groundwater flow system	Source aquifer groundwater flow system	LUT, Basin (regional), Bedrock (local)
7	Aquifer groundwater type (salinity)	Salinity of groundwater in the source aquifer	QRY, Fresh, Brackish, Saline, Hypersaline, Fluctuating, Stratified, Unknown, No data

Field Name		Description	Allowed Values
8	Aquifer groundwater type (pH)	pH of groundwater in the source aquifer	QRY, Acidic, Neutral, Alkaline, Fluctuating, Unknown, No data
9	Aquifer recharge source	Dominant recharge source of groundwater in the source aquifer	LUT, Infiltration (distant), Infiltration (local)
10	Groundwater connectivity regime (spatial)	Spatial nature of the connectivity between GDE and groundwater, including the type and direction of connection	Connected, gaining
11	Groundwater connectivity regime (temporal)	Temporal nature of the connectivity between GDE and groundwater	QRY, Aseasonal (ephemeral), Aseasonal (episodic), Aseasonal (intermittent), Seasonal, Near permanent, Permanent, Unknown, No data
12	GDE_CLASS	GDE class: 1.Surface ecosystems dependent on the surface expression of groundwater; 2.Surface ecosystems dependent on the sub-surface presence of groundwater; 3.Subterranean (caves and aquifers)	Text
13	Groundwater connectivity regime (temporal detailed)	Detailed temporal nature of the connection between the GDE and groundwater. For more details see “Queensland Groundwater Dependent Ecosystem Mapping Technical Specifications”	Text

Field Name		Description	Allowed Values
14	GDE Type	Type of GDE:1.Surface expression GDE; 2.Terrestrial GDE; 3.Subterranean GDE	Text
15	GDE Confidence	Confidence in the groundwater dependence of the ecosystem: 1.Known GDE; 2.Derived GDE – high confidence; 3.Derived GDE – moderate confidence; 4.Derived GDE – low confidence; 5.Unknown confidence	Text
16	Conceptual Model	Hyperlink to associated GDE conceptual model	Text
17	GDE Mapping Rule-Set ID	GDE mapping rule-set identifier	Text
18	GDE Mapping Rule-Set Name	GDE mapping rule-set name	Text
19	GDE Evidence	Evidence supporting GDE identification: 1.Field survey; 2.Expert opinion; 3.Report; 4.Journal article; 5.Stream gauge; 6.Monitoring bore	Text

L Conservation Status Table

Field Name		Description	Allowed Values
1	Site Number	Numerical identifier for spring wetland.	Primary Key, Number
2	Conservation Ranking (Spring)	Spring wetland conservation ranking applied at individual spring wetland/vent level as per the following rule set: Category 1a: Contains at least one GAB endemic species not known from any other location beyond this spring complex. Category 1b: Contains endemic species known from more than one spring complex; or has populations of threatened species listed under State or Commonwealth legislation that do not conform to Category 1a. Category 2: Provides habitat for populations of plant and/or animal species not known from habitat other than spring wetlands within 250km. Category 3: Spring wetland vegetation without isolated populations (Category 2) with at least one native plant species that is not a weedy cosmopolitan plant species (Appendix R). Category 4: a) Spring wetland vegetation comprised of exotic and/or only native weedy cosmopolitan wetland plant species (Appendix R) or a spring devoid of vegetation or b) the original spring wetland is destroyed by impoundment or excavation. The probability of important biological values being identified in the future is very low. No other wetland species. Category 5: All springs inactive. Conservation ranking can only be applied to spring wetlands which have associated flora and fauna records.	1a, 1b, 2, 3, 4a, 4b, 5
3	Conservation Ranking Rationale (Spring)	Detail of the attribute which results (Trigger) in the spring receiving a particular Conservation Rank. Refer to fields *Conservation Ranking (Spring)* and *Conservation Ranking (Complex Level)* in Conservation Status table.	Text, Blank
4	Conservation Ranking (Complex)	Spring wetland conservation ranking aggregated to the spring complex level. All spring wetlands within a spring complex are given the highest rank (*Conservation Ranking (Spring*) achieved by any constituent spring wetlands Conservation Status Table	1a, 1b, 2, 3, 4a, 4b, 5
5	Conservation Ranking Rationale (Complex)	Detail of the attribute which results (Trigger) in the spring complex receiving a particular Conservation Rank. Refer to Fields *Conservation Ranking (Complex Level)* and *Conservation Ranking (Spring Level)* Conservation Status Table	Text, Blank

M GIS-Group. South Australia Only Table

Field Name		Description	Allowed Values
1	Group Number	Spring group code in SA this is the same as the three letter code at the beginning of the vent id i.e. HWF in HWF003. (SA Data). Springs are naturally grouped and derive water from a similar fault or fracture and largely have similar water chemistry.	Text, Primary Key
2	Group Name	(SA Data) Spring group name as summarised in Gotch (2013) Volume IV. AWMSGAB	Text, Blank
3	Attribute 1	Spatial Attribute 1 i.e. Longitude, polygon, etc	Number, Blank
4	Attribute 2	Spatial Attribute 2 i.e. Latitude, polygon, etc	Number, Blank
5	Scald Endemic	Presence or absence of spring endemics	True/False, Blank

M GIS-Complex. South Australia Only Table

Field Name		Description	Allowed Values
1	Complex Number	Unique numerical identifier for spring complex (see Rec Plan and SA Spring Spatial Survey).	LUT, Any integer > 0, Blank
2	Complex Name	Name of spring complex to which spring wetland belongs. Slight variations on how this is derived exist between states. In Queensland a complex represents a group of springs or spring-groups such that no adjacent pair of springs or spring-groups is more than about 6km distant and all springs within the spring-complex are in a similar geomorphic setting. South Australia has no distance criteria, Complexes are naturally clustered Spring Groups located in a similar geomorphological setting. Geomorphic setting includes geological unit, landform, landscape position or soil type. Complexes can contain both active and inactive springs.	LUT, Text, Blank
3	Attribute 1	Spatial Attribute 1 i.e. Longitude, polygon, etc	Number, Blank
4	Attribute 2	Spatial Attribute 2 i.e. Latitude, polygon, etc	Number, Blank

