Funding for these projects has been provided by the Australian Government through the Bioregional Assessment Programme.
Foreword

The Department of Environment, Water and Natural Resources (DEWNR) is responsible for the management of the State’s natural resources, ranging from policy leadership to on-ground delivery in consultation with government, industry and communities.

High-quality science and effective monitoring provides the foundation for the successful management of our environment and natural resources. This is achieved through undertaking appropriate research, investigations, assessments, monitoring and evaluation.

DEWNR’s strong partnerships with educational and research institutions, industries, government agencies, Natural Resources Management Boards and the community ensures that there is continual capacity building across the sector, and that the best skills and expertise are used to inform decision making.

Sandy Pitcher
CHIEF EXECUTIVE
DEPARTMENT OF ENVIRONMENT, WATER AND NATURAL RESOURCES
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Summary

In 2012, the Australian Government established an Independent Expert Scientific Committee (IESC) on Coal Seam Gas (CSG) and Large Coal Mining (LCM) developments to provide independent, expert scientific advice on the future impact these activities may have on water resources. As part of this initiative, the South Australian Department of Environment, Water and Natural Resources (DEWNR) was commissioned by the Australian Government through the Department of the Environment to collate and ground-truth baseline groundwater, surface water and ecology information in areas with the potential for CSG and large coal mining development and conduct vulnerability assessments. This report forms part of the Arckaringa Basin and Pedirka Basin Groundwater Assessment, and attempts to characterise recharge mechanisms and rates and define the spatial extent of ground surface recharge zones providing inflow to the Pedirka Basin under present-day arid conditions.

Two contemporary recharge mechanisms operate in the Pedirka Basin; diffuse recharge and ephemeral river recharge. Contemporary diffuse recharge has previously been estimated by other authors using the chloride mass balance method and was found to be effectively zero. Contemporary ephemeral river recharge (ERR) is thought to occur where the Finke River flows across the outcropping edge of the Pedirka Basin sediments, as suggested by first-order potentiometric surface maps and previous regional hydrochemical sampling.

This study employed geochemical, hydraulic and geophysical techniques to characterise the connection between the Finke River and the Pedirka Basin. Two aquifers were identified in the study area: the Quaternary alluvial sediments associated with the Finke River; and the underlying glaciofluvial to periglacial Crown Point Formation, which is one of two major stratigraphic Permian sequences of the Pedirka Basin sediments. The western extent of the second major Permian sequence, the Purni Formation, is poorly constrained and presumed to pinch out subsurface to the east of the study area, and is therefore not considered in the current investigation. The geochemical composition and hydraulic characteristics of the alluvial aquifer are consistent with regular recharge via ERR from the Finke River. In contrast, the Crown Point aquifer in the study area is a poor aquifer and is generally characterised by low permeability sediments and brackish to saline groundwater. Three existing pastoral wells previously thought to be screened in the Crown Point aquifer have been reassigned to or regrouped with the alluvial aquifer considering the lithology, well yield and chemical composition.

Modern recharge via ERR is restricted to the alluvial aquifer and is associated with smaller flow events in the Finke River. Whilst it is likely that rare, large rainfall events result in recharge to the alluvial aquifer, the relatively enriched stable isotope signature suggests that the dominant recharge mechanism is associated with smaller more frequent rainfall events. Carbon-14 derived recharge rates to the alluvial aquifer via ERR ranged from 2.45 to 34.08 mm/y.

The investigation did not identify modern recharge to the Crown Point aquifer via ERR, owing to low permeability and limited storage capacity in the formation. Further, the hydraulic connection between the Crown Point aquifer and the overlying alluvial aquifer is minor owing to the characteristics of the Crown Point aquifer and low driving gradient. Stable isotope data suggests that the Crown Point aquifer is recharged via minor downward fluxes from the overlying alluvial aquifer during flood events in the Finke River. This long term flux was estimated using Carbon-14 derived groundwater velocities and ranged from 0.13 to 8.55 mm/y.

The results of the investigation indicate that modern recharge to the Crown Point aquifer via ERR is negligible relative to the connection between the Finke River and the alluvial aquifer.
1 Introduction

1.1 Background

In 2012, the Australian Government established an Independent Expert Scientific Committee (IESC) on Coal Seam Gas (CSG) and Large Coal Mining (LCM) developments to provide independent, expert scientific advice on the future impact these activities may have on water resources. The IESC is a statutory body under the Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act) which provides scientific advice to Australian governments on the water-related impacts of CSG and LCM development proposals. Under the EPBC Act, the IESC has several legislative functions to:

- Provide scientific advice to the Commonwealth Environment Minister and relevant state ministers on the water-related impacts of proposed CSG or LCM developments
- Provide scientific advice to the Commonwealth Environment Minister on:
  - Bioregional assessments being undertaken by the Australian Government, and
  - Research priorities and projects commissioned by the Commonwealth Environment Minister
- Publish and disseminate scientific information about the impacts of CSG and LCM activities on water resources.

The Bioregional Assessment Programme is a transparent and accessible programme of baseline assessments that increase the available science for decision making associated on potential water-related impacts of CSG and LCM developments. A bioregional assessment is a scientific analysis of the ecology, hydrology, geology and hydrogeology of a bioregion with explicit assessment of the potential direct, indirect and cumulative impacts of CSG and LCM development on water resources. This Programme draws on the best available scientific information and knowledge from many sources, including government, industry and regional communities, to produce bioregional assessments that are independent, scientifically robust, and relevant and meaningful at a regional scale. For more information on bioregional assessments, visit <http://www.bioregionalassessments.gov.au>.

The South Australian Department of Environment, Water and Natural Resources (DEWNR), was funded by the Australian Government through the Department of the Environment to collate and ground-truth baseline groundwater, surface water and ecology information to inform the Bioregional Assessment Programme in the Lake Eyre Basin. The Lake Eyre Basin (LEB) bioregion (Figure 1.1) has been identified as one of six priority areas for a bioregional assessment across Australia. This report is part of a series of studies forming part of the Arckaringa Basin and Pedirka Basin Groundwater Assessment project. The Arckaringa Basin and Pedirka Basin Groundwater Assessment project is one of three water knowledge projects undertaken by DEWNR in the western LEB bioregion, including the:

- LEB Rivers Monitoring project
- Arckaringa Basin and Pedirka Basin Groundwater Assessment project
- LEB Springs project.

This report documents the investigation of focused ephemeral river recharge between the Finke River and the Pedirka Basin; and forms a key component of the Arckaringa Basin and Pedirka Basin Groundwater Assessment.
Figure 1.1 Lake Eyre Basin bioregion, showing coal bearing basins and the Great Artesian Basin
1.2 Pedirka Basin groundwater assessment

In 2013, DEWNR undertook a desktop assessment aimed at benchmarking hydrogeological knowledge for the Arckaringa and Pedirka Basins (Wohling et al., 2013). The Arckaringa Basin and Pedirka Basin Groundwater Assessment identified fundamental data gaps in the characterisation of the Pedirka Basin groundwater system, which included:

- Limited information on the hydrogeology and hydraulic behaviour of the two stratigraphic Permian units (Crown Point Formation and Purni Formation). In particular, an insufficient basis to determine whether the Permian aquifers are hydraulically separate from the overlying Great Artesian Basin (GAB) aquifer.

- The absence of dedicated investigation wells completed in the Crown Point Formation and Purni Formation. As a consequence there was no information on vertical gradients between Permian formations and the GAB sequence, and no assessment of inter-aquifer and inter-basin hydraulic connection.

- Uncertainty surrounding recharge mechanisms, recharge rates and the spatial extent of recharge zones providing inflow to the Pedirka Basin.

- Very limited information on the permeability of the Permian formations and no published aquifer parameters (transmissivity, storage coefficients) for either the Purni or Crown Point formations.

- Uncertainty surrounding the potential connection between the Permian formations and Dalhousie Springs, including the nature of any discharge mechanism and the magnitude of discharge from the Pedirka Basin.

As part of the Pedirka Basin Groundwater Assessment, DEWNR has developed an investigation program to further our knowledge regarding these knowledge gaps. The program aims to deliver several targeted studies that will feed into a broader assessment of the Pedirka Basin hydrogeology and inform the LEB Bioregional Assessment. There are three key themes for targeted investigation: aquifer connectivity, focused ephemeral river recharge and Dalhousie Springs discharge. This report details the findings from the focused ephemeral river recharge investigation.

1.3 Site description

The study area is located on the north-western margin of the Pedirka geological basin, approximately 860 km north-north-west of Adelaide and 160 km south-east of Alice Springs (Figure 1.1). The Pedirka Basin is centered on the South Australia/Northern Territory border, with roughly 60 % of the basin located in the Northern Territory and 40 % in South Australia. The ephemeral river recharge study area is located on Lilla Creek Station approximately 25 km west of Aputula (Finke community) and is broadly defined by the extent of outcropping Crown Point Formation (Figure 1.2).

The physiography, geology and hydrogeology of the region has previously been described in detail by others (Wohling et al. 2013; Love et al. 2013a). The following is a brief summary of the information provided in these reports, specific to the study area.

The study area is located in one of the driest parts of the continent and is characterised by active aeolian sand dunes associated with the Simpson Desert; an alluvial floodplain associated with the Finke River; and mesas or plateaus of outcropping Jurassic to Carboniferous aged sediments. The Finke River riparian area and other minor drainage channels support predominantly River Red Gum, Coolibah, Gidgee and Mulga with a sparse understorey of native grasses, salt bush and annual flowers. Away from the river vegetation is scarce and generally consists of Sandhill Wattle, Spinifex, Canegrass and annual flowers in a good season (Figure 1.3). To the west of the study area are highlands and plateaus of the Newland, Black Hill and Musgrave Ranges that are the consequence of either gentle upwarping or faulted uplift of Proterozoic basement sequences (Love et al. 2013a).
Figure 1.2  Regional setting of study area
The majority of the Pedirka Basin occurs subsurface at depths greater than 400 m, with the north-western margin outcropping as mesas and plateaus. The Pedirka Basin consists of sediments deposited during the Permian (299–251 Ma), and unconformably overlies the Amadeus Basin/Warburton Basin sediments and, where these are absent, Proterozoic bedrock (a surface geology map is provided in Appendix H).

In the study area the Pedirka Basin sediments unconformably overlie sequences of the Devonian (416–359 Ma) Finke Group (Edgoose and Munson 2013). The Horseshoe Bend Shale sequence of the Finke Group outcrops as low mounds and mesas on the southern side of the Finke River in the west and east of the study area. The sequence consists of red-brown to green biotitic, calcareous and gypsiferous shale interbedded with fine to medium sandstone.

Two major formations are recognised within the Permian sequences of the Pedirka Basin; the Purni Formation and the underlying Crown Point Formation. The Purni Formation consists of fluvial and paludal interbedded sands, silts and clays, as well as coal beds within the paludal sequences. The western extent of Purni Formation is poorly constrained and presumed to pinch out subsurface to the east of the study area, and is therefore not considered in the current investigation. The Crown Point Formation is a glaciofluvial to periglacial unit consisting of conglomerate, diamicite, pebbly coarse-grained sandstone, fine sandstone and thick claystone beds. The formation is extensive across the Pedirka Basin and reaches a thickness of approximately 500 m. Outcropping of Pedirka Basin sediments is constrained to the Crown Point Formation, which outcrops on the Finke, Rodinga and Hale River 1:250,000 mapsheets (Figure 1.4; Figure 1.2). Groundwater within the Crown Point Formation...
is of variable quality and is often low yielding and saline, however in the study area on the north-western margin of the basin, the resource is potable and is used in the town of Apatula (Finke), a number of small outstations, and pastoral stock wells.

Figure 1.4  Outcropping Crown Point Formation visible in the background

The western margin of the Eromanga Basin/Great Artesian Basin (GAB) overlies the Pedirka Basin to the east of the study area. The De Souza Sandstone (synonymous with the Algebuckina Sandstone) is a formation within the GAB sequences and also outcrops on top of some of the mesas and plateaus within the study area (Figure 1.5), however the unit is not continuous and is constrained to the eastern boundary of the study area. The De Souza Sandstone consists of pebbly medium to coarse micaceous-quartzose sandstone that is coarsely cross-bedded with bands and lenses of claystone and siltstone (Wells 1969), in the study area outcrops are white friable sandstone. The sandstone sequences of the GAB are often termed the J aquifer (due to the Jurassic age of the De Souza sediments) and are partly recharged by surface water flows in the Finke River to the east of the study area near the township of Aputula (Finke). Love et al. (2013b) estimated contemporary rates of ephemeral river recharge to the GAB J aquifer at between 380–850 mm/y using Carbon-14 derived groundwater velocities.

Figure 1.5  De Souza Sandstone outcropping as discontinuous low mesas in the study area
In the study area the Quaternary (1.6–0.01 Ma) alluvial sediments are superficial and associated with minor and major ephemeral drainage channels. Regionally the alluvial sediments consist of alluvial gravel, sand, clay and red earth plains. Within the study area the alluvial sediments consist of fine to coarse sand, with very thin surficial mud drapes in the Finke River channel that do not act as a hydraulic barrier (Nanson and Price 1995) (Figure 1.6). A potable groundwater supply can often be found within the alluvial sediments (Wells 1969). Away from the drainage channels, unsaturated Quaternary aeolian sands form plains and longitudinal dunes that are associated with the Simpson Desert.

![Figure 1.6 Finke River during the dry season](image)

### 1.4 Recharge in the Pedirka Basin

Groundwater is often the only reliable water source in arid central Australia. Understanding the mechanisms and rates at which a groundwater resource is recharged is one of the most important components in any groundwater assessment and is imperative for effective groundwater management. Characterising contemporary recharge mechanisms and rates of inflow to the Pedirka Basin is critical to resolving the basin water balance and was identified as a research priority in the *Arckaringa Basin and Pedirka Basin Groundwater Assessment* (Wohling et al. 2013).

Previous authors (Wells et al. 1970; Love et al. 2013a; Wohling et al. 2013) have identified two recharge mechanisms likely to be operating in the Pedirka Basin (Figure 1.7):

1. Diffuse recharge, which describes the widespread infiltration of rainfall through the unsaturated zone to the water table (Healy 2012).¹
2. Focused recharge, which describes flux from surface water features such as rivers, creeks or lakes to an underlying or adjacent aquifer.¹ Recharge mechanisms in arid zones are typically dominated by focused recharge from major and minor ephemeral drainage channels, this process is known as ephemeral river recharge (ERR).

---

¹ Elsewhere in the literature diffuse recharge may also be termed local or direct recharge; focused recharge may also be termed indirect recharge.
Contemporary diffuse recharge to the Pedirka Basin has previously been estimated by Wohling et al. 2013 using the chloride mass balance method, which indicated that diffuse recharge is negligible (0.02–0.16 mm/y with an average 0.07 mm/y). This is consistent with estimated rates of diffuse recharge to the GAB aquifer (Love et al. 2013a), which overlies the Pedirka Basin sediments to the east of the study area (Section 1.3). Refining the estimate of diffuse recharge to the Pedirka Basin is not a priority in this study as it is effectively zero.

Contemporary ERR is thought to occur where the Finke River flows across the outcropping areas at the edge of the Pedirka Basin (Figure 1.2). Wohling et al. (2013) identified potable modern groundwater in the Crown Point Formation in this region, and produced first-order regional potentiometric surface maps that suggested groundwater mounding on the north-west margin of the basin. These findings suggest that active ERR is occurring, or has occurred under a wetter paleo-climate. This study aims to characterise ERR processes under present-day arid conditions.

### 1.5 Objectives

This study aims to investigate ephemeral river recharge processes where the Finke River flows across the outcropping edge of the Pedirka Basin. The assessment has the following specific objectives:

1. Improve the hydrogeological understanding of the aquifer systems and their connection to the Finke River
2. Define the spatial extent of the recharge zone to the Crown Point and/or other aquifers
3. Characterise recharge mechanisms to the Crown Point and/or other aquifers
4. Estimate recharge rates where sufficient data is available.
2 Methodology

2.1 Program design

Central Australia is dominated by ephemeral surface water features that display large spatial and temporal variation between flood events. When a flood event does occur, access is often poor. These characteristics combined with the remote location of the study area and limited established monitoring infrastructure (e.g. stream gauges) precludes the use of a number of traditional recharge investigation techniques.

The study employed a number of physical investigation techniques to characterise the geological controls on recharge mechanisms in the study area, and quantified recharge volumes using saturated zone techniques.

Three transects were located within and perpendicular to the Finke River (Figure 2.1) to investigate the extent of fresh groundwater beneath the river within the alluvial/Crown Point aquifers:

1. Maynard’s Transect is located on the western boundary of the study area upstream of the outcropping Crown Point Formation.
2. Paddy’s Transect is located in the north of the study area within the zone of outcropping Crown Point Formation.
3. Old Crown Transect is situated on the eastern boundary of the study area downstream of the outcropping Crown Point Formation.

A drilling program was initiated in August 2014 and drillholes were positioned along each transect to create a cross section of the river sediments and the adjacent aquifer(s). Where groundwater was intersected the drillholes were constructed as piezometers and gamma logged to provide geophysical interpretation of the lithology. The drilling program included a nested piezometer site in the alluvial sediments and the underlying Crown Point aquifer to develop an understanding of vertical flow characteristics. Hydraulic tests were undertaken in each piezometer to estimate the hydraulic conductivity of aquifer sediments.

Ground penetrating electromagnetic induction (EM-34) surveys were used to infill data along each transect between the spot data points provided by the piezometers. The EM-34 surveys also helped to map the halo of fresh groundwater around the Finke River and to estimate the extent of the recharge influence from the river into the adjacent aquifer(s).

Geochemical tracers (isotopes and chemistry) were collected from each piezometer to assess connectivity between the river and aquifer(s), provide information on recharge rates/mechanisms and the source and history of groundwater.

Historical geological and geochemical data was used where possible, however existing information was sparse and often unreliable.
Figure 2.1 Study area
2.2 Drilling and construction

The drilling program commenced on 5 August 2014 and concluded two weeks later on 20 August 2014. A total of 288 m was drilled at 11 locations in the study area over 13 days of active drilling. The ephemeral river recharge investigation included the construction of ten monitoring piezometers and one test production well. A nested piezometer site was constructed adjacent to the Finke River in the alluvial sediments and underlying Crown Point Formation.

Drilling Solutions P/L were engaged to complete the drilling program and mobilised out of Adelaide in early-August. Site supervision and logging was undertaken by hydrogeologists from DEWNR. The holes were drilled using a truck mounted MK 5/2 Investigator rig crewed by a team of three under the supervision of head driller, Michael Southby. The MK 5/2 Investigator rig is a top head drive equipped to drill using rotary air, rotary mud, and solid and hollow auger drilling methods. Water for the drilling process was sourced from stock well RN015950 (Paddy’s bore), located adjacent to the Finke River (Figure 2.1).

Drilling of each hole commenced with the installation of 2.5 m by 200 mm diameter steel surface casing to a depth of 2 m below natural surface. Drilling then recommenced using mud rotary with a 165 mm blade bit, or 200 mm hollow augers to total drill depth. Where air rotary was used, the casing was cemented and allowed to cure before drilling recommenced with a 165 mm blade bit. Drill cuttings were collected every 1 m and laid out in order of increasing depth for logging by the site hydrogeologist. Small cutting samples were collected in chip trays. Piezometers were constructed using either 80 or 100 mm class 12 PVC and 1 mm machine cut class 12 PVC screens in accordance with minimum bore construction guidelines (NUDLC, 2012) and completed with a steel standpipe set in a 1 m² concrete slab. The test production well was constructed with 100 mm class 12 PVC casing and a 6 m length of stainless steel 1 mm aperture wire-wound screen. Where the drillhole did not collapse, the annulus was filled with coarse sand, capped with bentonite pellets, and filled with a 20:1 cement/bentonite grout from 5 m to surface. Where the annulus collapsed, a 20:1 cement/bentonite grout was placed from the top of the collapsed sediments (slough) to surface. Key construction details are summarised in Section 3.1 and full details are provided in Appendix B.

On completion piezometers and the production well were developed using compressed air for a minimum of one hour. Well yields were generally low (<0.1 L/s) and unable to be accurately measured during air lift, particularly those piezometers constructed in the Crown Point Formation. Subsequent hydraulic testing (Section 2.4) allowed for estimation of formation hydraulic conductivity. Water returns during drilling were analysed for in situ parameters (pH, electrical conductivity (EC) and temperature), however given the low yields it is considered that water quality collected during later hydrochemical sampling is more representative of groundwater conditions.

Following completion of the drilling program, all constructed piezometers were gamma logged using a portable Auslog downhole geophysical logging system.

2.3 EM-34 survey

Ground deployed electromagnetic induction (EM) is a geophysical technique commonly employed in hydrogeological studies to investigate spatial variation in water quality and/or the lithological composition within aquifers. The method uses the principle of induction to measure the electrical conductivity of the subsurface. An EM instrument generates a primary magnetic field by passing an electric current through a transmitting coil. This field penetrates the underlying ground inducing a secondary current in the subsurface material and generating a secondary magnetic field that is measured by the receiver sensor on the EM instrument. The depth of penetration of the primary magnetic field dictates the exploration depth of the technique and is controlled by the coil separation and orientation. The conductivity response of subsurface soil and rock is influenced by a number of factors described in detail by McNeil (1980a), these include: the porosity of the sediments, the moisture content (degree of saturation), the electrical conductivity of the pore water, the temperature and phase state of the pore water, and the texture of the soil/rock (in particular the clay content).

The EM surveying in this study was completed using a Geonics EM-34 instrument, which has an investigation depth of between 7.5 and 60 m. The EM-34 consists of a transmitting loop and a receiving loop, which are joined by an electrical cable to form the primary coil. The instrument is designed with three interchangeable cable lengths: 10, 20 and 40 m that control the exploration depth. When operating the transmitting and receiving loops can be positioned in either a vertical or horizontal
position, this changes the orientation of the primary magnetic field and also affects the exploration depth of the instrument. Table 2.1 summarises the exploration depth of the EM-34 using the three different cable lengths and loop orientations.

Table 2.1  Exploration depths for EM-34 at different coil separations, after McNeil (1980b)

<table>
<thead>
<tr>
<th>Coil separation (m)</th>
<th>Estimated exploration depth</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Horizontal dipole</td>
</tr>
<tr>
<td>10</td>
<td>7.5</td>
</tr>
<tr>
<td>20</td>
<td>15</td>
</tr>
<tr>
<td>40</td>
<td>30</td>
</tr>
</tbody>
</table>

The EM survey undertaken in this study primarily aims to map the halo of fresh groundwater around the Finke River in order to estimate the extent of the recharge influence from the river into the adjacent aquifer(s). Accordingly a coil separation of 20 m was selected to target a consistent conductivity response from within the saturated zone of the aquifer(s).

EM-34 surveys were conducted along three transects to investigate the extent of fresh groundwater beneath the Finke River within the alluvial/Crown Point aquifers (Figure 2.1). Maynard’s transect is located on the upstream edge of the postulated recharge zone, Paddy’s transect is within the recharge zone and Old Crown Transect is situated at the downstream end of the recharge zone. The three transects are oriented perpendicular to the course of the Finke River to align with groundwater flow lines away from the water course (Section 3.2). Three short 500 m EM-34 transits were also completed at the end of the three transects. These sections are oriented parallel to the main channel of the Finke River and aim to investigate the relative conductivity beneath the river at the three transect locations.

2.4  Hydraulic testing

Slug tests, also known as rising or falling head tests, involve the rapid removal, addition or displacement of groundwater in a well and subsequent monitoring of the water level as it returns to an equilibrium state. The rate of the water-level recovery is a function of the horizontal conductivity of the aquifer and the construction of the well (Butler, 1998). Relative to conventional pumping tests, the set up and implementation of slug tests is rapid (minutes to hours), making it achievable to test a series of wells in a short investigation program. However, it is important to note that slug tests have several limitations relative to conventional pumping tests. Slug tests are a single-well test and thus do not yield information on aquifer storativity. The derived hydraulic conductivity from slug tests is also only applicable to a very small volume of aquifer around each well (Kruseman and De Ridder, 1994).

In this study slug tests have been used to investigate the relative hydraulic conductivity of the Quaternary alluvial aquifer and the Crown Point aquifer in the ten piezometers constructed during the drilling program. The tests were completed using a 3 m length of 50 mm (OD) PVC pipe. This slug was weighted with sand to overcome the buoyancy of the pipe and ensure it fully penetrated the saturated zone of the aquifer during testing. The slug was initially lowered to within 1 m of the watertable before being released and allowed to free fall until fully submerged. The subsequent water-level displacement was recorded at 5 second intervals by a Solinst Level Logger suspended on a stainless steel cable at the bottom of the well. The slug was left in place until the water level returned to within 98 % of the pre-test level with the exception of wells RT2B and B1A, which have very low permeability and only recovered 37 % in 14 hours and 48 % in 18 hours respectively. When the water level in the test well approached pre-test levels the slug was removed and the water level recovery data collected using the pressure loggers. In those wells which displayed relatively quick recovery (RT1, RT2C, RT3, RT5A) multiple rising and falling head tests were conducted to increase confidence in the test results. The slug test results were analysed using Aqtesolv Pro (Hydrosolve, 2006).

2.5  Groundwater sampling

The analysis and comparison of multiple isotope and environmental tracers from multiple wells/aquifers can provide important insights into aquifer processes (IESC, 2014; Scanlon et al. 2002). Groundwater samples were collected from the ten piezometers constructed during the drilling program on three separate visits between 10 September and 26 October 2014.
The groundwater sampling methodology including sample preparation and preservation, laboratory analysis and analytical accuracies are documented in Appendix E. Wells were purged for a minimum of three well volumes and sampled when field parameters had stabilised. In situ parameters (temperature, electrical conductivity (EC), pH, dissolved oxygen (DO), alkalinity) were measured in the field and samples were collected and analysed for major ions, metals, stable isotopes of water ($\delta^2$H and $\delta^{18}$O), strontium isotope ratios ($\delta^{87}$Sr/$\delta^{86}$Sr), carbon isotopes ($\delta^{14}$C and $\delta^{13}$C) and chlorofluorocarbons (CFC-11 and CFC-12) with the exception of:

- Piezometer B1A was low yielding (<0.05 L/s with >24hr recovery time) and minimal sample was retrieved following purging. EC, pH and major ions were analysed by the CSIRO laboratory, no other samples were recovered.
- Groundwater was not observed during drilling at location B1B (upslope of B1A) and the drillhole was backfilled rather than being constructed as a piezometer. It is likely that no free water was observed at this location as the Crown Point aquifer has very low local permeability.
- Chlorofluorocarbons were not sampled at piezometers RT2C, RT4 and RT5 as the risk of atmospheric contamination could not be overcome. Despite the pump rate being lowered, air bubbles were entrained in the pump discharge pipe, contaminating the sample.

The water samples collected from each of the constructed piezometers are listed in Table 2.2. The location of the piezometers is shown in Figure 2.3.

![Groundwater sampling](image)

**Figure 2.2  Groundwater sampling**

**Table 2.2  Groundwater analysis parameters for constructed piezometers**

<table>
<thead>
<tr>
<th>Bore ID</th>
<th>Name</th>
<th>Alkalinity</th>
<th>Major and minor ions</th>
<th>Strontium isotopes</th>
<th>Carbon isotopes</th>
<th>Stable isotopes</th>
<th>CFCs</th>
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<td>Y</td>
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<td>Full suite</td>
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<td>N</td>
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<td>Partial suite</td>
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<tr>
<td>RN019074</td>
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<td>Y</td>
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<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Full suite</td>
</tr>
</tbody>
</table>
A number of existing wells in the study area have historical chemical-data available and/or were sampled by DEWNR in December 2012 (Wohling et al. 2013). Where construction details or geological logs were available, the chemical results for these wells have been included in the current report to compliment the new data set. The list of existing wells along with the chemical data available are shown in the Table 2.3. The location of existing wells is shown in Figure 2.3.

### Table 2.3  Historical groundwater data from existing wells

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<tr>
<th>Bore ID</th>
<th>Name</th>
<th>Alkalinity</th>
<th>Major and minor ions</th>
<th>Strontium isotopes</th>
<th>Carbon isotopes</th>
<th>Stable isotopes</th>
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</tr>
<tr>
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<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Full suite</td>
</tr>
<tr>
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<td>Peter's Bore</td>
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<td>Y</td>
<td>Y</td>
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<td>Y</td>
<td>Y</td>
<td>Full suite</td>
</tr>
<tr>
<td>RN000507</td>
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<td>Y</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>Partial suite</td>
</tr>
<tr>
<td>RN002012</td>
<td>Old Crown Well</td>
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<td>Y</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>Partial suite</td>
</tr>
<tr>
<td>RN012397</td>
<td>Old Crown Well New</td>
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<td>Y</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>Partial suite</td>
</tr>
<tr>
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<td>A24/34</td>
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<td>N</td>
<td>Partial suite</td>
</tr>
<tr>
<td>RN004634</td>
<td>A24/5</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>Partial suite</td>
</tr>
</tbody>
</table>
Figure 2.3  Location of existing wells and new piezometers
2.6 Surveying

The installed piezometers were surveyed by Fyfe Surveying on 14 October 2014 using an NTGL10 (R8) GPS unit, with measurements converted to metres Australian Height Datum (m AHD) using Ausgeoid 09. Measurements were made relative to the concrete pad, top of PVC casing and top of steel stand pipe, and referenced to the local AUSPOS authority Lilla Creek 1 BM (± 10 m horizontal, ± 20 mm vertical).

All groundwater level measurements from metres below ground surface (mbgs) were made relative to the top of the PVC standpipe, with the exception of RT2A which was relative to the top of the steel casing as the PVC was cut too short. Groundwater level measurements were then converted to metres Australian Height Datum (m AHD).

As drillhole B1B (RN019074) did not intersect groundwater during drilling it was not included in the well survey described above. The location of B1B was recorded by DEWNR using a Garmin hand-held GPS unit with reported accuracy ±4 m. Surface height was estimated using the national 1-second Digital Elevation Model (DEM) satellite derived data, which incorporates data that is Commonwealth of Australia (2014). The national 1-second DEM data displayed on Figure 1.1 and Figure 1.2 has been used with permission from the Commonwealth however the Commonwealth, has not evaluated the data as altered and incorporated within the DEM and therefore gives no warranty regarding its accuracy, completeness, currency or suitability for any particular purpose.

The aerial photography was sourced from SPOT 6 satellite imagery captured on 6/6/2014 with a spatial resolution of 1.5 m, and LANDSAT 8 satellite imagery captured in 2014 with a spatial resolution of 15 m.

2.7 Recharge rates

Several techniques are available to estimate rates of groundwater recharge in arid environments, each with its own advantages and limitations, inherent assumptions and uncertainty. The application of multiple recharge estimation techniques reduces the assumptions associated with any one technique and therefore increases reliability and constrains the end estimate of recharge (Scanlon et al. 2002; Coes et al. 2007). This study employs two saturated-zone techniques to assess modern recharge mechanisms and to quantify recharge rates within the study area:

1. The Darcy flux method uses the difference in vertical hydraulic head gradients at the nested site (RT2) to calculate vertical groundwater flow velocities and estimate recharge at the local scale.

2. The environmental tracer method uses radiocarbon age tracer data at the nested site (RT2) to calculate vertical groundwater flow velocities and estimate recharge at the regional scale.

2.7.1 Darcy flux method

Recharge (R) to the Crown Point aquifer can be estimated using Darcy’s Law (Herczeg and Love 2007; Kalbus et al. 2006; Healy 2010), which states that in saturated media the vertical groundwater velocity, or groundwater flux, is equal to the product of the hydraulic conductivity and the hydraulic gradient. The average vertical hydraulic conductivity and measured hydraulic head gradients at the nested site (RT2) may be used to calculate vertical groundwater flux (or recharge) as a function of depth and distance between the screen mid-points of each piezometer:

\[ R = q = -K \left( \frac{dh}{dl} \right) \]  

(Equation 1)

where \( R \) is recharge to the aquifer, \( q \) is the groundwater recharge and indicates water flux from the alluvial aquifer to the underlying Crown Point aquifer, \( K \) is the average hydraulic conductivity of aquifer material between the screen mid-points, \( dh \) is the head difference between the two nested piezometers, and \( dl \) is the length difference between the screen mid-points.
The $K$ value used is an average (calculated as the harmonic mean)\(^2\) value based on the ratio of aquifer media between the screen mid-point of the two piezometers. For example, the measured hydraulic conductivity for the alluvial aquifer and Crown Point aquifer at the nested site is 0.38 m/d and 0.01 m/d respectively. If there was 50% alluvial sediments and 50% Crown Point Formation between the screen mid-points of the two piezometers, then the average K value would be 0.02 m/d.

This method is best applied to natural groundwater systems as it assumes steady groundwater flow with minimal pumping. A pastoral well (RN015198) approximately 1 km to the east of the nested site was not pumping at the time of the aquifer tests. It is not anticipated that pumping at RN015198 would impact the groundwater regime at the nested site over the long term considering the low pump rate (<1 L/s). No other operational pastoral wells are located in the vicinity of the nested site.

This method also assumes constant porosity and hydraulic conductivity in each aquifer, and constant vertical water flux between aquifers in the saturated zone. The hydraulic conductivity was indicated by aquifer tests and was consistent for each aquifer across the study area (reported in Section 3.3). The lithology of the alluvial aquifer was consistent across the study area and a porosity range of 0.29-0.49 for medium sand (Hydrosolve 2006; Hazel 2009; Kruseman and De Ridder 1994; Fetter 2001) can be applied. The Crown Point aquifer in the study area is variable but generally fine grained, consolidated and stratified (described in Section 3.1). At the nested site the Crown Point aquifer consisted predominantly of sandy clay. Laboratory analysis of exploration drillhole cores throughout the basin indicate porosity values range from 0.03-0.32 (Wohling et al. 2013).

Whilst porosity at the nested site will likely be different to that deeper in the basin, these measured values are more constrained than porosity estimates for this lithology in published literature (0.2–0.6, Hydrosolve (2006); Hazel (2009); Kruseman and De Ridder (1994); Fetter (2001)). Sensitivity testing can be undertaken on porosity and the estimated recharge rate reported as a range to reflect this uncertainty.

Hydraulic heads were measured at the nested site prior to hydrochemical sampling on 25th October 2014 at 11am, and converted to reduced standing water level (RSWL) in metres relative to Australian Height Datum (m AHD) using the survey data (Section 2.6). As fluid density is affected by temperature, salinity and pressure, the measured groundwater level depends on pressure within an aquifer and the density of the water column in the well/piezometer (Post et al. 2007). As there is a strong salinity contrast between the alluvial aquifer and Crown Point aquifer (Section 3.4.1), hydraulic heads were density corrected for temperature and salinity effects before considering the direction of groundwater flow, using the method proposed by Luscinsky (1961):

$$h_{f,i} = \frac{\rho_i}{\rho_f} h_i - \frac{\rho_i - \rho_f}{\rho_f} z_i$$

(Equation 2)

Where $h_{f,i}$ is the freshwater hydraulic head (m), $\rho_i$ is the water density at the measured point (kg/m$^3$), $\rho_f$ is the density of freshwater (kg/m$^3$), $h_i$ is the measured hydraulic head (m) and $z_i$ is the elevation head (m). The average of field-measured groundwater temperature was applied (26.6°C), as variations in the field are most likely a reflection of ambient air temperature at the time of measurement.

### 2.7.2 Age tracer data

Isotopic recharge estimation techniques are often more reliable in arid regions where low net water fluxes dominate (Herczeg and Love 2007). Where groundwater age is measured from discrete depths, the age tracer data may be used to calculate vertical groundwater flow and provide a relatively direct estimate of recharge. Recharge rates were calculated using the linear model described in Cook and Böhlke (2000) and Herczeg and Love (2007):

$$R = \frac{z\delta}{t}$$

(Equation 3)

Where $R$ is recharge to the aquifer, $z$ is depth to the screen mid-point, $\delta$ is the porosity of aquifer material, and $t$ is the uncorrected apparent carbon-14 age (screen length 3 m).

\(^2\) When averaging over any spatial arrangement of discreet K values, the averaging depends on orientation relative to the direction of the hydraulic head gradient (Freeze and Cherry 1979; Maidment 1993; Domenico and Schwarz 1998). When groundwater flow (recharge in this case) is perpendicular to stratigraphic layering, the average K is calculated as the harmonic mean and will be weighted towards the lowest K value. When groundwater flow is parallel to stratigraphic layering, the average K is calculated as the arithmetic mean and will be weighted towards the highest K value. In the study area the average K was calculated as the harmonic mean.
As per the discussion in Section 2.7.1, a porosity range of 0.29–0.49 was applied to the alluvial aquifer, and a range of 0.03–0.32 was applied to the Crown Point aquifer. Sensitivity testing was undertaken on porosity and the estimated recharge rate is reported as a range to reflect this uncertainty.

The method assumes vertical flow and that horizontal flow is constant with depth, which is consistent with the conceptual model of ephemeral river recharge. However, in the study area the Crown Point Formation is heterogeneous but generally fine grained, consolidated and stratified. Macrodispersivity may affect the measured groundwater ages as there are likely alternating layers of different hydraulic conductivity resulting in mixing of groundwaters from different layers (Appelo and Postma 2010).
3 Results and discussion

3.1 Drilling program

The following section summarises the stratigraphy encountered during drilling for the ephemeral river recharge investigation. The results of the drilling program are summarised below in Table 3-1 and Figure 3.5. A detailed compositional record providing a lithological description for each drillhole and an interpretation of the sequence from both the drill cuttings and the geophysical logs can be found in Appendix B.

3.1.1 Quaternary sediments

Aeolian sediments

Quaternary (Q) aeolian sediments were encountered away from the Finke River along Paddy’s Transect (RT4, RT5) and Old Crown Transect (B5B). The aeolian sediments comprise surficial yellowish red to red, fine grained, unconsolidated sands that are unsaturated and form wind-blown longitudinal sand dunes and plains (Figure 3.1). Aeolian sediments were 9 m deep at Old Crown Transect and 3–5 m deep along Paddy’s Transect.

Alluvial sediments

Alluvial sediments were encountered near the Finke River at Maynard’s Transect (B1A), Old Crown Transect (B5A) and Paddy’s Transect (RT1, RT2, RT3). The sediments were consistent across the study area and comprise yellowish red, fine to coarse grained, rounded to sub-angular quartz sand that is unconsolidated, porous, and of alluvial provenance (Figure 3.2). Adjacent to the river, the sediments were up to 18 m deep at Paddy’s Transect (RT2) and 16 m deep at Old Crown Transect (B5A), however were relatively shallow at Maynard’s Transect (5 m, B1A). The thickness of the alluvial sediments are variable but generally pinch out with distance from the river, suggesting that the alluvial aquifer is constrained to within a kilometre from the Finke River. The distribution of riparian vegetation visible on satellite imagery may provide an indication of the relative extent of the alluvial aquifer.

Figure 3.1 Quaternary aeolian sediments encountered away from the Finke River
3.1.2 Crown Point Formation

The Crown Point Formation (Cp) in the study area consists of variable facies and lithology. Along Maynard’s Transect in the west (B1A, B1B), the lithology consists of dark brown heavy plastic clay with clasts of claystone, quartzite, sandstone and shale. Along Paddy’s Transect, the lithology consists of reddish yellow sandy clay with trace sandstone close to the river at RT2, consolidated mudstone at RT4, and diamictite with clasts of claystone, quartzite and sandstone at RT5. Diamictite was also encountered at the Old Crown Transect in the east (B5A, B5B), which consisted of clasts of quartzite, sandstone, shale and conglomerate in a clayey sand matrix.

In outcrop the Crown Point Formation consisted of variable sized (pebbles/cobbles/boulders) rounded clasts of quartzite with smaller fragments of granite, schist, conglomerate, shale and sandstone, often in a matrix of clayey sandstone or siltstone (Figure 3.3). In outcrop the formation generally appears consolidated with no visible porosity and limited fracturing, however interbedded sandstone units appear consolidated yet friable and may have secondary porosity via fracturing.

The Crown Point Formation is at variable depths across the study area. Adjacent to the Finke River, the formation was intersected at greater than 16 m depth at Old Crown Transect and Paddy’s Transect, however outcrops in the river between these two transects (Figure 3.3c) and is near-surface (< 5 m) at Maynard’s Transect. Away from the river, the formation is at surface, or near-surface.

The previously classified Devonian Horseshoe Bend Shale that outcrops to the south of drillhole B1B on Maynard’s Transect (Figure 2.1) has been reclassified as Crown Point Formation based on field observations (Figure 3.3a).