M GIS-Wetland. South Australia Only Table

Field Name		Description	Allowed Values
1	Site Number	Numerical identifier for spring wetland. Numbers with the prefix “-“refer to potential spring locations that have been searched but no spring found.	Primary key, >= 0
2	Name	European name	Text, Blank
3	Attribute 1	Spatial Attribute 1 i.e. Longitude, polygon, etc	Number, Blank
4	Attribute 2	Spatial Attribute 2 i.e. Latitude, polygon, etc	Number, Blank

QRY_Complete Species List and Status_Proof of Concept Query. SA and QLD

Field Name		Description	Allowed Values
1	Complex Number/ Group Number/ Site Number	Numerical identifier for Complex, Group or spring wetland.	Text OR Number
2	Taxon ID	Unique identifier for Flora or Fauna Taxa.	Number
3	Taxon Name	Accepted Full Taxon name excluding Author(s)	Text
4	Common name	Common name of the taxa	Text, Blank
5	Species Type	IN BDSA, Species can be : F= fish, B= Bird, R = reptiles, A= Amphibious, and others to be determined	Text, Blank
6	EPBC	Taxon Listed as Threatened under the Environment Protection and Biodiversity Conservation Act 1999	Text, Blank
7	NCA	Taxon Listed under Queensland Nature Conservation Act	Text, Blank
8	NPWA Species	Presence in spring wetland of flora and/or fauna taxa listed as rare, endangered or vulnerable under the South Australian National Parks and Wildlife Act 1972.	True/False
9	Spring Endemic	Taxon endemic to GAB springs	True/False
10	Scald Endemic	Taxon Endemic to scalds associated with springs	True/False
11	Invasive Taxa	Naturalised taxon recognised as potentially invasive in wetland habitats e.g. 'Ponded Pasture' taxa	True/False

QRY_Species Summary and Group Status_Proof of Concept Query. SA and QLD

Field Name		Description	Allowed Values
1	Complex Number/ Group Number/ Site Number	Numerical identifier for Complex, Group or spring wetland.	Text OR Number
2	Species Type	IN BDSA, Species can be : F= fish, B= Bird, R = reptiles, A= Amphibious, and others to be determined	Text, Blank
3	Number of species	Number of individual species found in the spring wetland, group or complex.	Number, Blank
4	EPBC	Number of taxon listed as Threatened under the Environment Protection and Biodiversity Conservation Act 1999in the spring wetland, group or complex.	True/False
5	NCA	Number of taxon Listed under Queensland Nature Conservation Act in the spring wetland, group or complex.	True/False
6	NPWA Species	Number of taxon listed as rare, endangered or vulnerable under the South Australian National Parks and Wildlife Act 1972 in the spring wetland, group or complex.	True/False
7	Spring Endemic	Number of taxon endemic to GAB springs found in the spring wetland, group or complex.	True/False
8	Scald Endemic	Number of taxon Endemic to scalds found in the spring wetland, group or complex.	True/False
9	Invasive Taxa	Number of naturalised taxon recognised as potentially invasive in wetland habitats (e.g. 'Ponded Pasture' taxa) in the spring wetland, group or complex.	True/False

QRY_Vent Summary Status_To be deleted OR used as a last proof of concept

Field Name		Description	Allowed Values
1	Complex Number/ Group Number/ Site Number	Numerical identifier for Complex, Group or spring wetland.	>= 0
2	Vent ID	Unique identifier for an individual spring vent. Multiple vents from the same wetland are differentiated using underscore and a number.	Text
3	Group Number	Spring group code	Text, Blank
4	Complex Number	Unique numerical identifier for spring complex (see Rec Plan and SA Spring Spatial Survey).	LUT, Any integer > 0, Blank
5	Location Data/ Date	Date most recent location was measured	Query
6	Water Data/ Date	Date most recent water data collected	Query
7	Flora Data/ Date	Date most recent Flora data collected	Query

Data Comprehensiveness

The ‘Spring Status’ and the ‘Region’ fields used in the database are essential to assess the comprehensiveness of the data. Table 1 presents the comprehensiveness of the dataset for permanent springs. Ephemeral springs have been included in the database haphazardly.

Table 1: Assessment of the recharge and discharge permanent spring survey‘s comprehensiveness per region and per supergroup.

Fields			Comprehensiveness of survey
Region	Supergroup	Discharge	
Galilee			>98%
Other Non-GAB			>80%
Non-GAB Carnarvon Basalt			>80%
SEQ			Unknown
CQC			Unknown
Main Range Basalt			Unknown
Tertiary Springs			>80%
GAB	Barcaldine	Discharge	>98%
		Outcrop	>98%
	Flinders River	Discharge	>95%
		Outcrop	>70%
	Springsure	Discharge	>98%
		Outcrop	>85%
	Springvale	Discharge	>98%
	Eulo	Discharge	>95%
	NSW	Discharge	>95%

Data Dependency

Data included in the database have mostly been collected in the field (Table 2). However, some information is sometimes derived from other fields. Attributes that depend on others are listed in the Table 3. Field that can include information from both field data and derived data are flagged in Table 4.

Table 2: List of attributes where the data have been surveyed in the field or assessed from local knowledge.

Table	Field Name	Measured fields
Site Details	Spring Status	Field Assessment
Site Details	Active	Field assessment
Site Details	Inactivity Rationale	Field assessment
Site Details	Exposed by Excavation	Field assessment
Site Details	Latitude	Field assessment
Site Details	Longitude	Field assessment
Site Details	Horizontal Coordinate System	Field assessment
Site Details	Vertical Coordinate System	Field assessment
Site Details	Elevation Source	Field assessments
Site Details	Survey Device (accuracy)	Field assessment
Site Details	Spring RE	Field assessment
Spring	Spring Wetland Length	Field assessment
Spring	Spring Wetland Width	Field assessment
Spring	Spring Wetland Area	Field assessment
Spring	% Connectivity	Assessed/surveyed
Condition	Visit Number	Assessed/surveyed
Condition	Date	Assessed/surveyed
Condition	Excavation Damage (proportion)	Assessed/surveyed
Condition	Excavation Damage (type)	Field assessment
Condition	Pig Damage	Field assessment
Condition	Stock Damage	Field assessment