Logging of the Crown Point Formation was both a function of the mixed lithology and the drilling technique (air/mud rotary or hollow augers), which does not provide intact samples and results in limited control of sample returns at the surface. During drilling the change in stratigraphy was estimated and the piezometer constructed in the target aquifer. Following completion of the drilling program, all constructed piezometers were gamma logged using a portable Auslog downhole geophysical logging system, which revealed the change in stratigraphy with greater clarity. Piezometers RT2C and B5A were targeting the alluvial aquifer however were over drilled by approximately 1 m into the Crown Point Formation. Hydrochemical sampling (described in Section 3.4) indicates that the Crown Point Formation is not contributing to the chemical signature at these locations, owing to the very low transmissivity of the formation (described in Section 3.3). Wells RT2C and B5A have therefore been assigned to the alluvial aquifer.
### Table 3-1  Summary of drilling program

<table>
<thead>
<tr>
<th>Well ID</th>
<th>Well name</th>
<th>Easting MGA94 Z53</th>
<th>Northing MGA94 Z53</th>
<th>Completion date</th>
<th>Drill depth (m)</th>
<th>Stratigraphy encountered</th>
<th>DTW m BGS*</th>
<th>RWL m AHD</th>
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<td>18.0</td>
<td>Q/Cp</td>
<td>10.01</td>
<td>251.78</td>
</tr>
</tbody>
</table>

Q – Quaternary sediments.
Cp – Crown Point Formation

* Depth to water (DTW) taken prior to slug tests 09-13/09/2014 measured in metres below ground surface (m BGS), corrected for density effects as described in Section 2.7.1.

# Reduced water level (RWL) density corrected. Wells were surveyed as described in Section 2.6.
Figure 3.3  Crown Point Formation outcrop in the study area

a) south-west of dry drillhole B1B.  b) north-west of RTS.  c) outcrop in the Finke River between Paddy’s and Old Crown Transects.
A summary of the well completion details are provided in Table 3-2 and in Figure 3.5. The full construction details can be found in Appendix B. The Statement of Bore, containing the driller’s well logs and construction records are provided in Appendix C.

Groundwater elevation is generally higher near the Finke River and decreases with distance from the river. This is consistent with the Finke River acting as a recharge source to the alluvial aquifer. Conceptual hydrogeological cross sections have been prepared for each transect (Section 3.2). Recharge to the Crown Point aquifer via vertical flux appears to be minor due to low permeability (Section 3.3) and driving gradient (Section 3.5.1).

Figure 3.4  a) nested piezometer site at RT2  b) piezometer RT3  c) typical well pad following completion

Table 3-2  Summary of well construction details

<table>
<thead>
<tr>
<th>Well ID</th>
<th>Well name</th>
<th>Aquifer monitored</th>
<th>Casing type ID (mm)</th>
<th>Casing from (m)</th>
<th>Casing to (m)</th>
<th>Screen type</th>
<th>Screen from (m)</th>
<th>Screen to (m)</th>
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<tbody>
<tr>
<td>RN019066</td>
<td>RT1</td>
<td>Q</td>
<td>PVC (80)</td>
<td>+0.23</td>
<td>16.0</td>
<td>PVC</td>
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<td>15</td>
</tr>
<tr>
<td>RN019067</td>
<td>RT2A</td>
<td>Cp</td>
<td>PVC (100)</td>
<td>0.06</td>
<td>29.0</td>
<td>S/S</td>
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<td>28</td>
</tr>
<tr>
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<td>Cp</td>
<td>PVC (80)</td>
<td>+0.22</td>
<td>39.0</td>
<td>PVC</td>
<td>35</td>
<td>38</td>
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<td>Q</td>
<td>PVC (80)</td>
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<td>PVC</td>
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<td>19</td>
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<td>PVC (80)</td>
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<td>16</td>
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<tr>
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<td>Cp</td>
<td>PVC (80)</td>
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<td>PVC</td>
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<td>Cp</td>
<td>PVC (80)</td>
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<td>PVC</td>
<td>25</td>
<td>28</td>
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<tr>
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<td>B1A</td>
<td>Cp</td>
<td>PVC (80)</td>
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<td>PVC</td>
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<td>Cp</td>
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<tr>
<td>RN019075</td>
<td>B5A</td>
<td>Q</td>
<td>PVC (80)</td>
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<td></td>
</tr>
<tr>
<td>RN019005</td>
<td>B5B</td>
<td>Cp</td>
<td>PVC (100)</td>
<td></td>
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<td></td>
<td></td>
</tr>
</tbody>
</table>

Q – Quaternary sediments.
Cp – Crown Point Formation
+ Depth above ground surface.
B1B was a dry drillhole and backfilled on completion of drilling.
Figure 3.5  Drilling results
3.2 EM-34 survey

EM-34 surveys were conducted along three transects as described in Section 2.3. The results are displayed in Figure 3.6–Figure 3.10 and show the extent of the fresh groundwater beneath the Finke River within the alluvial/Crown Point aquifers.

Maynard’s Transect

Maynard’s Transect commences on the southern side of the Finke River on a subdued rise of outcropping Crown Point. It runs in a north-west direction across a sparsely vegetated plain intersecting sandier alluvial soils and open woodlands after 330 m and the bank of the main river channel after 520 m.

The apparent conductivity of the terrain across Maynard’s Transect is very high, with the horizontal dipole reading off the scale (>300 mS/cm) over the first 400 m. The horizontal dipole readings decrease slightly as the terrain shifts from clay dominated soils associated with the Crown Point to sandier soils of the Finke River alluvial deposits. However, the apparent conductivity is consistently high (>225 mS/cm) beneath and around the main river channel. This suggests that influx of low conductivity water from the Finke River to the alluvial/Crown Point aquifer is limited within this reach of the river and/or evapotranspiration has resulted in a loss of water and accumulation of salts.

Paddy’s Transect

Paddy’s Transect starts in an alluvial flat surrounded by outcropping Crown Point Formation and runs in a south-west direction, perpendicular to the orientation of the Finke River. The transect initially climbs up a series of sand dunes before descending onto the alluvial flat of the Finke River and then dropping sharply into the main river channel at the 2000 m mark. The transect continues for a further 1000 m on the south-western side of the Finke River through open woodland established on low alluvial terraces of the river.

The apparent conductivity is initially high but falls away as the elevation increases over the sand dunes. In this section of Paddy’s Transect the watertable is over 25 m below the land surface and the bulk of the EM response is coming from the unsaturated zone. The low EM readings are representative of the sandy unsaturated soils of the Quaternary aeolian dunes. Through this section the apparent conductivity of the vertical dipole reading (blue line) is higher than the horizontal dipole (red line). The vertical dipole has a greater exploration depth than the horizontal dipole orientation (30 m as opposed to 15 m) and the higher conductivity in the vertical reading is consistent with the presence of saline groundwater at depth (25 m).

The apparent conductivity increases rapidly as Paddy’s Transect descends from the sand dunes onto the alluvial terrace with readings for the horizontal dipole reaching the maximum range of 300 mS/cm. The very high apparent conductivity is likely a response to the relatively shallow (<20 m) and very saline (14 520 µS/cm) watertable, as evidenced in piezometer RT4. The apparent conductivity drops gradually and stabilises around 100 mS/cm at a distance of approximately 250 m from the main channel of the Finke River. This zone of low conductivity continues for another 250 m on the south-west side of the river. Data gathered from RT1/RT2C/RT3 indicate that shallow groundwater in the alluvial aquifer is fresh (<1000 µS/cm) within the area around the river channel. This zone of low apparent conductivity is interpreted as the zone within the alluvial aquifer that is actively influenced by the influx of fresh water from the Finke River.

Old Crown Transect

The Old Crown transect starts on a flat lying alluvial sand plain around 1000 m to the west of the main Finke River channel. The transect traverses through dense scrub and passes an abandoned stock bore (RN12397) before descending to alluvial terraces of the Finke River after approximately 600 m. The main channel of the Finke River is intersected 950 m along the Old Crown transect.

The apparent conductivity is very high over the first 500 m of the Old Crown transect. Groundwater depth and quality data from piezometer B5B and well RN12397 suggests the high conductivity readings are the result of a shallow (<15 mBGS) and saline (>15000 µS/cm) watertable in the Crown Point Formation. The apparent conductivity drops rapidly from 600 m and plateaus at approximately 100 mS/cm for the remainder of the Old Crown Transect. This low conductivity zone extends for 350 m east of the main river channel and is interpreted as the section of the alluvial aquifer receiving active recharge from the Finke River. The low apparent conductivity is consistent with the presence of fresh (1200 µS/cm) groundwater in the alluvial...
aquifer at well B5A. A comparison of the horizontal and vertical dipole measurements across this zone reveals that the conductivity of the deeper penetrating vertical measurements is on average 40% higher than the shallower horizontal readings. This may suggest that groundwater in the Crown Point Formation below the alluvial aquifer is relatively higher in conductivity. Although there is no direct evidence from well data along the Old Crown Transect this finding is consistent with the pattern of increasing groundwater salinity at depth observed in the nested wells RT2A/B/C on Paddy’s Transect.

River Transects

Three EM-34 transects of 500 m length were completed running downstream along the main channel of the Finke River. These transects commence at the end of the Maynard’s, Paddy’s and the Old Crown Transects respectively. A comparison of the three transects reveals that the apparent conductivity beneath the Finke River bed at Paddy’s Transect and Old Crown Transect is relatively low suggesting active recharge is occurring from flows in the river. In contrast the apparent conductivity beneath the river bed near Maynard’s Transect is over double the southern transects and indicates very limited surface water is recharging the aquifer system at this location. This information was used to constrain the recharge zone extent shown on Figure 4.1.
Figure 3.7 EM-34 results for Paddy’s Transect

The values at the mid-screen in the top pane represent salinity as EC (µS/cm). The triangles show density corrected groundwater level. The lower pane shows the EM-34 horizontal and vertical dipole readings as apparent conductivity (mS/cm).
Figure 3.8  EM-34 results for Maynard’s Transect

The values at the mid-screens in the top pane represent salinity as EC (µS/cm). The triangles show density corrected groundwater level. The lower pane shows the EM-34 horizontal and vertical dipole readings as apparent conductivity (mS/cm).
Figure 3.9 EM-34 results for Old Crown Transect

The values at the mid-screens in the top pane represent salinity as EC (µS/cm). The triangles show density corrected groundwater level. The lower pane shows the EM-34 horizontal and vertical dipole readings as apparent conductivity (mS/cm).
Figure 3.10 EM-34 results within the Finke River

Horizontal and vertical dipole readings as apparent conductivity (mS/cm) within the Finke River at Paddy’s Transect, Maynard’s Transect and the Old Crown Transect, respectively.
3.3 Hydraulic testing

Slug tests were undertaken on the ten constructed piezometers to estimate the relative hydraulic conductivity of the Quaternary alluvial and Crown Point aquifers. Results were analysed using the pumping test software Aqtesolv Pro (Hydrosolve, 2006) applying the Bouwer-Rice (1976) solution for unconfined, steady-state flow conditions. The Bouwer-Rice (1976) solution is based on a modified Thiem equation and is applied when the following assumptions are valid:

1. The aquifer is unconfined, homogeneous, has uniform thickness and is of infinite areal extent.
2. Flow to the well is quasi-steady-state and the addition/removal of water from the well is instantaneous.

These assumptions are generally valid for piezometers constructed in the alluvial aquifer (RT1, RT2C, RT3, B5A). The aquifer extent is finite, however, boundaries are unlikely to influence the test results given the piezometer locations and the relatively small water-level displacement. Hydraulic conductivity in the Crown Point piezometers (RT2A, RT2B, RT4, RT5, B1A, B5B) appears predominantly derived from secondary porosity, as evidenced by drill logs and outcrop observations. The fractures that form the aquifer are of limited extent and are heterogeneous and therefore fail to meet two of the underlying assumptions of the Bouwer-Rice (1976) solution. For the purpose of comparison with the alluvial piezometers the Bouwer-Rice (1976) method has been applied to the Crown Point piezometers, however, the derived hydraulic conductivity estimates are expected to have a greater level of uncertainty.

A summary of the results from the slug test analysis is presented in Table 3-3, a copy of the curve matching analysis for each individual rising and falling head test is provided in Appendix D.

Table 3-3 Summary of hydraulic conductivity (K) estimated from the slug test analysis

<table>
<thead>
<tr>
<th>Site ID</th>
<th>Aquifer</th>
<th>K Min (m/d)</th>
<th>K Max (m/d)</th>
<th>K Ave(^3) (m/d)</th>
</tr>
</thead>
<tbody>
<tr>
<td>RT1</td>
<td>Alluvial</td>
<td>1.45</td>
<td>2.02</td>
<td>1.69</td>
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<tr>
<td>RT2A</td>
<td>Crown Point</td>
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<td>0.01</td>
</tr>
<tr>
<td>RT2B</td>
<td>Crown Point</td>
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<td>0.0003*</td>
<td>0.0003*</td>
</tr>
<tr>
<td>RT2C</td>
<td>Alluvial</td>
<td>0.34</td>
<td>0.42</td>
<td>0.38</td>
</tr>
<tr>
<td>RT3</td>
<td>Alluvial</td>
<td>4.79</td>
<td>6.29</td>
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</tr>
<tr>
<td>RT4</td>
<td>Crown Point</td>
<td>0.03</td>
<td>0.04</td>
<td>0.03</td>
</tr>
<tr>
<td>RT5</td>
<td>Crown Point</td>
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<td>0.06</td>
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<td>Crown Point</td>
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<td>0.001</td>
<td>0.09</td>
<td>0.01</td>
</tr>
</tbody>
</table>

* The very low permeability of the formation around RT2B may be influenced by drilling mud which could not be completely removed during development.

The derived hydraulic conductivity for wells screening the alluvial aquifer ranges from 0.27 to 6.29 m/d with an average value of 0.68 m/d. The hydraulic conductivity of the Crown Point Formation is estimated at between 0.001 and 0.09 m/d with an average value of 0.01 m/d. Test results for RT2B yielded a very low hydraulic conductivity of 3 x 10\(^{-4}\) m/d. Although it was developed for several hours it is thought the permeability of the formation around RT2B may be impeded by drilling mud. As a consequence this result has not been included in the average values for the Crown Point aquifer.

\(^3\) Average K was calculated as the harmonic mean as per the discussion in Section 2.7.1.
Results show two distinct permeability groupings (see Figure 3.11). The alluvial aquifer has a higher hydraulic conductivity range consistent with an aquifer composition of fine, well-sorted sand. The Crown Point aquifer has a lower relative hydraulic conductivity range indicative of an aquifer matrix characterised by silt to clayey sands. With respect to permeability, the slug test results suggest that within the study area the Crown Point forms a very marginal aquifer.


![Figure 3.11 Slug test hydraulic conductivity results and range of unconsolidated sediments](image)

### 3.4 Groundwater chemistry and environmental tracers

Groundwater samples were analysed for a suite of chemical and isotopic constituents as described in Section 2.5. Historic geochemistry data for existing pastoral wells was sourced from Wohling et al. 2013 and the Northern Territory online water data tool (Natural Resources Maps NT - [http://www.lrm.nt.gov.au/nrmapsnt](http://www.lrm.nt.gov.au/nrmapsnt)). Chemical data for Finke River surface water (n=6) were sourced from Fulton et al. 2013 and Duguid 2013, which were collected opportunistically during flow events between November 2008 and April 2011 at the Stuart Highway Bridge gauging station approximately 150 km upstream from the study area. The mean-weighted rainfall chemical composition at Alice Springs (n=28) was sourced from Crosbie et al. 2012.

The desktop investigation (Wohling et al. 2013) identified three wells thought to be screened in the Crown Point aquifer that displayed relatively low chloride and groundwater mounding, suggesting active modern recharge from the Finke River. Maynard’s Bore (RN015198) and Paddy’s Bore (RN015950) did not have reliable lithology logs and were originally assigned to the Crown Point aquifer based on surface geology mapping. The drilling program (Section 3.1) and EM-34 surveys (Section 3.2) indicate that these wells are screened in the alluvial aquifer, which is supported by the chemical composition reported in the following sections. Peter’s Bore (RN015949) is located on outcropping Crown Point Formation on the bank of the Finke River within a few metres of the main channel (Figure 2.1; Figure 3.12), and was originally assigned to the Crown Point aquifer. The well construction details for Peter’s Bore are unreliable however the geological log indicates fine white soft sandstone overlain by fine white sand. Stratigraphically Peter’s Bore accesses a discrete fine-grained sandstone unit of the Crown Point Formation which appears to be far more permeable than the lithology encountered elsewhere in the formation. The well yield (>1 L/s) and chemical composition are anomalous compared to all other wells and are not indicative of the permeability or groundwater quality of the Crown Point aquifer in the study area. Hydrostratigraphically the well is more reflective of the characteristics of the alluvial aquifer considering yield and groundwater chemical composition. Without further evidence, Peter’s Bore (RN015949) will herein be grouped with the alluvial aquifer wells and piezometers considering the proximity to the river, well yield, chemical composition and the nature of the discrete sandstone unit.
3.4.1 Field chemistry

Field chemistry readings collected during hydrochemical sampling of piezometers, along with historical data for existing wells in or near the study area are summarised in Table 3-4. Where more than one data point was available for existing wells, the most recent value is reported here. The full data set is provided in Appendix A.

The alluvial aquifer is fresh with salinity less than 1200 µS/cm across the study area. The salinity of the Crown Point aquifer has an average EC 14 times greater than that recorded in the alluvial aquifer. Salinity in the Crown Point aquifer was variable and ranged from 3100 µS/cm at RT2 to 27 400 µS/cm at B5B, with an average of 12 500 µS/cm. Groundwater temperature ranged from 24.8 to 26.9 °C in the alluvial aquifer and 22.4 to 32.8 °C in the Crown Point aquifer however temperature variation is most likely related to ambient air temperature during sampling. Groundwater pH ranged from 7.2 to 8.9 in the alluvial aquifer and 6.4 to 7.7 in the Crown Point aquifer. There is a distinct difference in dissolved oxygen between the two aquifers, which ranged from 4.9 to 9.6 mg/L in the alluvial aquifer and was less than 2.3 mg/L in the Crown Point aquifer.

High salinity, slightly acidic pH and low dissolved oxygen levels in the Crown Point aquifer suggests limited connection with the recharge source.
Table 3-4  Field chemistry for new piezometers and existing wells

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<th>Site ID</th>
<th>Aquifer</th>
<th>Date</th>
<th>Temp</th>
<th>pH</th>
<th>EC (µS/cm)</th>
<th>DO (mg/L)</th>
<th>Alkalinity (mg/L)</th>
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<td>1000</td>
<td>6.7</td>
<td>150</td>
</tr>
<tr>
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<td>RT2A</td>
<td>Cp</td>
<td>26/10/2014</td>
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</table>

Q – Quaternary alluvial sediments
Cp – Crown Point Formation
EC and pH at B1A were tested at the laboratory as minimal sample was retrieved. B1B was a dry drillhole.
Alkalinity reported as CaCO₃-Alkalinity
*calculated from reported TDS 2 230 mg/L
^stratigraphically this well accesses a discrete sandstone unit of the Crown Point Formation. Based on hydrostratigraphy the well has herein been grouped with alluvial aquifer piezometers/wells (see discussion in Section 3.4).

3.4.2 Major ion chemistry

The relative cationic and anionic composition of groundwater from the alluvial aquifer and Crown Point aquifer is plotted in Figure 3.13. The recharge source water from the Finke River, and the two end-members rainfall and seawater are plotted for comparison. The full chemical results including ion balances are provided in Appendix A.

The piper diagram clearly indicates the difference between the two aquifers in the study area. The alluvial aquifer is characterised by Ca-HCO₃ type water that is similar to Finke River surface water, which shows some evolution from rain water. The Crown Point aquifer is characterised by Na-Cl type water that is similar to oceanic water.

Two groundwater wells with historical chemistry data and previously unknown aquifer (Old Crown wells RN000507 and RN002012) are similar in composition to wells completed in the Crown Point aquifer, and will be interpreted as Crown Point aquifer wells herein. Both wells were recorded as dry in 1991 and have been backfilled.
Comparing major ion ratios can provide insight into the mechanisms contributing to groundwater chemical composition, which is controlled by rainfall, evaporation/evapotranspiration, water-rock interaction and aeration.