Table	Field Name	Measured fields
Condition	Dominant Surface Composition (vent level)	Field assessment
Condition	General Morphology (vent level)	Field assessment
Condition	Mound length	Field assessment
Condition	Mound width	Assessed/surveyed
Condition	Relative mound height	Assessed/surveyed
Condition	Surface expression (Saturation)	Assessed/surveyed
Observers	Visit Number	Assessed/surveyed
Observers	Observer Number	Assessed/surveyed
Observers	Observer Name	Assessed/surveyed
Photos	Visit Number	Assessed/surveyed
Photos	Description	Assessed/surveyed
Photos	Locality	Assessed/surveyed
Photos	Direction	Assessed/surveyed
Photos	Latitude	Assessed/surveyed
Photos	Longitude	Assessed/surveyed
Flora Record	Visit Number	Assessed/surveyed
Flora Record	Taxon ID	Assessed/surveyed
Flora Record	Taxon Name	Assessed/surveyed
Flora Record	Method	Assessed/surveyed
Flora Record	Abundance	Assessed/surveyed
Flora Record	Genetically Distinct populations	Assessed/surveyed
Flora Record	DNA	Assessed/surveyed
Fauna Record	Visit Number	Assessed/surveyed
Fauna Record	Taxon ID	Assessed/surveyed
Fauna Record	Method	Assessed/surveyed
Fauna Record	Abundance	Assessed/surveyed
Fauna Record	Genetically Distinct populations	Assessed/surveyed
Fauna Record	DNA	Assessed/surveyed

Table	Field Name	Measured fields
Water	Visit Number	Assessed/surveyed
Water	Distance from vent	Assessed/surveyed
Water	Latitude	Assessed/surveyed
Water	Longitude	Assessed/surveyed
Water	pH	Assessed/surveyed
Water	Temperature	Assessed/surveyed
Water	Conductivity	Assessed/surveyed
Water	Alkalinity	Assessed/surveyed
Water	Hydrogeological Report Exists	Assessed/surveyed
Water	Detailed water chemistry	Assessed/surveyed
Water	Method of recording	Assessed/surveyed
Chemistry	Visit Number	Assessed/surveyed
Chemistry	Distance from Vent (in m)	Assessed/surveyed
Chemistry	Sample ID	Assessed/surveyed
Chemistry	Parameters	Assessed/surveyed
Chemistry	Value	Assessed/surveyed

Table 3: List of attributes where the data depend on other database fields and/or external data. The 'Dependent on' column highlights the source from where the data was derived.

Table	Field Name	Dependent on
Site Details	Property Name	Cadastre
Site Details	Supergroup Name	Geology, Latitude, longitude
Site Details	Source Aquifer	Geology, pH, Alkalinity, Conductivity, Head
Site Details	Discharge	Geology, pH, Alkalinity, Conductivity, Aquifer
Site Details	Region	Geology, Aquifer
Site Details	Surface Geology	Geology, can be confirmed or revised with field observation.
Spring	Estimated Spring Flow	Derived from 'Wetland area'
Photos	Bioregion	Bioregional Mapping
Flora Record	Disjunct/isolated population	Herbrecs
Flora Taxa	Taxon Name Including Author	Taxon Name, Herbrecs
Flora Taxa	Spring Endemic	Literature
Flora Taxa	Scald Endemic	Literature
Flora Taxa	NCA	Literature
Flora Taxa	EPBC	Literature
Flora Taxa	Naturalised	Literature
Flora Taxa	Widespread colonisers	Literature
Flora Taxa	Non-wetland Incidental Taxa	Literature
Flora Taxa	Invasive Taxa	Literature
Fauna Record	Disjunct/isolated population	Literature
Fauna Taxa	Species Type	Literature
Fauna Taxa	Spring Endemic	Literature or Expert opinion

Table	Field Name	Dependent on
Fauna Taxa	Scald Endemic	Literature or Expert opinion
Fauna Taxa	NCA	Literature
Fauna Taxa	EPBC	Literature
Fauna Taxa	Naturalised	Literature or Expert opinion
Fauna Taxa	Widespread colonisers	Literature or Expert opinion
Fauna Taxa	Non-wetland Incidental Taxa	Literature or Expert opinion
Fauna Taxa	Invasive Taxa	Literature or Expert opinion
GDE – ATLAS	Aquifer name	Region
GDE – ATLAS	Aquifer geology	Region
GDE – ATLAS	Aquifer confinement	Region
GDE – ATLAS	Aquifer porosity	Region
GDE – ATLAS	Aquifer groundwater flow system	Region
GDE – ATLAS	Aquifer groundwater type (salinity)	Conductivity
GDE – ATLAS	Aquifer groundwater type (pH)	pH
GDE – ATLAS	Aquifer recharge source	Region
GDE – ATLAS	Groundwater connectivity regime (spatial)	Region
GDE – ATLAS	Groundwater connectivity regime (temporal)	Surface Expression
Conservation Status	Conservation Ranking 2012 (Vent)	QRY
Conservation Status	Conservation Ranking Rationale 2012 (Vent)	QRY
Conservation Status	Conservation Ranking 2012 (Complex)	QRY
Conservation Status	Conservation Ranking Rationale 2012 (Complex)	QRY
Conservation Status	Risk Rating	QRY
QRY_Complete Species List and Status	Complex Number/ Group Number/ Site Number	QRY
QRY_Complete Species List and Status	Taxon ID	QRY

Table	Field Name	Dependent on
QRY_Complete Species List and Status	Taxon Name	QRY
QRY_Complete Species List and Status	Common name	QRY
QRY_Complete Species List and Status	Species Type	QRY
QRY_Complete Species List and Status	EPBC	QRY
QRY_Complete Species List and Status	NCA	QRY
QRY_Complete Species List and Status	NPWA Species	QRY
QRY_Complete Species List and Status	Spring Endemic	QRY
QRY_Complete Species List and Status	Scald Endemic	QRY
QRY_Complete Species List and Status	Invasive Taxa	QRY
QRY_Species Summary and Group Status	Complex Number/ Group Number/ Site Number	QRY
QRY_Species Summary and Group Status	Species Type	QRY
QRY_Species Summary and Group Status	Number of species	QRY
QRY_Species Summary and Group Status	EPBC	QRY
QRY_Species Summary and Group Status	NCA	QRY

Table	Field Name	Dependent on
QRY_Species Summary and Group Status	NPWA Species	QRY
QRY_Species Summary and Group Status	Spring Endemic	QRY
QRY_Species Summary and Group Status	Scald Endemic	QRY
QRY_Species Summary and Group Status	Invasive Taxa	QRY
QRY_Vent Summary Status	Complex Number/ Group Number/ Site Number	QRY
QRY_Vent Summary Status	Vent ID	QRY
QRY_Vent Summary Status	Group Number	QRY
QRY_Vent Summary Status	Complex Number	QRY
QRY_Vent Summary Status	Location Data/ Date	QRY
QRY_Vent Summary Status	Water Data/ Date	QRY
QRY_Vent Summary Status	Flora Data/ Date	QRY

Table 4: List of attributes where the data has either been measured in the field or derived from other sources.