Coastal rainfall can be considered as diluted seawater and rock/mineral interactions in groundwater are typically deduced by comparing groundwater composition to standard seawater dilution ratios. The chemical composition of coastal rainfall, which is Na-Cl type water, is very different to the composition of inland rainfall, which is often Ca or Na-HCO₃ type water. This effect is shown in Figure 3.14, which compares rainfall at Adelaide (coastal) to Alice Springs (inland). Interpretation of the mechanisms contributing to groundwater chemical composition in the study area would be very different if compared to typical seawater dilution ratios. Groundwater composition in the study area is therefore compared to ionic ratios in the recharge source water (Finke River). Ionic ratios in Alice Springs rainfall are also shown as the data set is statistically more robust.

Figure 3.13 Piper plot illustrating the major ion composition of the alluvial aquifer and Crown Point aquifer
Plots of major ions against chloride are provided in Appendix F. The alluvial aquifer and Crown Point aquifer are dissimilar in chemical composition. The chloride concentration of groundwater from the alluvial aquifer is low (82–216 mg/L), which is indicative of active and regular recharge in this region (Leaney et al. 2013). Chloride concentration in the Crown Point aquifer is much higher (1820–9370 mg/L), the noticeable increase in chloride and other major ions within a few kilometers of the recharge source suggests limited recharge to the Crown Point aquifer via ephemeral river recharge from the Finke River.

A number of ionic ratios in the Crown Point aquifer deviate from that of the recharge source, indicating that processes other than mixing or evapoconcentration are contributing to the composition of the groundwater (e.g. ion exchange or mineral/rock weathering). An assessment of rock/mineral weathering in the Crown Point aquifer is made in the following sections. Saturation indices were calculated using PhreeQC geochemical modelling software (Parkhurst and Appelo 2013).

The saturation indices for halite (NaCl) indicate that recharge source water and aquifers are subsaturated with respect to halite with potential for dissolution. The chloride to bromide ratio (Cl/Br) is a useful geochemical tracer to identify halite dissolution, as bromide is excluded from the halite crystal lattice and commonly results in Cl/Br ratios >10^4; however dissolution of even minor amounts of halite can increase the Cl/Br ratio above the seawater range (Cartwright et al. 2004). Cl/Br ratios in the study area are shown on Figure 3.15a and suggest very minor halite dissolution, however it is not a dominant control on groundwater composition. This is consistent with the plot of Br v. Cl (Figure 3.15b), which shows that groundwaters plot well above the halite dissolution trend indicating insignificant addition of chloride from halite dissolution.
It is noted that the Cl/Br ratio in groundwaters may also reflect that of the recharge source water, however bromide data is not available for Finke River surface water. The concentration of bromide in the Finke River would need to be 1–2 orders of magnitude less than that in the alluvial aquifer to result in a similar Cl/Br ratio to groundwaters in the study area.

The saturation indices for the common sulfate mineral gypsum (CaSO₄) are generally less than -2 in the recharge water and alluvial aquifer, and slightly less than zero in the Crown Point aquifer. Both aquifers are subsaturated with respect to gypsum however the plot of Ca v. SO₄ (Figure 3.16a) indicates an obvious source of SO₄. It is unlikely that the source of SO₄ is from anthropogenic sources considering the remote location; or from atmospheric deposition as diffuse recharge is effectively zero (Section 1.4); or from pyrite (FeS₂) oxidation as pyrite was not recorded in any of the existing or new drillholes in the study area and there is no concurrent decrease in pH. The relatively higher saturation index in the Crown Point aquifer combined with an increase in sulfate suggests some dissolution of a sulfate mineral and/or oxidation of sulfides in the Crown Point aquifer. Figure 3.16a demonstrates that groundwater in the Crown Point aquifer plots to the left of the gypsum dissolution line, indicating a loss of Ca relative to SO₄. The loss of Ca relative to SO₄ in the Crown Point aquifer, with the concurrent increase in Na (Figure 3.16b), suggests that cation exchange is also occurring. It is likely that Ca is being exchanged for Na on the surface of clay colloids.

Figure 3.15 Chloride versus bromide results

a) Cl/Br ratios for groundwaters in the study area. b) Br v. Cl showing seawater dilution (3.45x10⁻³) and halite dissolution (10⁻⁴) trends.
Figure 3.16 Results for calcium and sodium versus sulfate

a) Ca v. SO₄ showing gypsum dissolution trend (1) and ionic ratios for recharge source water. b) Na v. SO₄ (mmol/L) suggests source of Na.

The saturation indices for calcite (CaCO₃) and dolomite (CaMg(CO₃)₂) are generally greater than zero in both the alluvial aquifer and Crown Point aquifer, indicating equilibrium to saturation with respect to calcite and dolomite. No carbonate minerals were observed during drilling (Section 3.1) and carbonates have only been logged in one existing well in or near the study area. The geological log for well RN004634 (A24/5, Crown Point aquifer) indicates the presence of marine carbonates (limestone). It is not clear whether data for RN004634 is reliable as it was drilled in 1966, with no historical chemical data, and is abandoned and unable to be located. Further, marine sequences have not been identified in the Crown Point Formation (Mond and Yeates 1973; Munson and Ahmad 2013) and strontium isotopes (Section 3.4.4) do not indicate dissolution of marine carbonates. If carbonates are present in the study area, it is more likely that they are of continental origin (pedogenic).

The HCO₃:Si ratio (Figure 3.17a) initially suggests that carbonate dissolution is occurring in the Crown Point aquifer with the exception of RTS (Hounslow 1998), however this may be related to high pCO₂ and open system conditions which can influence HCO₃ concentrations (see Section 3.4.5). The plot of Ca v. HCO₃ (Figure 3.17b) is often used to illustrate carbonate dissolution if data plots along typical mineral dissolution lines. In this case the data are unclear as the recharge source water is quite similar to mineral dissolution trends, and ion exchange in the Crown Point aquifer is likely masking any observable trends. Carbonate dissolution is further explored using strontium isotopes (Figure 3.20).
Figure 3.17 Results for silica and calcium versus bicarbonate

a) HCO$_3$/Si ratios for groundwaters in the study area. b) Ca v. HCO$_3$ showing rainfall (0.2) and Finke River (0.54) dilution, calcite (0.5) and dolomite dissolution (0.25) trends.

3.4.3 $\delta^2$H and $\delta^{18}$O

For the objectives of this study, stable isotopes of water ($\delta^2$H and $\delta^{18}$O) provide insight into the mechanisms of groundwater recharge. The $\delta^2$H and $\delta^{18}$O composition of groundwater from the alluvial aquifer and Crown Point aquifer are plotted in Figure 3.18 against the Alice Springs Local Meteoric Water Line (LMWL). The LMWL was calculated using stable isotope data from International Atomic Energy Association (GNIP, 1962–1987) and Crosbie et al. 2012 (2007–2011). The black squares represent rainfall threshold values, which are the rainfall amount-weighted mean $\delta^2$H and $\delta^{18}$O composition of rainfall events in excess of a monthly threshold volume (after Kretschmer and Wohling 2014; after Leaney et al. 2013). For example, the $>0$ mm threshold is the amount-weighted mean isotope composition of all rainfall events (shown as grey dots) – which includes events with relatively depleted (negative) values and smaller events with enriched (positive) values.

$\delta^2$H and $\delta^{18}$O values for groundwater samples from the alluvial aquifer and Crown Point aquifer plot close to the LMWL, indicating rapid recharge and minimal evaporation. In this arid region, groundwater that has a long residence time in the soil zone is subject to evaporation, often plotting on an evaporation line that is offset to the LMWL with a slope between 3–6 (Coplen et al. 2000). This does not however include the effects of evapotranspiration, which does not fractionate stable isotopes and results in a loss of water and accumulation of salts; a process that is likely contributing to higher salinity in the Crown Point aquifer. The isotope values for the alluvial aquifer and Crown Point aquifer are similar in composition to the amount-weighted mean rainfall of less than 50 mm/month.

To provide a regional context, the GAB J aquifer (described in Section 1.3) is recharged downstream of the study area by large flood events in the Finke River that generally have a depleted isotopic signature (Love et al. 2013), as shown by the dashed grey line on Figure 3.18. The GAB J aquifer recharge zone is characterised by transmissive fractured sandstone with an unsaturated zone of ~70 m.

In contrast, the unsaturated zone in the alluvial aquifer consists of only a few metres (Figure 3.7) and the aquifer extent in the study area is generally less than a kilometre from the river (Section 3.1), resulting in limited storage capacity for larger flood events. The unsaturated zone in the Crown Point aquifer is similar however the formation also has very low permeability (Section 3.3) which limits the potential for lateral flow.

Whilst it is likely that rare, large rainfall events result in recharge to the alluvial aquifer, the relatively enriched isotope signature of groundwaters suggests that the dominant recharge mechanism is associated with smaller more frequent rainfall events of less than 50 mm/month. Considering that the stable isotope signature is similar in both aquifers, yet there is a disparity in age (Section 3.4.5), it is likely that during flood events in the Finke River the hydraulic head in the alluvial aquifer is increased resulting in a small downward flux to the underlying Crown Point aquifer. These estimates of recharge rates and mechanisms
are consistent with those estimated elsewhere in the region (summarised in Leaney et al. 2013; Fulton et al. 2013; Kretschmer and Wohling 2014).

It should be noted that the Crown Point aquifer near the recharge source plots similarly to the regional Crown Point aquifer in the Pedirka Basin (Fulton et al. 2013), suggesting the groundwater has a similar meteoric origin and evolution.

![Figure 3.18 δ²H and δ¹⁸O composition plotted against the Alice Springs LMWL](image)

### 3.4.4 Strontium isotope ratio (⁸⁷Sr/⁸⁶Sr)

Field-filtered groundwater samples were collected from nine of the constructed piezometers and analysed for strontium (Sr) concentration and ⁸⁷Sr/⁸⁶Sr isotope ratios. Data for three existing wells was sourced from Wohling et al. 2013. Strontium data is not available for Finke River water however strontium concentrations in rainfall were sourced from Crosbie et al. 2012. Whole-rock samples of alluvial sediments and Crown Point Formation outcrop were analysed for Sr isotope ratios, which represents the amount-weighted average ⁸⁷Sr/⁸⁶Sr value of all minerals forming the aquifer rocks. The aquifer minerals, or pore waters within each aquifer, were not analysed for the current study.

The Sr concentration in groundwater is controlled initially by evapoconcentration of rainfall derived strontium (marine aerosols and wind-blown dust), and dissolution of Sr bearing minerals in the unsaturated and saturated zones. Strontium isotope ratios in groundwater are not altered by evapoconcentration or mineral precipitation, but rather by ion exchange and mineral dissolution, unless the mineral already had a Sr isotope signature that was similar to groundwater (Raiber et al. 2009; Shand et al. 2009; Dogramaci and Herczeg 2002).

The ⁸⁷Sr/⁸⁶Sr ratios of groundwater are plotted against the reciprocal of the Sr concentration in Figure 3.19, along with the seawater end-member (Kennish 2000; Angino et al. 2003) and host rock ratios for comparison. In this instance, the application of Sr isotopes is limited due to the lack of isotopic variation (Shand et al. 2009), however the results contribute to validating the conceptual hydrogeological model. Crown Point aquifer samples cluster close to the Y-axis indicating a relatively high Sr concentration. Strontium concentrations are consistent with salinity and are on average 12 times greater in the Crown Point aquifer compared to the alluvial aquifer (Table 3-5). The general disparity in strontium concentrations suggests limited recharge to the Crown Point aquifer from the alluvial aquifer or via ephemeral river recharge from the Finke River.
Figure 3.19a shows that the Sr isotope ratio in the alluvial aquifer is slightly more radiogenic compared to the Crown Point aquifer. Considering this graph in conjunction with the stable isotope results (Section 3.4.3) and major ion chemistry (Section 3.4.2), it is likely that ion exchange is the dominant process contributing to the Sr isotope signature in the Crown Point aquifer, with perhaps minor carbonate dissolution. Plotting ionic ratios (Figure 3.20a) or Sr isotope ratios (Figure 3.20b) against the $\delta^{13}C$ signature can reveal carbonate dissolution if there is a clear trend of $\delta^{13}C$ enrichment (more positive) with a change in the ratio along a flow path (Shand et al. 2009; Buckley et al. 1998; Harrington 1999). There does not appear to be a definitive trend in either aquifer and if pedogenic carbonate dissolution is occurring, it appears to be a minor process. It is noted that ion exchange and $\delta^{13}C$ in the unsaturated zone may be masking the trends. The Sr isotope ratios in groundwater are more radiogenic than modern seawater (0.70916) and are not consistent with marine carbonate dissolution (0.706–0.709). The Sr isotope ratios also suggest that silicate weathering is not a dominant process in either aquifer, as more radiogenic ratios would be expected (McNutt 2000; Harrington 1999).

Sr concentration or isotope data is not available for Finke River surface water, however the Sr isotope ratios in the alluvial aquifer may be reflective of the recharge source as rainfall becomes progressively more radiogenic with distance inland due to the addition of atmospheric dust (Raiber et al. 2009).

Figure 3.19 Strontium isotope results

a) Groundwater Sr isotope ratios for the alluvial aquifer and Crown Point aquifer  b) Sr results compared to whole rock averages and seawater ratios.
Figure 3.20 a) Sr/Ca v. δ\(^{13}\)C  b) \(^{87}\)Sr/\(^{86}\)Sr v. δ\(^{13}\)C

Figure 3.21 illustrates that the Sr isotope signature in the regional Crown Point aquifer is significantly less radiogenic with distance from the recharge zone. Whilst this may indicate ion exchange and/or mineral dissolution, inter-aquifer connectivity with overlying/underlying formations controls the Sr isotope signature in the regional Crown Point aquifer (Fulton et al. 2015).

Figure 3.21 Sr isotope signatures in the study area compared regionally
Table 3-5  Strontium concentrations in rainfall, the alluvial aquifer and Crown Point aquifer

Chloride data are provided for comparison.

<table>
<thead>
<tr>
<th>Site ID</th>
<th>Aquifer</th>
<th>$^{87}$Sr/$^{86}$Sr isotope ratios</th>
<th>Sr (mg/L)</th>
<th>1/Sr</th>
<th>Cl (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rainfall</td>
<td>N/A</td>
<td>N/A</td>
<td>&lt;0.05</td>
<td>20.00</td>
<td>N/A</td>
</tr>
<tr>
<td>RT1</td>
<td>Q</td>
<td>0.71914</td>
<td>0.29</td>
<td>3.42</td>
<td>82</td>
</tr>
<tr>
<td>RT2A</td>
<td>Cp</td>
<td>0.71868</td>
<td>1.55</td>
<td>0.65</td>
<td>1820</td>
</tr>
<tr>
<td>RT2B</td>
<td>Cp</td>
<td>0.71819</td>
<td>3.24</td>
<td>0.31</td>
<td>3590</td>
</tr>
<tr>
<td>RT2C</td>
<td>Q</td>
<td>0.71961</td>
<td>0.33</td>
<td>3.03</td>
<td>148</td>
</tr>
<tr>
<td>RT3</td>
<td>Q</td>
<td>0.71962</td>
<td>0.38</td>
<td>2.67</td>
<td>133</td>
</tr>
<tr>
<td>RT4</td>
<td>Cp</td>
<td>0.71893</td>
<td>4.09</td>
<td>0.24</td>
<td>4250</td>
</tr>
<tr>
<td>RT5</td>
<td>Cp</td>
<td>0.71922</td>
<td>3.51</td>
<td>0.28</td>
<td>2980</td>
</tr>
<tr>
<td>BSA</td>
<td>Q</td>
<td>0.71957</td>
<td>0.34</td>
<td>2.91</td>
<td>216</td>
</tr>
<tr>
<td>BSB</td>
<td>Cp^</td>
<td>0.71939</td>
<td>10.20</td>
<td>0.10</td>
<td>9370</td>
</tr>
<tr>
<td>Maynard’s Bore</td>
<td>Q</td>
<td>0.71977</td>
<td>0.47</td>
<td>2.13</td>
<td>170</td>
</tr>
<tr>
<td>Peter’s Bore</td>
<td>Cp^</td>
<td>0.72011</td>
<td>0.24</td>
<td>4.24</td>
<td>130</td>
</tr>
<tr>
<td>Paddy’s Bore</td>
<td>Q</td>
<td>0.71965</td>
<td>0.37</td>
<td>2.74</td>
<td>120</td>
</tr>
</tbody>
</table>

Q – Quaternary alluvial sediments
Cp – Crown Point Formation
^stratigraphically the well accesses a discrete sandstone unit of the Crown Point Formation, however has been grouped as alluvial aquifer as per the discussion in Section 3.4
Sr samples were not recovered at B1A/B and are not included in the table.
Alice Springs rainfall strontium was <0.05 mg/L between 2007–2011 (n=28) (Crosbie et al. 2012).
3.4.5 Groundwater dating

Groundwater dating is a useful technique to estimate groundwater recharge rates and mechanisms, and determine whether the recharge rates are reflective of the current or past climate. In the study area, groundwater dating was used to identify whether the Crown Point aquifer is actively being recharged by modern water. As groundwater sampled from each piezometer/well is a mixture of older and younger groundwater, the values reported in the results are a guide only.

Chlorofluorocarbons

The concentration of CFCs can be used to estimate groundwater ages up to approximately 50 years (Scanlon et al. 2002). Here the detectable concentration of CFCs is broadly used as a tracer of recent groundwater recharge.

CFC results are summarised in Table 3-6. The full results are provided in Appendix A. CFC results for RT1, RT3 and Paddy’s Bore were at the laboratory detection limit, suggesting a groundwater residence time of greater than 50 years at these locations. CFCs were detected in groundwater at alluvial wells Maynard’s Bore and Peter’s Bore, and along the Old Crown Transect in both the alluvial aquifer (BSA) and Crown Point aquifer (B5B), indicating modern recharge at these locations.

CFCs were analysed in RT2A and RT2B however the results have been discounted as it is likely that the groundwater was contaminated with atmospheric CFC concentrations during development. These nested piezometers are screened in the Crown Point aquifer, have very low permeability (<0.05 L/s) and are screened at a greater depth than the overlying alluvial aquifer piezometers RT1 and RT3, where CFC results indicated a groundwater residence time of greater than 50 years. Groundwater may also have been exposed to the atmosphere during purging as the recovery time at RT2A was greater than 3 hours, and RT2B greater than 24 hours. This interpretation is consistent with 14C results described in the next section.

Table 3-6  CFC concentrations in groundwater where samples could be recovered

<table>
<thead>
<tr>
<th>Site ID</th>
<th>Aquifer</th>
<th>CFC-11 pg/kg</th>
<th>CFC-12 pg/kg</th>
<th>Apparent age</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>RT1</td>
<td>Q</td>
<td>&lt;24.723</td>
<td>19.344</td>
<td>&lt;1965</td>
<td>Residence time &gt;50yrs</td>
</tr>
<tr>
<td>RT2</td>
<td>Cp</td>
<td>35.087</td>
<td>31.674</td>
<td>N/A</td>
<td>Contaminated</td>
</tr>
<tr>
<td>RT2B</td>
<td>Cp</td>
<td>&lt;24.723</td>
<td>90.197</td>
<td>N/A</td>
<td>Contaminated</td>
</tr>
<tr>
<td>RT3</td>
<td>Q</td>
<td>&lt;24.723</td>
<td>19.344</td>
<td>&lt;1965</td>
<td>Residence time &gt;50yrs</td>
</tr>
<tr>
<td>BSA</td>
<td>Q</td>
<td>37.493</td>
<td>58.727</td>
<td>1967-1975</td>
<td>Modern</td>
</tr>
<tr>
<td>B5B</td>
<td>Cp</td>
<td>45.913</td>
<td>44.702</td>
<td>1970-1975</td>
<td>Modern</td>
</tr>
<tr>
<td>Maynard’s Bore</td>
<td>Q</td>
<td>16.00</td>
<td>36.000</td>
<td>&lt;1971</td>
<td>Modern</td>
</tr>
<tr>
<td>Peter’s Bore</td>
<td>Cp^</td>
<td>7.500</td>
<td>44.000</td>
<td>&lt;1973</td>
<td>Modern</td>
</tr>
<tr>
<td>Paddy’s Bore</td>
<td>Q</td>
<td>1.000</td>
<td>9.000</td>
<td>&lt;1965</td>
<td>Residence time &gt;50yrs</td>
</tr>
</tbody>
</table>

Q – Quaternary alluvial sediments
Cp – Crown Point Formation

B1A/B have not been included in the table as minimal sample was retrieved at B1A and B1B was a dry drillhole.
RT2C/RT4/RT5 have not been included in the table as risk of contamination could not be overcome and samples were not recovered (discussed in Section 2.5).