Table	Field Name	Measured fields	Dependent on
Site Details	Elevation - AHD (metres)	Assessed/surveyed	The digital elevation model (DEM) when ‘DEM’ is entered in the ‘Elevation source’ field. Otherwise, it is measured in the field using a Differential GPS.
Site Details	Adjacent Environment RE	Assessed/surveyed	RE Mapping unless the field observations allow a more accurate RE description.

LEBSA DATABASE: CONTACT ORGANISATION

Queensland Herbarium, Department of Science, Information Technology, and Innovation

CONTACT POSITION

LEBSA Database Manager, Boris Laffineur

MAIL ADDRESS

Brisbane Botanic Gardens, Mt Coot-tha, Mt Coot-tha Road

SUBURB/PLACE/LOCALITY

TOOWONG

STATE

QLD

COUNTRY

AUSTRALIA

POSTCODE

4066

TELEPHONE

07 38969547

FACSIMILE

07 38969624

ELECTRONIC MAIL ADDRESS

Boris.laffineur@dsiti.qld.gov.au

METADATA DATE: 20/07/2015

Metadata References

CSIRO. 2009. Australian Soil and Land Survey Field Handbook. 3rd Edition. Collingwood

Cox, R., Barron, A. 1998. Great Artesian Basin Resource Study (November 1998). Great Artesian Basin Consultative Council, Canberra.

Fatchen, T. 2001. Vegetated wetland area as an index of mound spring flows. Proceedings 4th Mound Spring Researchers Forum. Friday 23 February 2001. Department of Environment and Heritage, Adelaide, pp. 5-8

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

Fensham R.J., Fairfax R.J. 2009. Development and trial of a spring wetland monitoring methodology in the Great Artesian Basin, Queensland. Department of Environment and Resource Management

Fensham, R.J., Ponder, W.F., Fairfax, R.J. 2010. Recovery plan for the community of native species dependent on natural discharge of groundwater from the Great Artesian Basin. Report to Department of the Environment, Water, Heritage and the Arts, Canberra. Queensland Department of Environment and Resource Management, Brisbane.

Fensham, R.J., Pennay, C., Drimer, J. 2011. Ecological and Botanical survey of springs in the Surat Cumulative Management Area. Queensland Herbarium.Department of Science, Information Technology, Innovation and the Arts.

Habermehl, M.A. 1982. Springs in the Great Artesian Basin, Australia - their origin and nature. Bureau of Mineral Resources, Geology and Geophysics, Canberra.

Ponder, W. F. 1986. Mound Springs of the Great Artesian Basin. Limnology in Australia.

Petus, C., Lewis, M., White, D.C (2013). Monitoring temporal dynamics of Great Artesian Basin wetland vegetation, Australia, using MODIS NDVI. Ecological Indicators 34, pp41– 52.

Queensland Herbarium. 2014. Regional Ecosystem Description Database (REDD). Version 8.1 (April 2014). Queensland Department of Science, Information Technology, Innovation, Brisbane. https://environment.ehp.qld.gov.au/regional-ecosystems/ (Accessed 20/04/2015)

Sattler, P.S., Williams, R.D. (1999) (eds). The Conservation Status of Queensland's Bioregional ecosystems. Environmental Protection Agency, Brisbane.

White D. C., Lewis M.M. (2011) A new approach to monitoring spatial distribution and dynamics of wetlands and associated flows of Australian Great Artesian Basin springs using QuickBird satellite imagery. Journal of Hydrology. 408:1-2, pp 140–152.

Wilson, N., Tickle, P.K., Gallant, J., Dowling, T., Read, A. 2011. 1 second SRTM Derived Hydrological Digital Elevation Model (DEM-H) version 1.0. Commonwealth of Australia (Geoscience Australia). http://www.ga.gov.au/metadata-gateway/metadata/record/gcat_a05f7893-0050-7506-e044-00144fdd4fa6/1+second+SRTM+Derived+Hydrological+Digital+Elevation+Model+%28DEM-H%29+version+1.0 (Accessed 20/04/2015)

12.3 Appendix C

Additional information example

JERSEY SPRINGS (BARCALDINE SUPERGROUP)

Status: Active

Location: -23.07446°S, 145.49937°E (1107; see table for full location details)

Property: Politic/Taree

Preliminary site #: 129, 129A, 130, nv409

Site #: 1107, 1108, 129, 130

Field survey date: 6 April 2013

Informant: Bryceson & Gen Hawkins

Inspected plans: Survey Run Plan, Mitchell District M.57.106 (1876); 4 mile series 1 sheet 10B (1919)

Marked on survey plan as unnamed springs but not 4 mile map.

Survey Plan Mitchell District M.57.106 (1876). Springs south of the sawpit are Jersey Springs; the ones marked to the north on the Clermont-Aramac road are Friendly Springs

J. Alfred Griffiths did not map or visit them, but described (19/6/1897):

'Across the eastern side of the Aramac Run & mainly at the foot of the tableland ranges, are numerous springs of similar character to those on the Western & Northern edges of the artesian field from Springvale to Norman River. The following are the main groups:

> *G. The Jersey Springs near the middle of the west boundary of block Jersey but mainly on the block Friendly Springs are estimated to yield 100,000gpd.*

These springs were mentioned in an article on 'The New Resumptions' published in *The Western Champion and General Advertiser for the Central-Western Districts* on 2 December 1901, p.1:

> *From Coreena 216 square miles have been resumed. This includes three portions in different corners of the run. No. 1, of 63 square miles, embraces a strip for 15 miles along the Barcaldine-Aramac road. This is good downs country with four dams on it and some fencing improvements. No. 2 is on the north-west, known as the Jersey block, of 25 square miles, with good springs on it. This is desert country.*

There are three springs on Taree and one on Politic, situated on a large open scalded plain at the headwaters of creeks flowing into Sandy Creek. Bryceson's Spring is the most northern spring, and has been excavated. The substrate has a strong smell and the water is corrosive and changes colour, and can be yellow, black or green at different times. When the air pressure drops, the spring trickles down the gully. Kangaroo Bog (site 1108) lies in a peaty hollow with *Eucalytpus camaldulensis*, while Black Pond (site 130) is a pool in a *Eucalytpus camaldulensis/ Melaleuca bracteata* hollow. All springs on Taree have been fenced.