^stratigraphically the well accesses a discrete sandstone unit of the Crown Point Formation, however has been grouped as alluvial aquifer as per the discussion in Section 3.4.
Radiocarbon (carbon-14)

Under normal geochemical conditions the main source of carbon in recharging water is soil CO₂ from plant root respiration and microbial degradation of soil organic matter (Kalin 2000). Following recharge, the groundwater dissolved inorganic carbon (DIC) is isolated from the atmosphere and undergoes radioactive decay at a known rate (Plummer and Glynn 2013), which allows the apparent age of groundwater to be calculated from the ¹⁴C content. However, Mook (1992) was certainly correct when stating that radiocarbon dating of groundwater is complicated and often questionable owing to the aqueous geochemistry of carbon in the unsaturated and saturated zones. There are a number of factors that must be considered when interpreting radiocarbon ages, as certain processes can alter the ¹⁴C content of DIC in groundwater:

- Determination of the initial ¹⁴C content, A₀, of DIC in groundwater recharge. Modelled values of A₀ can be sensitive to the δ¹³C of soil gas CO₂ resulting from respiration of plants in the unsaturated zone that utilise C₃, C₄ or CAM photosynthetic pathways. Consideration also needs to be given to whether recharge waters have evolved in isotopic equilibrium with soil gas under open or closed system conditions, and whether recharge and environmental conditions were the same at the time of recharge as what they are today (Plummer and Glynn 2013).
- Geochemical reactions in the aquifer, predominantly the dissolution of carbonate minerals as the addition of this ‘dead carbon’ dilutes the ¹⁴C in groundwater and results in an overestimate of apparent age.
- Physical processes, such as mixing, dispersion, leakage or diffusive exchange with confining layers.

Various hydrochemical and/or isotopic correction models have been developed that account for the above factors if it can be determined that these processes have altered the ¹⁴C content.

It is unlikely that physical processes have greatly altered the ¹⁴C content considering the conceptual hydrogeological model (Section 1.4), the aquifers encountered (Section 3.1), the limited connection between the alluvial aquifer and the underlying Crown Point aquifer (sections 3.3, 3.4, 4.1) and the local scale of the study area.

The number of data points in each aquifer is limited however there is no definitive trend of δ¹³C enrichment with decreasing ¹⁴C in either aquifer (Figure 3.22a). This plot suggests that there may be minor carbonate dissolution but it does not appear to be a significant source of DIC to groundwater.

The range of δ¹³C values in groundwater are consistent with the δ¹³C of soil gas CO₂ resulting from respiration of C₃ plants (trees, shrubs and herbs) and C₄ plants (grasses) in the unsaturated zone. The δ¹³C values of C₃ and C₄ plants in the region are approximately -18±2 ‰⁴ and -14±1 ‰⁴ respectively (Johnson et al. 2005; Murphy et al. 2012). The δ¹³C values of DIC in the alluvial aquifer ranged from -16.20 to -12.15 ‰ and in the Crown Point aquifer from -15.66 to -7.82 ‰. Therefore the ¹⁴C activities of groundwater in the study area have not been corrected for water-rock interaction using any of the correction models, and interpretation of the ¹⁴C data considers the maximum apparent uncorrected age to indicate whether groundwater is modern, sub-modern, or old.

If the ¹⁴C and δ¹³C data from the study area is entered into the most appropriate correction model for the study area (Pearson model; Fontes and Garnier model), all piezometers correct to modern water with the exception of RT2A/B. This is clearly unreasonable as it is not consistent with the conceptual hydrogeological model or the hydraulic and hydrochemical results.

The ¹⁴C activities and maximum apparent ages for groundwater collected from piezometers and existing wells in the study area are summarised in Table 3-7 and Figure 3.22. The full results are provided in Appendix A.

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⁴ Raw value ~ -27 ‰ plus the expected fractionation from HCO₃ in the unsaturated zone of ~ 8-9 ‰ (considering pH 6-9 and average temperature 26.6°C).

⁵ Inputs: initial A₀ 108 pmC based on unsaturated zone soil gas in the Ti Tree Basin (Wood et al. 2014); initial δ¹³C -18 ‰ for the alluvial aquifer (based on C₃ plants) -27 ‰ plus expected fractionation from HCO₃ in the unsaturated zone of ~ -9 ‰ considering pH 6-9 and average temperature 26.6°C) and -14 ‰ for the Crown Point aquifer (based on C₄ plants); and mineral input of non-marine pedogenic carbonate -4 ‰.
Qualitatively the $^{14}$C activities in groundwater generally indicate modern groundwater in the alluvial aquifer and sub-modern groundwater in the Crown Point aquifer. Groundwater samples from Paddy’s Bore and Maynard’s Bore show $>100$ pmC which is consistent with CFC results and indicate recharge occurring post-1950. At the multi-level nested site (RT2), groundwater age increases with depth and $^{14}$C activities decrease from $89.7$ pmC in the alluvial aquifer to $59.4$ pmC in the underlying Crown Point aquifer. Results along Paddy’s Transect show increasing groundwater age with distance from the Finke River; however results at the northern extent (RT5) show influence from the minor ephemeral channel flowing from the north-west (visible on satellite imagery). The $^{14}$C result and salinity at Peter’s Bore support regrouping with the alluvial aquifer (Section 3.4) and suggest modern recharge to the Crown Point aquifer at this location. However current knowledge suggests that the sandstone unit encountered at Peter’s Bore is discreet and not continuous, and therefore it is unknown whether this represents a major recharge zone. Further work could be undertaken to characterise the extent of the sandstone units within the Crown Point Formation adjacent to the Finke River, as these may represent areas of greater recharge to the Crown Point aquifer. Results at the Old Crown Transect are consistent with CFC results and indicate a component of modern water in the Crown Point aquifer (B5B). The age tracer results at B5B are not consistent with salinity ($28,000$ µS/cm) and hydraulic conductivity ($0.075$ m/d) which suggest a long groundwater residence time. However the density corrected heads show a relatively flat hydraulic gradient ($0.00072$ m) indicating potential for mixing during recharge pulses from the Finke River. It is posited that stratified variable groundwater flow paths occur at the Old Crown Transect resulting in mixing of old and young groundwaters. Considering the geochemical composition and hydraulic characteristics it is highly unlikely that significant modern recharge to the Crown Point aquifer is occurring at this location.

Overall the $^{14}$C activities in the Crown Point aquifer suggest limited modern recharge via ephemeral river recharge from the Finke River.

Table 3-7  Carbon-14 concentrations and uncorrected apparent groundwater ages

Chloride data are provided for comparison.

<table>
<thead>
<tr>
<th>Site ID</th>
<th>Aquifer</th>
<th>Constructed depth (m)</th>
<th>Screen midpoint (m AHD)</th>
<th>$^{14}$C (pmC)</th>
<th>$\delta^{13}$C (‰)</th>
<th>Uncorrected apparent age (years BP)</th>
<th>Cl (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
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Q – Quaternary alluvial sediments
Cp – Crown Point Formation

B1A/B have not been included in the table as minimal sample was retrieved at B1A and B1B was a dry drillhole.

^stratigraphically the well accesses a discrete sandstone unit of the Crown Point Formation, however has been grouped as alluvial aquifer as per the discussion in Section 3.4.
Figure 3.22a illustrates that there is no definitive trend of δ¹³C enrichment with increasing groundwater age (decreasing ¹⁴C pmC) in either aquifer. Figure 3.22b supports this as there is no definitive trend of increasing bicarbonate concentration with δ¹³C enrichment in either aquifer. These plots suggest that carbonate dissolution is not a dominant process in either aquifer. This is further explored using strontium isotopes (Section 3.4.4).

Figure 3.22  a) Relationship between δ¹³C and δ¹⁴C  b) HCO₃ v. δ¹³C

3.5  Recharge rates

The study employed two saturated zone techniques to estimate recharge to the alluvial aquifer and Crown Point aquifer. The methodology used for each estimate is described in Section 2.7.

3.5.1  Darcy flux method

Field measured groundwater hydraulic heads at the nested site (RT2) were corrected for salinity and temperature effects using the method described in Section 2.7.1. The correction process resulted in a change in groundwater levels between 0.014 m (RT2A) and 0.103 m (RT2B). The corrected groundwater levels indicate that there was an upward hydraulic gradient from the Crown Point aquifer to the overlying alluvial aquifer, with a vertical gradient of 0.21 m. The values used in the calculations are given in Table 3-8, and are visually presented in Figure 3.23 (Carbon-14 results are provided for comparison).

If standard drilling and sampling procedures are carefully followed to achieve maximum accuracy and precision, the smallest achievable uncertainty related to hydraulic head measurements are between 0.1–0.25 % (Post and von Asmuth, 2013), or ±0.07 m if equated to the above hydraulic gradient including the potential survey error (Section 2.6). Even if the potential error is doubled, the density corrected hydraulic heads indicate an upward vertical flux.

The corrected hydraulic heads indicate that at the time of sampling, there was no potential for recharge to enter the Crown Point aquifer from the alluvial aquifer. However the vertical gradient is small and it is likely that temporally there is a downward gradient to the Crown Point aquifer, following flood events in the Finke River that increase head in the alluvial aquifer. This long term flux to the Crown Point aquifer has been estimated using age tracer data (Section 3.5.2).
Table 3-8  Density corrected hydraulic heads at the nested site

Where the average field groundwater temperature was 26.6°C, freshwater density ($\rho_f$) was 999 kg/m³, and density as a function of temperature and salinity ($\rho_i$) ranged from 997.1 to 1002.6 kg/m³.

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<th>Surface elevation (m AHD)</th>
<th>Aquifer</th>
<th>Lab TDS (mg/L)</th>
<th>Depth to mid-screen (m)</th>
<th>Reference point ($z_i$) (m AHD)</th>
<th>Field DTW (m)</th>
<th>Field measured head ($h_i$) (RWL m AHD)</th>
<th>Density corrected head ($h_{fi}$) (RWL m AHD)</th>
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Q – Quaternary alluvial sediments
Cp – Crown Point Formation
* Depth to water (DTW) taken prior to hydrochemical sampling on 26/10/2014 at 11am measured in metres below ground surface (m BGS).
# Reduced water level (RWL). Wells were surveyed as described in Section 2.6.

Figure 3.23 Diagram of density corrected hydraulic heads at the nested site
3.5.2 Age tracer data

Radiocarbon data collected at each piezometer were used to estimate recharge rates to the alluvial aquifer, and long term average annual recharge rates to the Crown Point aquifer via vertical flux from the alluvial aquifer. The method is described in Section 2.7.2 and uses Equation 3, which is repeated here:

\[ R = \frac{z\theta}{t} \]  (Equation 3)

Where \( R \) is recharge to the aquifer, \( z \) is depth to the screen mid-point, \( \theta \) is the porosity of aquifer material, and \( t \) is the apparent carbon-14 age (screen length 3 m). The values used in the calculations are presented in Table 3-9.

The distance to the screen mid-points (\( z \)) was based on surveyed elevations reported in Table 3-7 and described in Section 2.6. Porosity (\( \theta \)) was sensitivity tested using the upper and lower values, with the resultant recharge estimate reported as a range to reflect the uncertainty.

Carbon-14 derived recharge rates to the alluvial aquifer ranged from 2.45 to 34.08 mm/y. Carbon-14 derived recharge rates from the alluvial aquifer to the underlying Crown Point aquifer ranged from 0.13 to 8.55 mm/y, however the recharge estimates for piezometers RT5 and B5B are influenced by a component of modern groundwater and it is highly unlikely that significant modern recharge to the Crown Point aquifer is occurring at these locations (discussed further in Section 3.4.5). If the results at RT5 and B5B are dismissed the recharge rates to the Crown Point aquifer range from 0.13 to 2.83 mm/y.

The spatial variability of lower and upper recharge estimates is reported below in Table 3-9 and presented in Figure 3.24 and Figure 3.25.

### Table 3-9 Carbon-14 recharge estimates to the alluvial and Crown Point aquifer

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<th>Depth to screen mid-point (m)</th>
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<th>Recharge min (mm/y)</th>
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Alluvial aquifer  \( 2.45 – 34.08 \)

Crown Point aquifer \( 0.13 – 8.55 \)

* results at RTS and BSB are influenced by a component of modern groundwater as per the discussion in Section 3.4.5.

^ stratigraphically the well accesses a discrete sandstone unit of the Crown Point Formation, however has been grouped as alluvial aquifer as per the discussion in Section 3.4.

B1A/B have not been included in the table as minimal sample was retrieved at B1A and B1B was a dry drillhole.

Q – Quaternary alluvial sediments

Cp – Crown Point Formation

N/A – Not applicable
Figure 3.24 Spatial variability of lower recharge rates
Figure 3.25 Spatial variability of upper recharge rates
4 Site characterisation

4.1 Aquifers

The drilling program (Section 3.1) and ground penetrating EM-34 geophysical surveys (Section 3.2) identified two aquifers in the study area: an alluvial aquifer associated with the Finke River, and the Crown Point aquifer within the glaciofluvial to periglacial sediments of the Crown Point Formation.

An alluvial aquifer was identified in the Quaternary sediments associated with the Finke River, the extent of which is broadly delineated by the limit of riparian vegetation visible on satellite imagery. The aquifer composition is consistent across the study area and consists of fine to coarse unconsolidated quartz sand. The alluvial aquifer is fresh (EC <1200 µS/cm; TDS <800 mg/L), near-neutral (pH 7.2 to 8.9), oxygenated (DO 4.9 to 9.6 mg/L) and characterised by Ca-HCO₃ type water that is similar to Finke River surface water (Section 3.4). Age tracer data broadly indicates modern water in the alluvial aquifer, with Carbon-14 >100 pmC at Paddy’s and Maynard’s Bores which is consistent with recharge occurring post-1950 (Section 3.4.5). The aquifer sediments are relatively transmissive and permeable with hydraulic conductivity ranging from 0.27 to 6.29 m/d (Section 3.3). Groundwater elevation is generally higher close to the main river channel and was intersected 7.5–8.5 mbgs along Paddy’s Transect and 8 mbgs along Old Crown Transect. The alluvial sediments were unsaturated along Maynard’s Transect indicating that the alluvial aquifer does not locally extend upstream of this point, however ~400 m downstream the alluvial aquifer is tapped by the existing pastoral well RN015198, which indicates that locally the edge of the alluvial aquifer is between Maynard’s Transect and RN015198.

In contrast to the alluvial aquifer, the Crown Point aquifer in the study area is a poor aquifer. The Crown Point Formation in the study area consists of variable facies and lithology, varying between heavy plastic clay/sandy clay/mudstone/diamictite, often with clasts of claystone, quartzite, sandstone and shale. The Crown Point aquifer is generally brackish to saline (average EC 12 500 µS/cm; TDS 7 300 mg/L), near-neutral (pH 6.4 to 7.7) with low oxygen conditions (DO <2.3 mg/L) and characterised by Na-Cl type water that is similar to oceanic water. Ionic ratios, ⁸⁷Sr/⁸⁶Sr isotope ratios and δ¹³C indicate that ion exchange and gypsum dissolution are the dominant hydrochemical controls on water quality in the Crown Point aquifer (Section 3.4). Age tracer data generally indicates sub-modern water in the Crown Point aquifer and increasing groundwater age with depth. Age tracer results at the northern extent of Paddy’s Transect (RT5) indicate influence from the minor ephemeral drainage channel flowing from the north-west; and results at Old Crown Transect indicate mixing of sub-modern and modern groundwaters that suggest stratified variable groundwater flow paths in the east of the study area (Section 3.4.5). The aquifer generally displayed very low permeability, with hydraulic conductivity nearly two orders of magnitude less than the alluvial aquifer and ranging from 0.001 to 0.09 m/d with an average of 0.01 m/d (Section 3.3). At Maynard’s Transect in the west groundwater was intersected adjacent to the river at 7.2 mbgs (B1A) however hydraulic testing indicated very low permeability (<0.005 m/d); groundwater was not intersected upslope of this location to a depth of 40 mbgs (B1B). At Paddy’s Transect groundwater was intersected at ~8 mbgs near the river (RT2) and >16 mBGS away from the river (RT4, RT5). At Old Crown Transect in the east groundwater was intersected at 10 mbgs away from the river (B5B).

The desktop investigation (Wohling et al. 2013) identified three wells thought to be screened in the Crown Point aquifer that displayed relatively low chloride and groundwater mounding, suggesting active modern recharge from the Finke River. Maynard’s Bore (RN015198), Paddy’s Bore (RN015949) and Peter’s Bore (RN015949) have been reassigned to or grouped with the Quaternary alluvial aquifer considering the lithology, well yield and chemical composition (Section 3.4).

The approximate extent of the alluvial aquifer in the study area has been mapped using information provided by drilling, geophysical surveys, geochemical tracers, the distribution of historical wells that have failed (Figure 4.1) and the spatial extent of riparian vegetation.

Wohling et al. 2013 (p 98) reported transient waterholes in the bed of the Finke River adjacent to Crown Point Formation outcrop near the study area. It is likely that these waterholes are temporary features associated with depressions in the underlying lower permeability Crown Point Formation that have retained water from previous flow events. If they were associated with the alluvial aquifer it is likely that they would be permanent features.
It is important to note that the hydraulic and geochemical properties of the Crown Point aquifer on the margin of the Pedirka Basin in the study area may not be representative of the aquifer deeper in the basin. Permeability in the regional Crown Point aquifer is reported to range 0.08–3 m/d (Wohling et al. 2013; Fulton et al. 2013). The literature also refers to a coarse grained sandstone unit that marks the top of the Crown Point Formation (summarised in Munson and Ahmad 2013) which is equivalent to the Tirrawarra Sandstone in the Cooper Basin (Figure 1.1). It is considered that the Crown Point Formation in the study area generally consists of lower permeability fine-grained basal units and such overlying coarse-grained units of higher permeability have eroded away.

4.2 Groundwater recharge

The geochemical composition and hydraulic characteristics of the alluvial aquifer are consistent with open system conditions and modern recharge via ephemeral river recharge (ERR) from the Finke River. The extent of the potential recharge zone to the alluvial aquifer is shown on Figure 4.1 and was derived using information provided by drilling and geophysical surveys. The potential recharge zone begins near Maynard’s Transect and continues to the eastern boundary of the study area (Figure 4.1).

At Maynard’s Transect in the west and Paddy’s Transect in the north, groundwater elevation is generally higher near the Finke River and decreases with distance from the river, which is consistent with the Finke River acting as a recharge source to the alluvial aquifer. The groundwater gradient at Old Crown Transect in the east is relatively flat however it is likely that levels would decrease with distance from the river were this transect extended further to the west. The density corrected potentiometric surface for the alluvial aquifer and Crown Point aquifer near the Finke River are similar, and decrease along the river channel from ~263 m AHD in the west to ~251 m AHD in the east. The groundwater table in both aquifers is at a similar elevation to the base of the Finke River resulting in minimal unsaturated zone and limited storage capacity for large flood events.

The stable isotope ($\delta^{2}H$ and $\delta^{18}O$) signature of groundwaters in the study area indicates minimal evaporation during recharge, which in this arid environment is consistent with a rapid recharge mechanism. The unsaturated zone in the alluvial aquifer consists of only a few metres and the aquifer extent in the study area is generally less than a kilometre from the river, resulting in limited storage capacity. Whilst it is likely that rare, large rainfall events result in recharge to the alluvial aquifer, the relatively enriched isotope signature of groundwaters suggests that the dominant recharge mechanism is associated with smaller more frequent rainfall events of less than 50 mm/month (Section 3.4.3). Considering that the stable isotope signature is similar in both aquifers, yet there is a disparity in age, it is likely that during flood events in the Finke River the head in the alluvial aquifer is increased resulting in a small downward flux to the underlying Crown Point aquifer.