The Politic spring (site 129) is an excavated muddy hole surrounded by *Eucalyptus camaldulensis, E. coolibah* and *Melaleuca bracteata*, and is very heavily grazed by cattle. There are old yards on the sandy buffel grass rise above the spring. Site 129A in SPRLOC was unable to be located in 2013.

There are clumps of *Melaleuca bracteata* across the plain which look 'springy' but don't hold water for any length of time. *Calocephalus* sp. (Edgbaston J.Silcock JLS800) is abundant across the area, and ungrazed even where cattle grazing pressure is very high, while *Trianthema* sp. (Coorabulka R.W. Purdie 1404) and the Edgbaston form of *Sclerolaena glabra* are patchily common. Stone flakes are scattered in low densities across the area, mostly on claypans. The cumulative flow of the springs is much-reduced from Griffiths' 1897 estimate of 100 000 gallons per day.

Site #	Latitude	Longitude	Site Name	Description
1107	-23.07446°S	145.49937°E	Bryceson's Spring	Permanent pool; has been scooped out and fenced; *Melaleuca bracteata, Cyperus difformis, Cyperus polystachyus, Cynodon dactylon, Echinochloa colona, Juncus polyanthemus, Monochoria cyanea*
1108	-23.07830°S	145.50051°E	Kangaroo Bog	Red gum peaty hollow with puddles of free water; fenced; *Cyperus difformis, Cyperus* sp. (JLS1471)

129	-23.08137°S	145.50248°E	Politic	Excavated muddy hole with yards nearby; very high cattle grazing pressure
130	-23.08470°S	145.50000°E	Black Pond	*Eucalyptus camaldulensis/Melaleuca bracteata* hollow; fenced; *Dendrophthoe glabrescens*

Jersey Springs on the Taree-Politic boundary: (A) Bryceson's Spring (Site 1107) (B) Kangaroo Bog (Site 1108) (C) Politic spring (Site 129) (D) Black Pond (Site 130); (E) spring landscape, showing scalded plain with *Calocephalus* sp. abundant

12.4 Appendix D

Shoemaker bore log

Drilling Log

Well: Shoemaker-1 **Permit:** ATP 744P

Comet Ridge

SURFACE LOCATION

Latitude :	22° 03' 57.36" S
Longitude :	146° 14' 26.03" E
Easting :	421 645 mE
Northing :	7 559 680 mN
RT Elevation:	251.2 m
GL Elevation:	248.0 m
Datum:	GDA94, MGA Z55

HOLE SIZE

Diameter	Depth MD
8.500 in.	207.5
6.125 in.	536.8
3.780 in.	697.6

CASING

Diameter	Depth MD
7 in.	205.3 m
4.500 in.	536.8 m

SHOW SYMBOLS

	Oil	Gas
Good		
Fair		
Poor		
Trace		

DST SUMMARY

DST#1 Betts Creek 589.09-595.30mDF
IF/ISI/FF/FSI: 5/30/20/240 minutes
Water Cushion: 180m
FSI pressure: 838psi @ 590mDF

DST#2 Betts Creek 620.18-625.59mDF
IS/ISI/FF/FSI: 5/60/20/240 minutes
Water Cushion: 294m
FSI Pressure: 878psi @ 624.09mDF

LEGEND

- Test Interval
- MFT Depth
- Casing Shoe
- Sidewall Core
- Core

LITHOLOGY LEGEND

CONGLOMERATE	LIMESTONE
VERY COARSE SANDSTONE	DOLOMITE
SANDSTONE	SHALE
VERY FINE SANDSTONE	WEATHERED VOLCANIC
SILTSTONE	VOLCANIC
CLAYSTONE	BASALT
MUDSTONE	SHALY SANDSTONE
COAL	CARB. SILTSTONE
TUFF	CLAYEY SANDSTONE

Services

Engineer: M.Troughton
Geologist: J.Hulse
Wireline: Weatherford Wireline
Core Handling: Weatherford Labs
Operations Supervisor: G.Smith

DATES

Spud :	0700hrs 15/1/2010
Reached TD :	1130hrs 29/1/2010
Rig Release :	1700hrs 30/01/2010