Density corrected hydraulic heads at the nested piezometer site (RT2) indicated the potential for upward vertical flux from the Crown Point aquifer to the alluvial aquifer at the time of sampling (Section 3.5.1), however the vertical gradient is small and it is likely that temporally there is a downward gradient to the Crown Point aquifer following flood events in the Finke River. The long term flux to the alluvial aquifer and Crown Point aquifer was estimated using Carbon-14 derived groundwater recharge estimates (Section 3.5.2). Recharge rates ranged from 2.45 to 34.08 mm/y to the alluvial aquifer, and 0.13 to 8.55 mm/y to the Crown Point aquifer. Further work could be undertaken to characterise the extent of the sandstone units within the Crown Point Formation adjacent to the Finke River, as these may represent areas of greater recharge to the Crown Point aquifer.

Current knowledge suggests that the sandstone unit encountered at Peter’s Bore is discreet and not continuous.

A volumetric recharge estimate for the Crown Point aquifer would typically be calculated using the surface area of the overlying alluvial aquifer. Results of the current investigation suggest that the extent of alluvial aquifer is 17–18 km², however this would need to be confirmed with further drilling and/or geophysical transects before a total recharge volume could be estimated with confidence.

The Crown Point aquifer was previously thought to have been recharged via ERR from the Finke River (Wohling et al. 2013). Hydraulic and geophysical data indicate that the permeability of the Crown Point aquifer in the study area is generally too low to facilitate ERR. Further, potential storage capacity is limited as the watertable is at a similar elevation to the base of the river, resulting in low potential for lateral flow. The results of the investigation indicate that modern recharge to the Crown Point aquifer via ERR is negligible relative to the connection between the Finke River and the alluvial aquifer.
Figure 4.1 Approximate extent of alluvial aquifer and potential recharge zone extent
5 Conclusions

The study employed geochemical, hydraulic and geophysical techniques to characterise recharge mechanisms to the Crown Point aquifer and its connection to the Finke River.

The key findings in relation to the specific study objectives are:

Objective: Improve the hydrogeological understanding of the aquifer systems and their connection to the Finke River.

The drilling program and ground penetrating EM-34 geophysical surveys identified two geological units in the study area that form aquifers: the glaciofluvial to periglacial Crown Point Formation; and overlying Quaternary alluvial sediments associated with the Finke River. The Crown Point Formation in the study area forms a poor aquifer that is generally characterised by high salinity and very low permeability. Conversely, the overlying alluvial aquifer consists of permeable sediments and relatively fresh groundwater, however its extent is limited to within a few kilometres of the Finke River and is broadly delineated by the limit of riparian vegetation visible on satellite imagery.

Near the Finke River the potentiometric surface in both aquifers is at a similar elevation to the base of the river resulting in limited storage capacity for large flood events and low vertical hydraulic gradient between the aquifer systems.

Objective: Characterise recharge mechanisms to the Crown Point and/or other aquifers.

The investigation did not identify modern recharge to the Crown Point aquifer via ephemeral river recharge (ERR) from the Finke River, owing to low permeability and limited storage capacity in the formation. Modern recharge via ERR is restricted to the overlying alluvial aquifer and is associated with smaller flow events in the Finke River. Further, hydraulic connection between the Crown Point aquifer and the overlying alluvial aquifer is minor owing to the characteristics of the Crown Point aquifer and low driving gradient.

Objective: Define the spatial extent of the recharge zone to the Crown Point and/or other aquifers.

The extent of the potential recharge zone to the alluvial aquifer begins near Maynard’s Transect and continues to the eastern boundary of the study area (Figure 4.1). Results of the current investigation suggest that the extent of alluvial aquifer is 17–18 km², however this would need to be confirmed with further drilling and/or geophysical transects to increase confidence. As the Crown Point aquifer is recharged via downward vertical flux from the overlying alluvial aquifer, the extent of the recharge zone to the Crown Point aquifer is approximated by the extent of the alluvial aquifer.

Objective: Estimate recharge rates where sufficient data is available.

The long term flux to the alluvial aquifer and Crown Point aquifer was estimated using carbon-14 derived groundwater recharge estimates. Recharge estimates ranged from 2.45 to 34.08 mm/y to the alluvial aquifer, and 0.13 to 8.55 mm/y to the Crown Point aquifer.
6 Appendices
## A. Groundwater data

Table 6.1 Piezometer and existing well details

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Q = Quaternary alluvial sediments  
Cp = Crown Point aquifer  
UKN = Unknown  
NIU = Not in use  
BKF = Backfilled  
ABD = Abandoned  
USE = In use  
MON = Monitoring  
STK = Stock  
DTW = Depth to water, not density corrected.  
* = Dry in 1991

^stratigraphically Peter’s Bore accesses a discrete sandstone unit of the Crown Point Formation, however has been grouped as alluvial aquifer as per the discussion in Section 3.4.
Table 6.2  Groundwater hydrochemistry data

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<td>Na</td>
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DEWNR FRII: DEWNR Finke River Recharge Investigation 2014
DEWNR PB GWI: DEWNR Pedirka Basin Groundwater Investigation 2012
NTWRBd: Northern Territory Water Resource Branch database

IAPSO standard seawater

Table 6.3  Results for stable isotopes ($\delta^{2}H$ and $\delta^{18}O$) and strontium isotope ratios ($^{87}Sr/^{86}Sr$)

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<thead>
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<th>Site ID</th>
<th>Site name</th>
<th>Data source</th>
<th>Aquifer</th>
<th>Date</th>
<th>$\delta^{2}H$</th>
<th>$\delta^{18}O$</th>
<th>$^{87}Sr/^{86}Sr$</th>
<th>error (±)</th>
<th>Sr mg/L</th>
<th>1/Sr</th>
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<td>DEWNR FRRI</td>
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<tr>
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<td>DEWNR FRRI</td>
<td>Cp</td>
<td>26/10/2014</td>
<td>-55.52</td>
<td>-8.11</td>
<td>0.71868</td>
<td>1E-6</td>
<td>1.55</td>
<td>0.65</td>
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<td>RN019068</td>
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<td>DEWNR FRRI</td>
<td>Cp</td>
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<td>0.31</td>
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<td>Cp</td>
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<td>4.09</td>
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<td>Cp</td>
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<td>DEWNR FRRI</td>
<td>Cp</td>
<td>DRY</td>
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<td>DEWNR FRRI</td>
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<td>25/10/2014</td>
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Q  Quaternary alluvial sediments
Cp  Crown Point aquifer
DEWNR FRRI  DEWNR Finke River Recharge Investigation 2014
DEWNR PB GWI  DEWNR Pedirka Basin Groundwater Investigation 2012
^stratigraphically Peter’s Bore accesses a discrete sandstone unit of the Crown Point Formation, however has been grouped as alluvial aquifer as per the discussion in Section 3.4.
Table 6.4  Results for carbon (C) isotopes

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<th>$\delta^{14}$C (%)</th>
<th>$\delta^{14}$C error (±)</th>
<th>pmC (%)</th>
<th>pmC error (±)</th>
<th>Maximum apparent uncorrected reported $^{14}$C age (years BP)</th>
<th>Age error (±)</th>
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* $\delta^{13}$C has a reported error ±0.2.
Q  Quaternary alluvial sediments
Cp  Crown Point aquifer
DEWNR FRRI  DEWNR Finke River Recharge Investigation 2014
DEWNR PB GWI  DEWNR Pedirka Basin Groundwater Investigation 2012

^stratigraphically Peter's Bore accesses a discrete sandstone unit of the Crown Point Formation, however has been grouped as alluvial aquifer as per the discussion in Section 3.4.
Table 6.5 Results for chlorofluorocarbons (CFCs)

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<th>Date</th>
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<th>CFC-12 error (±)</th>
<th>Lab note</th>
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<td>Close to detection limit – not much young water</td>
</tr>
<tr>
<td>RN015198</td>
<td>Maynard’s Bore</td>
<td>DEWNR PB GWI</td>
<td>Q</td>
<td>4/12/2012</td>
<td>16.000</td>
<td>-</td>
<td>36.000</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>RN015949</td>
<td>Peter’s Bore</td>
<td>DEWNR PB GWI</td>
<td>Cp^</td>
<td>4/12/2012</td>
<td>7.500</td>
<td>-</td>
<td>44.000</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>RN015950</td>
<td>Paddy’s Bore</td>
<td>DEWNR PB GWI</td>
<td>Q</td>
<td>4/12/2012</td>
<td>1.000</td>
<td>-</td>
<td>9.000</td>
<td>-</td>
<td></td>
</tr>
</tbody>
</table>

Q Quaternary alluvial sediments
Cp Crown Point aquifer
DEWNR FRRI DEWNR Finke River Recharge Investigation 2014
DEWNR PB GWI DEWNR Pedirka Basin Groundwater Investigation 2012

^Stratigraphically Peter’s Bore accesses a discrete sandstone unit of the Crown Point Formation, however has been grouped as alluvial aquifer as per the discussion in Section 3.4.
### Table 6.6 Saturation indices, PhreeQC geochemical modelling outputs

<table>
<thead>
<tr>
<th>Site ID</th>
<th>Site name</th>
<th>Calculated EC (µS/cm)</th>
<th>Calculated ion balance (%)</th>
<th>Calcite (CaCO$_3$)</th>
<th>Dolomite (CaMg(CO$_3$)$_2$)</th>
<th>Gypsum (CaSO$_4$·2H$_2$O)</th>
<th>Halite (NaCl)</th>
<th>Sylvite (KCl)</th>
</tr>
</thead>
<tbody>
<tr>
<td>RN019066</td>
<td>RT1</td>
<td>820</td>
<td>-7.65</td>
<td>0.54</td>
<td>0.93</td>
<td>-2.26</td>
<td>-6.71</td>
<td>-7.49</td>
</tr>
<tr>
<td>RN019067</td>
<td>RT2</td>
<td>7053</td>
<td>-7.57</td>
<td>0.22</td>
<td>0.66</td>
<td>-0.91</td>
<td>-4.39</td>
<td>-5.59</td>
</tr>
<tr>
<td>RN019068</td>
<td>RT2B</td>
<td>13500</td>
<td>-5.48</td>
<td>0.4</td>
<td>1.15</td>
<td>-0.56</td>
<td>-3.88</td>
<td>-5.04</td>
</tr>
<tr>
<td>RN019069</td>
<td>RT2C</td>
<td>921</td>
<td>-5.46</td>
<td>0.64</td>
<td>1.24</td>
<td>-2.05</td>
<td>-6.4</td>
<td>-7.13</td>
</tr>
<tr>
<td>RN019070</td>
<td>RT3</td>
<td>845</td>
<td>-5.49</td>
<td>0.58</td>
<td>1.07</td>
<td>-2.11</td>
<td>-6.56</td>
<td>-7.21</td>
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<tr>
<td>RN019071</td>
<td>RT4</td>
<td>14077</td>
<td>-2.13</td>
<td>0.67</td>
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<td>-0.55</td>
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<td>-5.02</td>
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<td>-5.24</td>
</tr>
<tr>
<td>RN019073</td>
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<td>14303</td>
<td>-5.9</td>
<td></td>
<td></td>
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</tr>
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<td>RN019075</td>
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<tr>
<td>RN000507</td>
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<tr>
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<td>Maynard’s Bore</td>
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<td>-1.97</td>
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<tr>
<td>RN012397</td>
<td>Old Crown Well New</td>
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<td>RN015949</td>
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<tr>
<td>RN015950</td>
<td>Paddy’s Bore</td>
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<td>-2.15</td>
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<tr>
<td>SW-FR-FC</td>
<td>Finke River surface water</td>
<td>508</td>
<td>3.88</td>
<td>-0.55</td>
<td>-1.45</td>
<td>-2.31</td>
<td>-7.19</td>
<td>-7.54</td>
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<tr>
<td>SW-FR-NC</td>
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<td>-1.34</td>
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<td>-7.73</td>
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<tr>
<td>SW-FR-OCC</td>
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<td>-2.28</td>
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<td>SW-FR-SH</td>
<td>Finke River surface water</td>
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<td>-2.84</td>
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<td>New Crown Rain</td>
<td>Rainfall</td>
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<td>-3.95</td>
<td>-4.07</td>
<td>-10.49</td>
<td>-10.22</td>
</tr>
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</table>

DEWNR Technical report 2015/06
### Table 6.7  Density corrected hydraulic heads

<table>
<thead>
<tr>
<th>Site ID</th>
<th>Site name</th>
<th>Laboratory EC (µS/cm)</th>
<th>Surface elevation (m AHD)</th>
<th>Mid-screen (m)</th>
<th>Total depth (m)</th>
<th>Field measured DTW (m)</th>
<th>Field measured head (m AHD)</th>
<th>Density corrected head (m AHD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>RN019066</td>
<td>RT1</td>
<td>740</td>
<td>265.03</td>
<td>13.5</td>
<td>16</td>
<td>7.46</td>
<td>257.57</td>
<td>257.56</td>
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<tr>
<td>RN019067</td>
<td>RT2A</td>
<td>6400</td>
<td>265.47</td>
<td>25</td>
<td>29</td>
<td>8.01</td>
<td>257.46</td>
<td>257.47</td>
</tr>
<tr>
<td>RN019068</td>
<td>RT2B</td>
<td>12000</td>
<td>265.38</td>
<td>36.5</td>
<td>39</td>
<td>8.39</td>
<td>256.99</td>
<td>257.09</td>
</tr>
<tr>
<td>RN019069</td>
<td>RT2C</td>
<td>810</td>
<td>265.39</td>
<td>17.5</td>
<td>20</td>
<td>7.94</td>
<td>257.45</td>
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<tr>
<td>RN019070</td>
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<td>740</td>
<td>265.86</td>
<td>14.5</td>
<td>17</td>
<td>8.54</td>
<td>257.33</td>
<td>257.31</td>
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<tr>
<td>RN019071</td>
<td>RT4</td>
<td>14520</td>
<td>270.96</td>
<td>23.9</td>
<td>26.4</td>
<td>16.27</td>
<td>254.70</td>
<td>254.73</td>
</tr>
<tr>
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<td>RT5</td>
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<td>26.5</td>
<td>29</td>
<td>17.25</td>
<td>250.70</td>
<td>250.72</td>
</tr>
<tr>
<td>RN019073</td>
<td>B1A</td>
<td>13000</td>
<td>269.88</td>
<td>15.5</td>
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<td>7.16</td>
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<td>262.75</td>
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<tr>
<td>RN019075</td>
<td>B5A</td>
<td>1200</td>
<td>259.49</td>
<td>13.75</td>
<td>18</td>
<td>8.09</td>
<td>251.40</td>
<td>251.39</td>
</tr>
<tr>
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<td>B5B</td>
<td>28000</td>
<td>261.79</td>
<td>14.5</td>
<td>17</td>
<td>10.06</td>
<td>251.73</td>
<td>251.78</td>
</tr>
</tbody>
</table>

**New piezometers**

**Existing wells**

RN002012  | Old Crown Well | 6000 | 265.70 | 12  | 14.5 | 12.8 | 252.90 | 252.90
RN004634  | A24/5         | 13600 | 266.40 | 12.5 | 15 | 4.9 | 261.50 | 261.53
RN015198  | Maynard’s Bore | 1220 | 273.60 | 17.5 | 20 | 4.9 | 268.70 | 268.68
RN012397  | Old Crown Well New | 15300 | 265.50 | 20.4 | 22.9 | 7.6 | 257.88 | 257.95
RN015949  | Peter’s Bore  | 900  | 267.20 | 30.6 | 33.1 | 6.6 | 260.60 | 260.55
RN015950  | Paddy’s Bore  | 840  | 269.50 | 17.5 | 20 | 7.0 | 262.50 | 262.48

Groundwater level measurements in new piezometers were taken prior to slug tests 09–13/09/2014. DTW measurements for existing wells are less reliable as data predates 1992. Corrected heads calculated using Equation 2 where density as a function of temperature = 996.7 kg/m³ and A=0.757 and B=-0.0042, \( pf = 999 \text{ kg/m}^3 \) and \( pi = 997.3 – 1003.8 \text{ kg/m}^3 \). Calculations for existing wells used field measured EC.
B. Well logs

Notes:

- bgl: Below ground level
- l/s: Litres per second

No drill cuttings displayed reaction to the field acid test.

Groundwater level measurements were taken prior to slug tests 09–13/09/2014 and corrected for density effects as described in Section 2.7.1
<table>
<thead>
<tr>
<th>Depth (metres)</th>
<th>Lithology</th>
<th>Gamma (cps)</th>
<th>Remarks</th>
<th>Well Construction Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Sand, yellowish red (5YR 4/6), fine grained, well sorted, sub-rounded to sub-angular, quartz sand.</td>
<td></td>
<td>Hollow augers 203 mm to 20.2 m.</td>
<td>80 mm Class 12 PVC Casing to 16 m</td>
</tr>
<tr>
<td>6</td>
<td>Thin clay layer at 6 m (5YR 3/4).</td>
<td></td>
<td></td>
<td>Cement 0 - 5 m</td>
</tr>
<tr>
<td>7.6 - 10</td>
<td>Thin cemented white sandstone layers.</td>
<td></td>
<td>Moist from ~7 m.</td>
<td>Bentonite 6.6 - 7 m</td>
</tr>
<tr>
<td>10</td>
<td>No returns.</td>
<td></td>
<td>Saturated from 10 m.</td>
<td>Collapse 7 - 16 m</td>
</tr>
<tr>
<td>12 - 15</td>
<td>Drillhole collapsed to 12 m after drilling. Reamed out using hollow augers with mud injection.</td>
<td>Screen (machine cut 0.5 mm) 12 - 15 m</td>
<td></td>
<td>Screen (machine cut 0.5 mm) 12 - 15 m</td>
</tr>
<tr>
<td>15 - 16</td>
<td></td>
<td></td>
<td>Sump 15 - 16 m</td>
<td></td>
</tr>
</tbody>
</table>

**Pedirka Basin Groundwater Study**

**Finke River Recharge Investigation**

**Site ID:** RT1  **Well ID:** RN019066

**Location:** Lilla Creek Station  **Logged By:** S Fulton  **Date Completed:** 07/08/2014

**Easting:** 7182915  **Nording:** 435013  **Elevation:** 265.03  **Date Completed:** 07/08/2014

**TOTAL DEPTH (m):** 20.2  **CONSTRUCTED DEPTH (mBGL):** 16  **CASING HEIGHT (m):** 0.23

**STANDING WATER LEVEL (mbgl):** 7.47  **SALINITY (μS/cm):** 1000  **ESTIMATED YIELD (l/s):** 0.1

**LITHOLOGY WELL CONSTRUCTION DETAILS**

<table>
<thead>
<tr>
<th>Depth (metres)</th>
<th>Lithology</th>
<th>Remarks</th>
<th>Well Construction Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Sand, yellowish red (5YR 4/6), fine grained, well sorted, sub-rounded to sub-angular, quartz sand.</td>
<td>Hollow augers 203 mm to 20.2 m.</td>
<td>80 mm Class 12 PVC Casing to 16 m</td>
</tr>
<tr>
<td>6</td>
<td>Thin clay layer at 6 m (5YR 3/4).</td>
<td></td>
<td>Cement 0 - 5 m</td>
</tr>
<tr>
<td>7.6 - 10</td>
<td>Thin cemented white sandstone layers.</td>
<td>Moist from ~7 m.</td>
<td>Bentonite 6.6 - 7 m</td>
</tr>
<tr>
<td>10</td>
<td>No returns.</td>
<td>Saturated from 10 m.</td>
<td>Collapse 7 - 16 m</td>
</tr>
<tr>
<td>12 - 15</td>
<td>Drillhole collapsed to 12 m after drilling. Reamed out using hollow augers with mud injection.</td>
<td>Screen (machine cut 0.5 mm) 12 - 15 m</td>
<td>Sump 15 - 16 m</td>
</tr>
</tbody>
</table>
SAND, yellowish red (5YR 4/6), fine grained, well rounded, well sorted, quartz, trace of sub-angular sandstone (grey).

~4 m thin band clay loam, dark reddish brown (5YR 3/4).

From 7 m fine to medium grained.

From 12 m medium to coarse grained with trace granule size angular quartz (< 5 mm).

SANDY CLAY, grey (10YR 5/1), medium to coarse grained, well rounded, well sorted, trace of cemented sandstone.

From 21 m, ~25% coarse grained sub-angular quartz sand.
SAND, yellowish red (5YR 4/6), fine grained, well rounded, well sorted, quartz, trace of sub-angular sandstone (grey).

~4 m thin band clay loam, dark reddish brown (5YR 3/4).

From 7 m fine to medium grained.

From 12 m medium to coarse grained with trace granule size angular quartz (< 5 mm).

SANDY CLAY, grey (10YR 5/1), medium to coarse grained, well rounded, well sorted, trace of cemented sandstone.

From 21 m, ~25% coarse grained sub-angular quartz sand.

~14 m harder bands.

~17 m harder band.

~19 m hard band.

~24 m hard band.
SAND, yellowish red (5YR 4/6), fine grained, well rounded, well sorted, quartz, trace of sub-angular sandstone (grey).

~4 m thin band clay loam, dark reddish brown (5YR 3/4).

From 7 m fine to medium grained.

From 12 m medium to coarse grained with trace granule size angular quartz (< 5 mm).

SANDY CLAY, grey (10YR 5/1), medium to coarse grained, well rounded, well sorted, trace of cemented sandstone.

~14 m harder bands.

~17 m harder band.

Hollow augers 200 mm to 20.03 m.

Moist from ~8 m. Injecting water from ~9 m to lift cuttings.

80 mm Class 12 PVC Casing to 20 m

Cement 0 - 5 m

Bentonite 5 - 7 m

Collapse 7 - 20 m

Screen (machine cut 0.5 mm) 16 - 19 m

Sump 19 - 20 m
**Pedirka Basin Groundwater Study**

**Finke River Recharge Investigation**

**Site ID:** RT3  **Well ID:** RN019070

**LITHOLOGY**

<table>
<thead>
<tr>
<th>Depth (metres)</th>
<th>Formation</th>
<th>Lithology</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td></td>
<td>SAND, yellowish red (5YR 5/6), very fine grained, well rounded, well sorted.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SANDY CLAY, dark reddish brown (5YR 3/4).</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SAND, brown (7.5YR 4/4), fine grained, well rounded, well sorted, quartz.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SANDY CLAY, dark reddish brown (5YR 3/4).</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SAND, brown (7.5YR 4/4), rounded to sub-angular, well sorted.</td>
</tr>
</tbody>
</table>

**GAMMA (cps)**

- Hollow augers 203 mm to 17.8 m.

**REMARKS**

- Hollow augers 203 mm to 17.8 m.

**WELL CONSTRUCTION DETAILS**

- 80 mm Class 12 PVC Casing to 17 m.
- Cement 0 - 5 m.
- Bentonite 6 - 8 m.
- Collapse 8 - 17 m.
- Screen (machine cut 0.5 mm) 13 - 16 m.
- Sump 16 - 17 m.

**Well Construction Details**

- **DEPTH (metres):**
  - 0
  - 10
  - 20
  - 30
  - 40

- **LITHOLOGY:**
  - SAND, yellowish red (5YR 5/6), very fine grained, well rounded, well sorted.
  - SANDY CLAY, dark reddish brown (5YR 3/4).
  - SAND, brown (7.5YR 4/4), fine grained, well rounded, well sorted, quartz.
  - SANDY CLAY, dark reddish brown (5YR 3/4).
  - SAND, brown (7.5YR 4/4), rounded to sub-angular, well sorted.

- **GAMMA (cps):**
  - Hollow augers 203 mm to 17.8 m.

- **REMARKS:**
  - Hollow augers 203 mm to 17.8 m.

- **WELL CONSTRUCTION DETAILS:**
  - 80 mm Class 12 PVC Casing to 17 m.
  - Cement 0 - 5 m.
  - Bentonite 6 - 8 m.
  - Collapse 8 - 17 m.
  - Screen (machine cut 0.5 mm) 13 - 16 m.
  - Sump 16 - 17 m.
**LITHOLOGY**

- **Quaternary**: Sandwich Creek Gravel, yellowish red (5YR 5/6), fine grained, well rounded.
- **Mudstone, light grey (7.5YR 7/1)**, trace of fine sand, consolidated.
- **Mudstone, dark yellowish brown (10YR 4/6)**.
- **Clay, yellowish brown (10YR 5/6)**.
- **Mudstone, dark yellowish brown (10YR 4/6)**.

**REMARKS**

- Hollow augers 203 mm to 8 m.
- Refusal at 8 m. Switch to air rotary 165 mm to 26.5 m.
- Injecting water from 12 m.

**WELL CONSTRUCTION DETAILS**

- **80 mm Class 12 PVC Casing to 26.4 m**
- **Cement 0 - 5 m**
- **Bentonite 10 - 12.2 m**
- **Gravel 12.2 - 26.4 m**
- **Screen (machine cut 0.5 mm) 22.4 - 25.4 m**
- **Sump 25.4 - 26.4 m**
SAND, red (2.5YR 5/8), fine grained, well rounded, well sorted.

SANDY CLAY, yellowish red (5YR 5/6), medium grained, well rounded.

Trace of grey mudstone from 8 - 10 m.

~14 m very thin bands clayey sand, dark red (2.5YR 3/8), fine to medium grained, well rounded.

DIAMICTITE, matrix of yellowish red (5YR 5/6) sandy clay, clasts of light grey claystone, white, grey and orange quartzite, ferruginised hard sandstone.

Air rotary
165 mm to 29.2 m.

8.1 - 10 m harder bands.

Softer drilling.

Hard drilling.

Some rig shudder on harder bands.
SAND, yellowish red (5YR 5/8), fine grained, angular to sub-rounded.

DIAMICTITE, matrix of yellowish red (5YR 5/6) sandy clay, clasts of grey and brown claystone, white and orange quartzite, ferruginised hard sandstone, cemented white sandstone.

SAND, yellowish red (5YR 5/6), fine to medium grained, rounded.

DIAMICTITE, matrix of dark red brown (5YR 3/2) heavy clay, plastic, clasts of grey and brown claystone, white and orange quartzite, ferruginised hard sandstone, cemented white sandstone.

Hollow augers 203 mm to 18 m.

Injecting water 3 – 4 m.

Moist from ~7 m. Very hard drilling, 2 m/hour, water injected.

EOH on refusal at 18 m.

80 mm Class 12 PVC Casing to 18 m

Cement 0 – 5.5 m

Gravel 5.5 – 18 m

Screen (machine cut 0.5 mm) 14 – 17 m

Sump 17 – 18 m
**LITHOLOGY**

<table>
<thead>
<tr>
<th>Depth (m)</th>
<th>Formation</th>
<th>Lithology Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Diamicrite</td>
<td>Matrix of dark reddish brown (SYR 3/4) silty clay, clasts of grey mudstone.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Diamicrite, matrix of dark reddish brown (SYR 3/4) light clay, clasts of white and grey quartzite, thin bands of weathered light grey claystone throughout.</td>
</tr>
</tbody>
</table>

**REMARKS**

- Air rotary 165 mm to 40 m.
- Soft drilling.
- Watertable not intersected.

**WELL CONSTRUCTION DETAILS**

- Drillhole backfilled and plugged with cement.
SAND, dark red (2.5YR 4/6), fine grained, well rounded, well sorted, dry.

SAND, reddish yellow (5YR 6/6), fine grained, sub-angular, quartz.

~9 m thin band of soft grey claystone.

DIAMICTITE, matrix of reddish yellow (5YR 5/6) sand, clasts of grey and white quartzite, ferruginised hard sandstone, cemented white sandstone, conglomerate, grey shale.

Air rotary
165 mm to 24 m. Horizon changes not clear.

Moist from ~8 m.

~14 m harder band.

Hard drilling from 18 m.

80 mm Class 12 PVC Casing to 18 m
Cement 0 - 7 m
Collapse 7 - 18 m
Screen (machine cut 0.5 mm) 10.5 - 13.5 m
80 mm Class 12 PVC Casing to 13.5 - 14 m
Screen (machine cut 0.5 mm) 14 - 17 m
Sump 17 - 18 m
Collapse 18 - 24 m

Pedirka Basin Groundwater Study
Finke River Recharge Investigation
Site ID: B5A
Well ID: RN019075

NORTHING: 717649
EASTING: 439946
ELEVATION: 259.49
LOCATION: Lilla Creek Station
DRILLER: Drilling Solutions
LOGGED BY: M Hancock
DATE COMPLETED: 19/08/2014
TOTAL DEPTH (m): 24
CONSTRUCTED DEPTH (mBGL): 18
CASING HEIGHT (m): 0.33
STANDING WATER LEVEL (mbgl): 8.1
SALINITY (μS/cm): 1000
ESTIMATED YIELD (l/s): 0.2
**LITHOLOGY**

- **DEPTH (metres):** 0
  - **Formation:** Quaternary
  - **LITHOLOGY:** SAND, light red (2.5YR 6/8), fine grained, well rounded, dry.

- **DEPTH (metres):** 10
  - **Formation:** Crown Point
  - **LITHOLOGY:** SANDY CLAY, dark red (2.5YR 3/6), quartz sand fine to medium grained, well rounded.

- **DEPTH (metres):** ~6 m and 8 m thin band soft reddish brown claystone.

- **DEPTH (metres):** 20
  - **LITHOLOGY:** CLAYEY SAND, dark red (2.5YR 3/6), fine grained, rounded.

- **DEPTH (metres):** ~10 m moist.

**REMARKS**

- **Air rotary 165 mm to 18 m.**
- **-10 m moist. Injecting water from 10 m.**
- **EOH on refusal at 18 m.**

**WELL CONSTRUCTION DETAILS**

- **100 mm Class 12 PVC Casing to 17 m**
- **Cement 0 - 5 m**
- **Bentonite 9 - 11 m**
- **Gravel 11 - 17 m**
- **Screen (machine cut 0.5 mm) 13 - 16 m**
- **Sump 16 - 17 m**
- **Collapse 17 - 18 m**
C. Drillers logs and completion records
**THE NORTHERN TERRITORY OF AUSTRALIA**  
**APPROVED FORM 21 (25/01/2011)**  
**STATEMENT OF BORE**  
*As per Water Regulations (2009)*

| Name of Owner: | LILLA CREEK STATION |
| Location/Address: | FINKE RIVER |
| Registration No.: | RN019073 |
| BC Permit No.: | NOT REQUIRED |
| Intended Use: | MONITORING |

**GPS Location:**  
Zone: GDA94  
Other: Specify  
Easting: 436861  
Northing: 7184762

<table>
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<tr>
<th>From</th>
<th>To</th>
<th>Particulars of Strata</th>
<th>Name of Drilling Company:</th>
<th>DRILLING SOLUTIONS</th>
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</thead>
<tbody>
<tr>
<td>0</td>
<td>4</td>
<td>RED SANDS</td>
<td>Name of Driller:</td>
<td>JASON KIRK</td>
</tr>
<tr>
<td>4</td>
<td>10</td>
<td>LIGHT RED SANDY SOIL</td>
<td>Name of supervising driller:</td>
<td>MICHAEL SOUTHBY</td>
</tr>
<tr>
<td>10</td>
<td>12</td>
<td>OFFF WHITE SANDY SOIL</td>
<td>Date Commenced:</td>
<td>10/08/2014</td>
</tr>
<tr>
<td>12</td>
<td>20</td>
<td>COURSE GRAVEL</td>
<td>Date Completed:</td>
<td>10/08/2014</td>
</tr>
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</table>

**Depth Drilled:** 20 (m)  
**Completion Depth:** 20 (m)

**METHOD OF DRILLING:**  
Other  
Auger  
Rev. Circ.  
Rotary Air  
Rotary Mud

**Specify:**

**HOLE DIAMETER**  
<table>
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<tr>
<th>From (m)</th>
<th>To (m)</th>
<th>Dia. (mm)</th>
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<tbody>
<tr>
<td>0</td>
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<td>NONE</td>
</tr>
<tr>
<td>1.9</td>
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<td>NONE</td>
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**PARTICULARS OF CASING**  
<table>
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<th>From</th>
<th>To</th>
<th>Dia (ID)</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5m</td>
<td>2m</td>
<td>219mm</td>
<td>STEEL</td>
</tr>
<tr>
<td>.4m</td>
<td>13m</td>
<td>80mm</td>
<td>PVC</td>
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**PARTICULARS OF PERFORATIONS OR SCREEN STRINGS**  
<table>
<thead>
<tr>
<th>From</th>
<th>To</th>
<th>Dia (ID)</th>
<th>Aperture</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>13</td>
<td>20</td>
<td>80mm</td>
<td>0.5mm</td>
<td>PVC</td>
</tr>
</tbody>
</table>

**Casing Suspended:** Yes  
**Method:**  
**Height of Casing above GL:** 0.3m

<table>
<thead>
<tr>
<th>Top of Packer Set at:</th>
<th>(m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length of Packer:</td>
<td>(m)</td>
</tr>
</tbody>
</table>

**Method of Packer Connection:**  

**CEMENTING/GRAVEL PACKING**  
<table>
<thead>
<tr>
<th>From</th>
<th>To</th>
<th>Type</th>
<th>Depth (m)</th>
<th>Yield (L/s)</th>
<th>SWL (m)</th>
<th>Duration (hr)</th>
<th>Quality</th>
<th>EC</th>
<th>pH</th>
<th>Bottle No.</th>
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</thead>
<tbody>
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<td></td>
<td>0.05</td>
<td>-7.48</td>
<td></td>
<td>TBC</td>
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<td></td>
</tr>
<tr>
<td>12</td>
<td>20</td>
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<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>10</td>
<td>BENTONITE</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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**WATER BEARING BEDS**  
<table>
<thead>
<tr>
<th>STRATA / WATER SAMPLES</th>
<th>Completion Yield:</th>
<th>Method:</th>
<th>Duration:</th>
<th>Bottle No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Completion SWL from GL:</td>
<td>-7.48</td>
<td>AILIFT</td>
<td>1 HOUR</td>
<td>13</td>
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</table>

<table>
<thead>
<tr>
<th>STRATA / WATER SAMPLES</th>
<th>Completion SWL from GL:</th>
<th>Method:</th>
<th>Duration:</th>
<th>Bottle No.</th>
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</thead>
<tbody>
<tr>
<td>Left at:DEWNR</td>
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<td></td>
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</table>

**NOTE:** No company advertising is to be imprinted on this certificate apart from where requested.
**LOCATION SKETCH OF BORE**  RN: RN019073

<table>
<thead>
<tr>
<th>NW</th>
<th>North</th>
<th>NE</th>
</tr>
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<tbody>
<tr>
<td>West</td>
<td>East</td>
<td></td>
</tr>
<tr>
<td>SW</td>
<td>South</td>
<td>SE</td>
</tr>
</tbody>
</table>

**LOCATION DESCRIPTION OF BORE**

**m/km**

| OF: |

**FINAL CONSTRUCTION STATUS**

- Capped [ ]
- Casing Pulled [ ]
- Left for Obs. [ ]
- Abandoned [ ]
- Equipped [ ]
- Backfilled [ ]
- Other [ ]

**ADDITIONAL INFORMATION ABOUT THE BORE:** *(Include any information which may assist for future reference)*

BORE WAS CAPPED WITH A STEEL LOCKABLE LID PAINTED WHITE WITH A 1m SQUARE PAD 300mm THICK

---

**FOR OFFICIAL USE ONLY**

**Name and licence number of driller:** Michael Savidge

**Signature and licence number of licensed driller:** Date: 15/8/14

**DESCRIPTION OF PROPERTY:**

- Rural [ ]
- Mineral [ ]
- Pastoral [ ]
- Reserve [ ]
- VCL [ ]
- Other [ ]

**Lease No:**

**Lot No:**

**Section No:**

**Hundred of:**

**Class of Bore:**

- Town [ ]
- Domestic [ ]
- Investigation [ ]
- Agriculture [ ]
- Mineral [ ]
- Pastoral [ ]
- Other [ ]

**Use of Bore:**

- Production [ ]
- Investigation [ ]
- Irrigation [ ]
- Observation [ ]
- Monitoring [ ]
- Roads [ ]
- None [ ]

**Grid Reference:**

- AMG [ ]
- Clarke [ ]
- Zone: [ ]
- Scale: [ ]

**Easting:**

**Northing:**

**Latitude:**

**Longitude:**

**Map Name:**

**Index Map Number:**

**Date Registered:**

**Bore Plotted on the map:** Yes [ ] No [ ]

**Dept Officer:**

**Signature:**

**Remarks:**
Name of Owner: LILLA CREEK STATION
Location/Address: FINKE RIVER
Intended Use: MONITORING

Name of Drilling Company: DRILLING SOLUTIONS
Name of Driller: JASON KIRK
Name of supervising driller MICHEAL SOUTHBY

Date Commenced: 10/08/2014
Date Completed: 10/08/2014
Depth Drilled: 29.02 (m)
Completion Depth: 29 (m)

METHOD OF DRILLING
Other Auger Rev. Circ. Rotary Air Rotary Mud

HOLE DIAMETER

<table>
<thead>
<tr>
<th>From (m)</th>
<th>To (m)</th>
<th>Dia. (mm)</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>2.1</td>
<td>280</td>
<td>NONE</td>
</tr>
<tr>
<td>1.9</td>
<td>29</td>
<td>80mm</td>
<td>NONE</td>
</tr>
</tbody>
</table>

PARTICULARS OF CASING

<table>
<thead>
<tr>
<th>From (m)</th>
<th>To (m)</th>
<th>Dia. (ID)</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
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<td>.4m</td>
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</tbody>
</table>

PARTICULARS OF PERFORATIONS OR SCREEN STRINGS

<table>
<thead>
<tr>
<th>From (m)</th>
<th>To (m)</th>
<th>Dia. (ID)</th>
<th>Aperture</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>23</td>
<td>29</td>
<td>80mm</td>
<td>0.5mm</td>
<td>PVC</td>
</tr>
</tbody>
</table>

Casing Suspended: Yes  No
Top of Packer Set at: (m)
Length of Packer: (m)
Method of Packer Connection:

Height of Casing above GL: 0.3 m

CEMENTING/GRAVEL PACKING

<table>
<thead>
<tr>
<th>From</th>
<th>To</th>
<th>Type</th>
<th>Depth (m)</th>
<th>Yield</th>
<th>SWL</th>
<th>Duration</th>
<th>Quality</th>
<th>EC</th>
<th>pH</th>
<th>Bottle No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
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<td>GROUTE</td>
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<tr>
<td>6</td>
<td>8</td>
<td>GRAVEL</td>
<td>1</td>
<td>-17.49</td>
<td>9031</td>
<td>7.15</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>5</td>
<td>6</td>
<td>BENTONITE</td>
<td>1</td>
<td>-17.49</td>
<td>9031</td>
<td>7.15</td>
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</table>

WATER BEARING BEDS

<table>
<thead>
<tr>
<th>From</th>
<th>To</th>
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<th>SWL</th>
<th>Duration</th>
<th>Quality</th>
<th>EC</th>
<th>pH</th>
<th>Bottle No.</th>
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<tr>
<td>0</td>
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<td>-17.49</td>
<td>9031</td>
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<td>GRAVEL</td>
<td>1</td>
<td>-17.49</td>
<td>9031</td>
<td>7.15</td>
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<tr>
<td>5</td>
<td>6</td>
<td>BENTONITE</td>
<td>1</td>
<td>-17.49</td>
<td>9031</td>
<td>7.15</td>
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</tbody>
</table>

STRATA / WATER SAMPLES

Completion Yield: 1
Method: AIRLIFT
Duration: 1 HOUR
Depth of Lift: 23

NOTE: No company advertising is to be imprinted on this certificate apart from where requested.
LOCATION SKETCH OF BORE RN: RN019072

<table>
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<th>NW</th>
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<th>West</th>
<th>East</th>
<th>SW</th>
<th>South</th>
<th>SE</th>
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<tbody>
<tr>
<td>OF:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

FINAL CONSTRUCTION STATUS

- Capped: [ ]
- Casing Pulled: [ ]
- Left for Obs.: [ ]
- Abandoned: [ ]
- Equipped: [ ]
- Backfilled: [ ]
- Other: [ ]

ADDITIONAL INFORMATION ABOUT THE BORE: (Include any information which may assist for future reference)
BORE WAS CAPPED WITH A STEEL LOCKABLE LID PAINTED WHITE WITH A 1m SQUARE PAD 300mm THICK

Note: The holder of the NT licence shall submit the form to the Department within 28 days of completion of any works.

I certify that the information contained above is true and correct, and that I have complied with the bore licensing requirements and conditions of the Bore Construction Permit as issued if a Bore Construction Permit was required.