WIRELINE

Run #1: MCG-CLDC-MPD-MDN-MDL-MSS

Rm @ 25°C	: 0.20
Rmf @ 25°C	: n/a
Rmc @ 25°C	: n/a
Rm @ 45°C BHT:	0.14

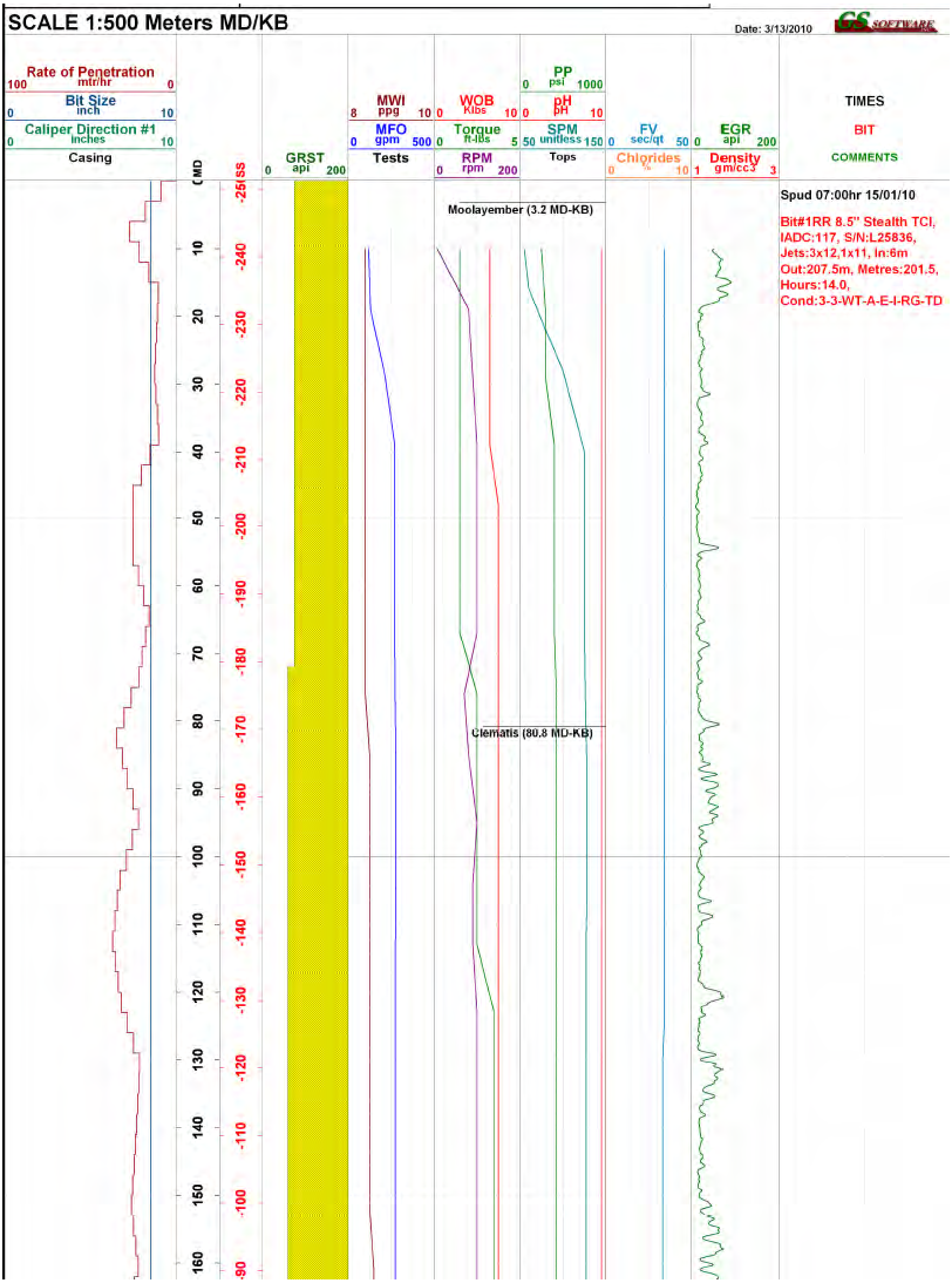
SUMMARY

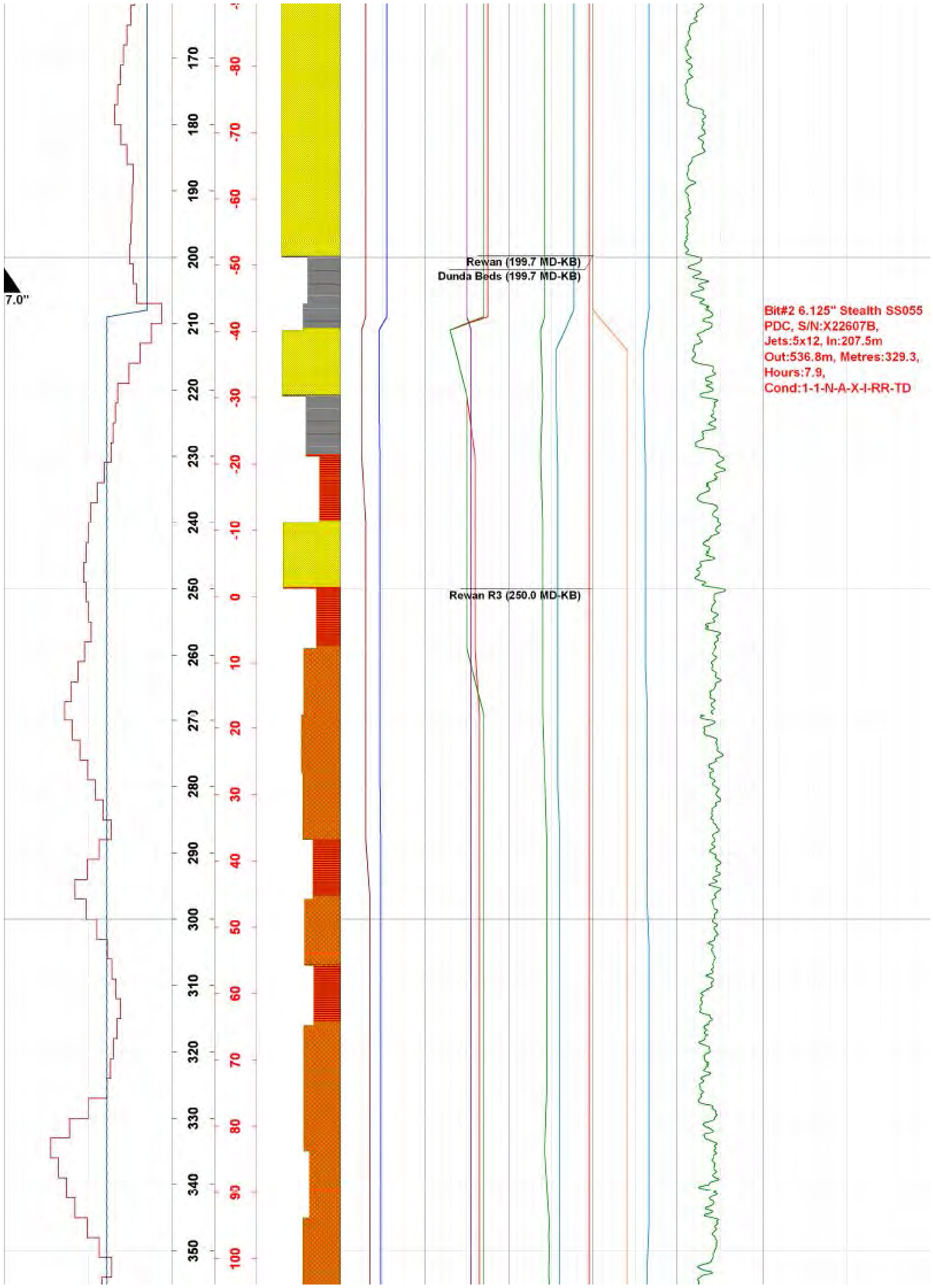
Operator:	Comet Ridge Limited
Country:	Australia
State:	Queensland
Rig Name:	Atlas #1
TD Logger:	698.2 m
TD Driller:	697.6 m

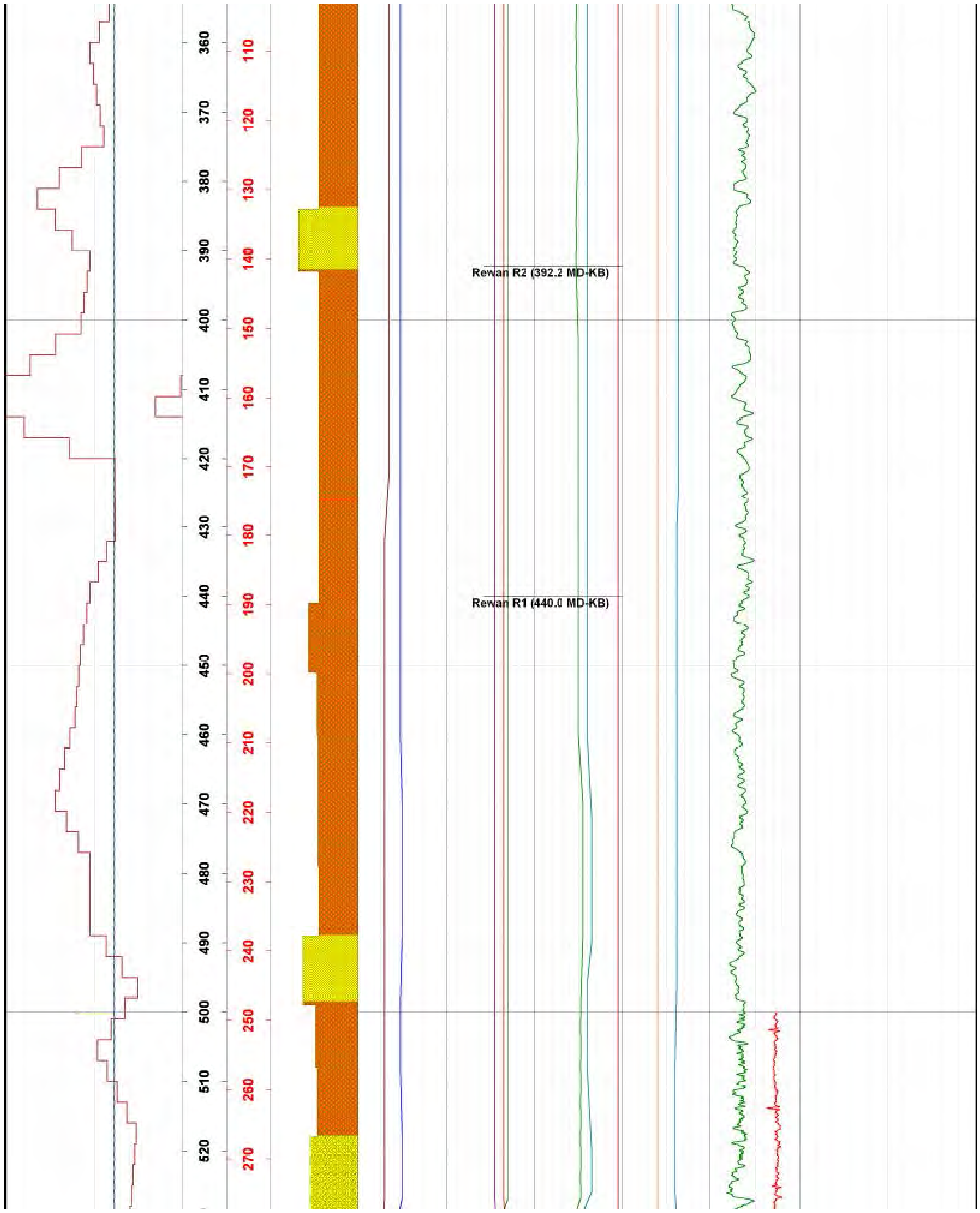
WELL REMARKS

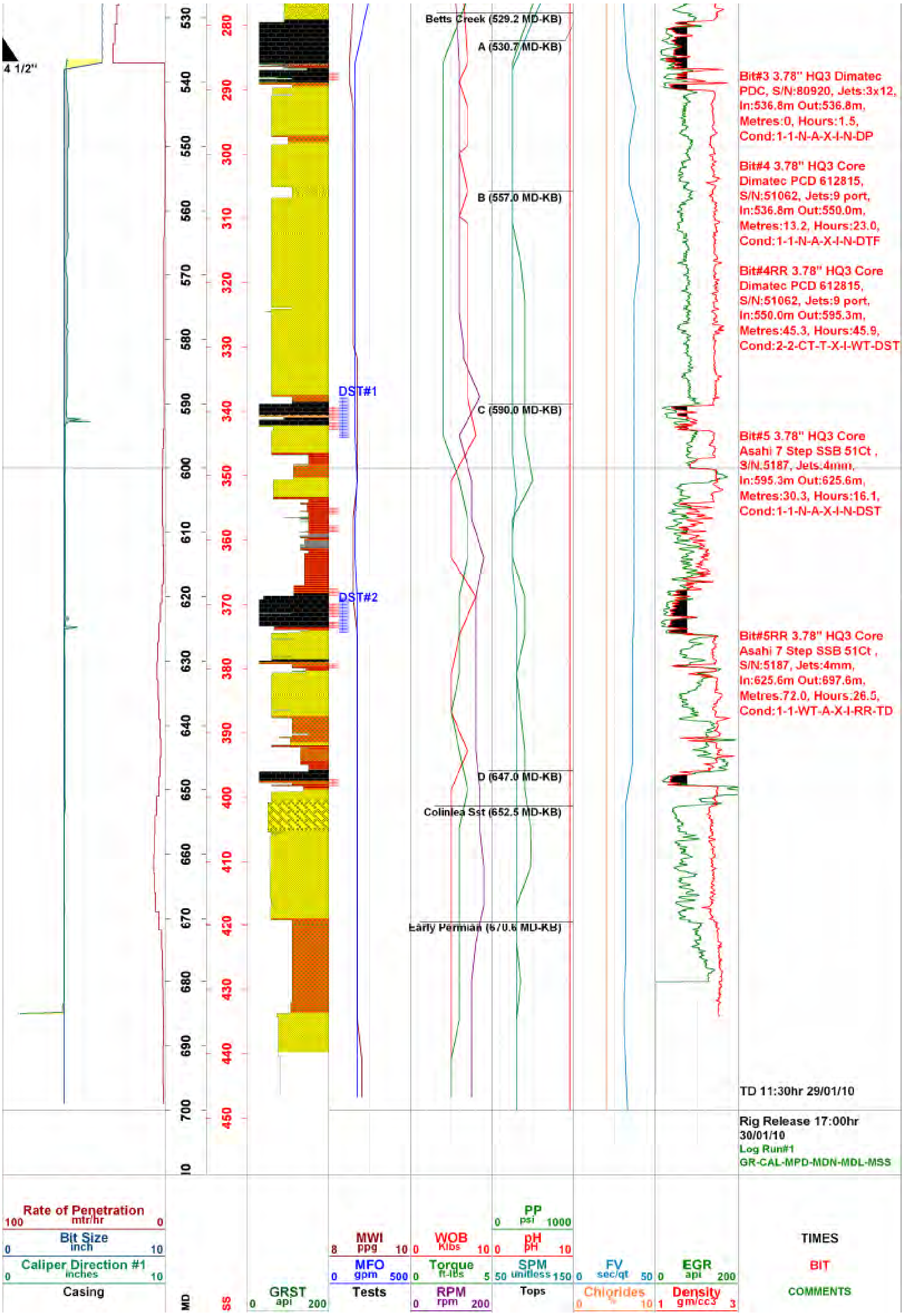
Shoemaker-1 was Plugged and Abandoned as programmed after successfully achieving all evaluation objectives.

Note: Desorption Intervals have been depth shifted -0.5m to match wireline log depths.


SCALE 1:500 Meters MD/KB
Date: 3/13/2010
GS SOFTWARE
Rate of Penetration mtr/hr 100 0
Bit Size inch 0 10
Caliper Direction #1 inches 0 10
Casing
CMD
SS
GRST api 0 200
MWI ppg 8 10
MFO gpm 0 500
Tests
WOB Klbs 0 10
Torque ft-lbs 0 5
RPM rpm 0 200
PP psi 0 1000
pH pH 0 10
SPM unitless 50 150
Tops
FV sec/qt 0 50
Chlorides 0 10
EGR api 0 200
Density gm/cc3 1 3
TIMES
BIT
COMMENTS
Moolayember (3.2 MD-KB)
Clematis (80.8 MD-KB)
Spud 07:00hr 15/01/10
Bit#1RR 8.5" Stealth TCI, IADC:117, S/N:L25836, Jets:3x12,1x11, In:6m Out:207.5m, Metres:201.5, Hours:14.0, Cond:3-3-WT-A-E-I-RG-TD


7.0"
Rewan (199.7 MD-KB)
Dunda Beds (199.7 MD-KB)
Rewan R3 (250.0 MD-KB)
Bit#2 6.125" Stealth SS055
PDC, S/N:X22607B,
Jets:5x12, In:207.5m
Out:536.8m, Metres:329.3,
Hours:7.9,
Cond:1-1-N-A-X-I-RR-TD


Rewan R2 (392.2 MD-KB)
Rewan R1 (440.0 MD-KB)



4 1/2"
530
540
550
560
570
580
590
600
610
620
630
640
650
660
670
680
690
700
280
290
300
310
320
330
340
350
360
370
380
390
400
410
420
430
440
450
DST#1
DST#2
Betts Creek (529.2 MD-KB)
A (530.7 MD-KB)
B (557.0 MD-KB)
C (590.0 MD-KB)
D (647.0 MD-KB)
Colinlea Sst (652.5 MD-KB)
Early Permian (670.6 MD-KB)
Bit#3 3.78" HQ3 Dimatec PDC, S/N:80920, Jets:3x12, In:536.8m Out:536.8m, Metres:0, Hours:1.5, Cond:1-1-N-A-X-I-N-DP
Bit#4 3.78" HQ3 Core Dimatec PCD 612815, S/N:51062, Jets:9 port, In:536.8m Out:550.0m, Metres:13.2, Hours:23.0, Cond:1-1-N-A-X-I-N-DTF
Bit#4RR 3.78" HQ3 Core Dimatec PCD 612815, S/N:51062, Jets:9 port, In:550.0m Out:595.3m, Metres:45.3, Hours:45.9, Cond:2-2-CT-T-X-I-WT-DST
Bit#5 3.78" HQ3 Core Asahi 7 Step SSB 51Ct , S/N:5187, Jets:4mm, In:595.3m Out:625.6m, Metres:30.3, Hours:16.1, Cond:1-1-N-A-X-I-N-DST
Bit#5RR 3.78" HQ3 Core Asahi 7 Step SSB 51Ct , S/N:5187, Jets:4mm, In:625.6m Out:697.6m, Metres:72.0, Hours:26.5, Cond:1-1-WT-A-X-I-RR-TD
TD 11:30hr 29/01/10
Rig Release 17:00hr 30/01/10
Log Run#1
GR-CAL-MPD-MDN-MDL-MSS
Rate of Penetration mtr/hr 100 0
Bit Size inch 0 10
Caliper Direction #1 inches 0 10
Casing
MD
SS
GRST api 0 200
MWI ppg 8 10
MFO gpm 0 500
Tests
WOB Klbs 0 10
Torque ft-lbs 0 5
RPM rpm 0 200
PP psi 0 1000
pH pH 0 10
SPM unitless 50 150
Tops
FV sec/qt 0 50
Chlorides % 0 10
EGR api 0 200
Density gm/cc3 1 3
TIMES
BIT
COMMENTS