Name and licence number of driller: Michael [Signature]
Signature and licence number of licensed driller: [Signature]
Date: 15/08/14

FOR OFFICIAL USE ONLY

<table>
<thead>
<tr>
<th>How Located:</th>
<th>GPS</th>
<th>TST</th>
<th>Survey</th>
<th>Hand Plotted</th>
<th>Other</th>
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</thead>
<tbody>
<tr>
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</tbody>
</table>

DESCRIPTION OF PROPERTY:

- Rural: [ ]
- Mineral: [ ]
- Pastoral: [ ]
- Reserve: [ ]
- VCL: [ ]
- Other: [ ]

- Lease No: [ ]
- Lot No: [ ]
- Hundred of: [ ]
- Section No: [ ]
- Town of: [ ]

- Class of Bore: Town [ ]
- Domestic [ ]
- Investigation [ ]
- Agriculture [ ]
- Mineral [ ]
- Pastoral [ ]
- Other [ ]

- Use of Bore: Production [ ]
- Investigation [ ]
- Irrigation [ ]
- Observation [ ]
- Monitoring [ ]
- Roads [ ]
- None [ ]

- Grid Reference: AMG [ ]
- Clark [ ]
- Zone: [ ]
- Scale: [ ]

- Easting: [ ]
- Latitude: [ ]
- Map Name: [ ]
- Northing: [ ]
- Longitude: [ ]
- Index Map Number: [ ]

Date Registered: Bore Plotted on the map? Yes [ ] No [ ]
Dept Officer: [Signature]
Remarks: [ ]
Name of Owner: LILLA CREEK STATION
Location/Address: FINKE RIVER
Intended Use: MONITORING

GPS Location: Zone: GDA94 Other: Specify:
From To Particulars of Strata
0 4 RED SANDS
4 10 LIGHT RED SANDY SOIL
10 12 OFFF WHITE SANDY SOIL
12 17.8 COURSE GRAVEL

Name of Drilling Company: DRILLING SOLUTIONS
Name of Driller: JASON KIRK
Name of supervising driller MICHAEL SOUTHBY

Date Commenced: 08/08/2014
Date Completed: 08/08/2014
Depth Drilled: 17.8 (m)
Completion Depth: 17 (m)

METHOD OF DRILLING
Other Auger Rev. Circ. Rotary Air Rotary Mud

HOLE DIAMETER
From (m) To (m) Dia. (mm) Type
0 2.1 280 NONE
1.9 17 100 NONE

PARTICULARS OF CASING
From To Dia (ID) Type
0.5m 2m 219mm STEEL
.4m 11m 100mm PVC

PARTICULARS OF PERFORATIONS OR SCREEN STRINGS
From To Dia (ID) Aperture Type
11 17 100mm 0.5mm PVC

Casing Suspended: Yes No
Top of Packer Set at: (m)
Method: Length of Packer: (m)
Height of Casing above GL: Method of Packer Connection:

0.3 m

CEMENTING/GRAVEL PACKING
From To Type
0 6 GROUTE
8 10 GRAVEL
6 8 BENTONITE

WATER BEARING BEDS
From To Yield SWL Duration Quality EC pH Bottle No.
0 6 -8.8 962 7.8

STRATA / WATER SAMPLES
Competition Yield: 1 Method: AIRLIFT Duration: 1 HOUR
Completion SWL from GL: -8.8 Depth of Lift: 11

NOTE: No company advertising is to be imprinted on this certificate apart from where requested.
**LOCATION SKETCH OF BORE**

| Locality | RN: RN019070 |

| NW | North | NE |
| West | East |  |
| SW | South | SE |

**LOCATION DESCRIPTION OF BORE**

**FINAL CONSTRUCTION STATUS**

- Capped [ ]
- Casing Pulled [ ]
- Left for Obs. [ ]
- Abandoned [ ]
- Equipped [ ]
- Backfilled [ ]
- Other [ ]

**ADDITIONAL INFORMATION ABOUT THE BORE:** *(Include any information which may assist for future reference)*

BORE WAS CAPPED WITH A STEEL LOCKABLE LID PAINTED WHITE WITH A 1m SQUARE PAD 300mm THICK

---

**Note:** The holder of the NT licence shall submit the form to the Department within 26 days of completion of any works.

I certify that the information contained above is true and correct, and that I have complied with the bore licensing requirements and conditions of the Bore Construction Permit as issued if a Bore Construction Permit was required.

Name and licence number of driller: [Blank]

Signature and licence number of licensed driller: [Blank]

Date: 15/8/14

**FOR OFFICIAL USE ONLY**

- How Located: [ ]
- GPS [ ]
- TST [ ]
- Survey [ ]
- Hand Plotted [ ]
- Other [ ]

**DESCRIPTION OF PROPERTY:**

- Rural [ ]
- Mineral [ ]
- Pastoral [ ]
- Reserve [ ]
- VCL [ ]
- Other [ ]

- Lease No: [Blank]
- Lot No: [Blank]
- Hundred of: [Blank]
- Section No: [Blank]
- Town of: [Blank]

**Class of Bore:**

- Town [ ]
- Domestic [ ]
- Investigation [ ]
- Agriculture [ ]
- Mineral [ ]
- Pastoral [ ]
- Other [ ]

**Use of Bore:**

- Production [ ]
- Investigation [ ]
- Irrigation [ ]
- Observation [ ]
- Monitoring [ ]
- Roads [ ]
- None [ ]

**Grid Reference:**

- AMG [ ]
- Clark [ ]
- Zone: [Blank]
- Scale: [Blank]

**Date Registered:**

- Bore Plotted on the map? [ ] Yes [ ] No [ ]

**Dept Officer:**

- Signature: [Blank]

**Remarks:**

[Blank]
**THE NORTHERN TERRITORY OF AUSTRALIA**
**APPROVED FORM 21 (25/01/2011)**
**STATEMENT OF BORE**
As per Water Regulations (2009)

<table>
<thead>
<tr>
<th>Name of Owner:</th>
<th>LILLA CREEK STATION</th>
<th>Registration No.:</th>
<th>RN019069</th>
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<tbody>
<tr>
<td>Location/Address:</td>
<td>FINKE RIVER</td>
<td>BC Permit No.:</td>
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<tr>
<td>Intended Use:</td>
<td>MONITORING</td>
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<table>
<thead>
<tr>
<th>GPS Location:</th>
<th>Zone: GDA94 Other: Specify:</th>
<th>Easting:</th>
<th>Northing:</th>
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<tr>
<td></td>
<td>53J</td>
<td>435130</td>
<td>7182953</td>
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</table>

<table>
<thead>
<tr>
<th>From</th>
<th>To</th>
<th>Particulars of Strata</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>4</td>
<td>RED SANDS</td>
</tr>
<tr>
<td>4</td>
<td>10</td>
<td>LIGHT RED SANDY SOIL</td>
</tr>
<tr>
<td>10</td>
<td>12</td>
<td>OFFF WHITE SANDY SOIL</td>
</tr>
<tr>
<td>12</td>
<td>20</td>
<td>COURSE GRAVEL</td>
</tr>
</tbody>
</table>

| Name of Drilling Company: | DRILLING SOLUTIONS |
| Name of Driller: | JASON KIRK |
| Name of supervising driller: | MICHAEL SOUTHBY |
| Date commenced: | 14/08/2014 |
| Date completed: | 14/08/2014 |
| Depth drilled: | 20.03 (m) |
| Completion depth: | 20 (m) |

**METHOD OF DRILLING**
- Other
- Auger
- Rev. Circ.
- Rotary Air
- Rotary Mud

**HOLE DIAMETER**
- From (m) To (m) Dia. (mm)
- Type

<table>
<thead>
<tr>
<th>From</th>
<th>To</th>
<th>Dia</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>2.1</td>
<td>280</td>
<td>NONE</td>
</tr>
<tr>
<td>1.9</td>
<td>20</td>
<td>100</td>
<td>NONE</td>
</tr>
</tbody>
</table>

**PARTICULARS OF CASING**
- From | To | Dia (ID) | Type
- 0.5m | 2m | 219mm | STEEL
- 0.4m | 14m | 100mm | PVC

<table>
<thead>
<tr>
<th>From</th>
<th>To</th>
<th>Dia (ID)</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>14</td>
<td>20</td>
<td>100mm</td>
<td>STEEL</td>
</tr>
</tbody>
</table>

**PARTICULARS OF PERFORATIONS OR SCREEN STRINGS**
- From | To | Dia (ID) | Aperture | Type

<table>
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<th>From</th>
<th>To</th>
<th>Dia (ID)</th>
<th>Aperture</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>14</td>
<td>20</td>
<td>100mm</td>
<td>0.5mm</td>
<td>STAINLESS STEEL</td>
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<table>
<thead>
<tr>
<th>From</th>
<th>To</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>6</td>
<td>GROUTE</td>
</tr>
<tr>
<td>11</td>
<td>20</td>
<td>GRAVEL</td>
</tr>
<tr>
<td>18</td>
<td>20</td>
<td>BENTONITE</td>
</tr>
</tbody>
</table>

**CEMENTING/GRAVEL PACKING**
- Depth (m) | Yield (L/s) | SWL (m) | Duration (hr) | Quality | EC | pH | Bottle No. |
<table>
<thead>
<tr>
<th></th>
<th></th>
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<th></th>
<th></th>
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</thead>
<tbody>
<tr>
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<td>7.92</td>
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</table>

**WATER BEARING BEDS**
- Strata/Water Samples: Completion Yield: 0.2 Method: AIRLIFT Duration: 1 HOUR
- Will be
- Completion SWL from GL: -8.21
- Depth of Lift: 17

**NOTE:** No company advertising is to be imprinted on this certificate apart from where requested.
LOCATION SKETCH OF BORE RN: RN019069

LOCATION DESCRIPTION OF BORE

<table>
<thead>
<tr>
<th>m/km</th>
<th>NW</th>
<th>North</th>
<th>NE</th>
<th>West</th>
<th>East</th>
<th>SW</th>
<th>South</th>
<th>SE</th>
</tr>
</thead>
</table>

OF:

FINAL CONSTRUCTION STATUS

Capped [ ]
Casing Pulled [ ]
Left for Obs. [ ]
Abandoned [ ]
Equipped [ ]
Backfilled [ ]
Other [ ]

ADDITIONAL INFORMATION ABOUT THE BORE: (Include any information which may assist for future reference)
BORE WAS CAPPED WITH A STEEL LOCKABLE LID PAINTED WHITE WITH A 1m SQUARE PAD 300mm THICK

Note: The holder of the NT licence shall submit the form to the Department within 28 days of completion of any works.

I certify that the information contained above is true and correct, and that I have complied with the bore licensing requirements and conditions of the Bore Construction Permit as issued if a Bore Construction Permit was required.

Name and licence number of driller: Michael Southby  Signature and licence number of licensed driller: SM  Date: 15/8/14

FOR OFFICIAL USE ONLY

How Located: [ ]
GPS [ ]
TST [ ]
Survey [ ]
Hand Plotted [ ]
Other [ ]

DESCRIPTION OF PROPERTY:

Rural [ ]
Mineral [ ]
Pastoral [ ]
Reserve [ ]
VCL [ ]
Other [ ]

Lease No: [ ]
Lot No: [ ]
Hundred of: [ ]
Portion No: [ ]
Section No: [ ]
Town of: [ ]

Class of Bore:

Town [ ]
Domestic [ ]
Investigation [ ]
Agriculture [ ]
Mineral [ ]
Pastoral [ ]
Other [ ]

Use of Bore:

Production [ ]
Investigation [ ]
Irrigation [ ]
Observation [ ]
Monitoring [ ]
Roads [ ]
None [ ]

Grid Reference:

Easting: [ ]
Latitude: [ ]
Zone: [ ]
Map Name: [ ]
Scale: [ ]

Northing: [ ]
Longitude: [ ]
Index Map Number: [ ]

Date Registered: Bore Plotted on the map? [ ]
Yes [] No []

Dept Officer: Signature: [ ]

Remarks:
Name of Owner: LILLA CREEK STATION
Registration No.: RN019068
Location/Address: FINKE RIVER
BC Permit No: NOT REQUIRED
Intended Use: MONITORING

GPS Location: Zone: GDA94 Other: Specify: Easting: 435130 Northing: 7182861

<table>
<thead>
<tr>
<th>From</th>
<th>To</th>
<th>Particulars of Strata</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>4</td>
<td>RED SANDS</td>
</tr>
<tr>
<td>4</td>
<td>10</td>
<td>LIGHT RED SANDY SOIL</td>
</tr>
<tr>
<td>10</td>
<td>12</td>
<td>OFFF WHITE SANDY SOIL</td>
</tr>
<tr>
<td>12</td>
<td>42</td>
<td>COURSE GRAVEL</td>
</tr>
</tbody>
</table>

Name of Drilling Company: DRILLING SOLUTIONS
Name of Driller: JASON KIRK
Name of supervising driller: MICHEAL SOUTHBY
Date Commenced: 12/08/2014
Date Completed: 13/08/2014
Depth Drilled: 42 (m)
Completion Depth: 39 (m)

METHOD OF DRILLING
Other Auger Rev. Circ. Rotary Air Rotary Mud
Specify: HOLE DIAMETER DRILLING FLUID
<table>
<thead>
<tr>
<th>From (m)</th>
<th>To (m)</th>
<th>Dia. (mm)</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>2.1</td>
<td>280</td>
<td>NONE</td>
</tr>
<tr>
<td>1.9</td>
<td>29</td>
<td>100</td>
<td>BIO-VIS</td>
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</tbody>
</table>

PARTICULARS OF CASING

<table>
<thead>
<tr>
<th>From</th>
<th>To</th>
<th>Dia (ID)</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5m</td>
<td>2m</td>
<td>219mm</td>
<td>STEEL</td>
</tr>
<tr>
<td>.4m</td>
<td>33</td>
<td>100mm</td>
<td>PVC</td>
</tr>
</tbody>
</table>

PARTICULARS OF PERFORATIONS OR SCREEN STRINGS

<table>
<thead>
<tr>
<th>From</th>
<th>To</th>
<th>Dia (ID)</th>
<th>Aperture</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>33</td>
<td>39</td>
<td>100</td>
<td>0.5mm</td>
<td>PVC</td>
</tr>
</tbody>
</table>

Casing Suspended: Yes No Top of Packer Set at: (m)
Method: Height of Casing above GL: 0.3 m
Length of Packer: (m)
Method of Packer Connection:

CEMENTING/GRAVEL PACKING

<table>
<thead>
<tr>
<th>From</th>
<th>To</th>
<th>Type</th>
<th>Depth (m)</th>
<th>Yield (L/s)</th>
<th>SWL (m)</th>
<th>Duration (hr)</th>
<th>Quality</th>
<th>EC</th>
<th>pH</th>
<th>Bottle No.</th>
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</thead>
<tbody>
<tr>
<td>0</td>
<td>6</td>
<td>GROUTE</td>
<td>0.2</td>
<td>-8.61</td>
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<td></td>
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</tr>
<tr>
<td>30</td>
<td>39</td>
<td>GRAVEL</td>
<td>15765</td>
<td>5.4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>28</td>
<td>30</td>
<td>BENTONITE</td>
<td>-8.61</td>
<td>Duration: 1 HOUR</td>
<td></td>
<td></td>
<td></td>
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<td></td>
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</table>

WATER BEARING BEDS

<table>
<thead>
<tr>
<th>Depth (m)</th>
<th>Yield (L/s)</th>
<th>SWL (m)</th>
<th>Duration (hr)</th>
<th>Quality</th>
<th>EC</th>
<th>pH</th>
<th>Bottle No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.2</td>
<td>-8.61</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

STRATA / WATER SAMPLES

Completion Yield: 0.2 Method: AIRLIFT Duration: 1 HOUR
Completion SWL from GL: -8.61 Depth of Lift: 30

NOTE: No company advertising is to be imprinted on this certificate apart from where requested.
LOCATION SKETCH OF BORE  RN: RN019068

LOCATION DESCRIPTION OF BORE

<table>
<thead>
<tr>
<th>m/km</th>
<th></th>
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</thead>
<tbody>
<tr>
<td>NW</td>
<td></td>
</tr>
<tr>
<td>North</td>
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</tr>
<tr>
<td>West</td>
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<tr>
<td>East</td>
<td></td>
</tr>
<tr>
<td>SW</td>
<td></td>
</tr>
<tr>
<td>South</td>
<td></td>
</tr>
<tr>
<td>SE</td>
<td></td>
</tr>
<tr>
<td>OF:</td>
<td></td>
</tr>
</tbody>
</table>

FINAL CONSTRUCTION STATUS

- Capped
- Casing Pulled
- Left for Obs.
- Abandoned
- Equipped
- Backfilled
- Other

ADDITIONAL INFORMATION ABOUT THE BORE: *(Include any information which may assist for future reference)*

BORE WAS CAPPED WITH A STEEL LOCKABLE LID PAINTED WHITE WITH A 1m SQUARE PAD 300mm THICK

Note: The holder of the NT licence shall submit the form to the Department within 28 days of completion of any works.

I certify that the information contained above is true and correct, and that I have complied with the bore licensing requirements and conditions of the Bore Construction Permit as issued if a Bore Construction Permit was required.

Name and licence number of driller: [Signature]

FOR OFFICIAL USE ONLY

How Located: GPS TST Survey Hand Plotted Other

DESCRIPTION OF PROPERTY:

- Rural
- Mineral
- Pastoral
- Reserve
- VCL
- Other

Lease No: Lot No: Hundred of:

Portion No: Section No: Town of:

Class of Bore: Town Domestic Investigation Agriculture Mineral Pastoral Other

Use of Bore: Production Investigation Irrigation Observation Monitoring Roads None

Grid Reference: AMG Clark Zone: Scale:

Easting: Latitude: Map Name:

Northing: Longitude: Index Map Number:

Date Registered: Bore Plotted on the map? Yes No

Dept Officer: Signature: Remarks:
**Name of Owner:** LILLA CREEK STATION  
**Location/Address:** FINKE RIVER  
**Registration No.:** RN019067  
**BC Permit No.:** NOT REQUIRED  

**Intended Use:** MONITORING  
**GPS Location:** Zone: GDA94 Other: Specify:  
Easting: 435130  
Northing: 7182840

### From To Particulars of Strata
- 0 4 RED SANDS
- 4 10 LIGHT RED SANDY SOIL
- 10 12 OFFF WHITE SANDY SOIL
- 12 29 COURSE GRAVEL

**Name of Drilling Company:** DRILLING SOLUTIONS  
**Name of Driller:** JASON KIRK  
**Name of supervising driller:** MICHEAL SOUTHBY  
**Date Commenced:** 10/08/2014  
**Date Completed:** 11/08/2014  
**Depth Drilled:** 30 (m)  
**Completion Depth:** 29 (m)

**METHOD OF DRILLING**  
Other Auger Rev. Circ. Rotary Air Rotary Mud

**Specify:**

**HOLE DIAMETER**  
<table>
<thead>
<tr>
<th>From (m)</th>
<th>To (m)</th>
<th>Dia. (mm)</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>2.1</td>
<td>280</td>
<td>NONE</td>
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<tr>
<td>1.9</td>
<td>29</td>
<td>80</td>
<td>NONE</td>
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**PARTICULARS OF CASING**

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<th>To</th>
<th>Dia (ID)</th>
<th>Type</th>
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</thead>
<tbody>
<tr>
<td>0.5m</td>
<td>2m</td>
<td>219mm</td>
<td>STEEL</td>
</tr>
<tr>
<td>.4m</td>
<td>23m</td>
<td>80mm</td>
<td>PVC</td>
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**PARTICULARS OF PERFORATIONS OR SCREEN STRINGS**

<table>
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<th>From</th>
<th>To</th>
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<th>Aperture</th>
<th>Type</th>
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<tbody>
<tr>
<td>23</td>
<td>29</td>
<td>80mm</td>
<td>0.5mm</td>
<td>PVC</td>
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</tbody>
</table>

**Casing Suspended:** Yes ☒ No ☐

**Height of Casing above GL:** 0.3 m

**Top of Packer Set at:** (m)

**Length of Packer:** (m)

**Method of Packer Connection:**

**CEMENTING/GRAVEL PACKING**  
<table>
<thead>
<tr>
<th>From</th>
<th>To</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>6</td>
<td>GROUTE</td>
</tr>
<tr>
<td>20</td>
<td>29</td>
<td>GRAVEL</td>
</tr>
<tr>
<td>18</td>
<td>20</td>
<td>BENTONITE</td>
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</tbody>
</table>

**WATER BEARING BEDS**  

<table>
<thead>
<tr>
<th>Depth (m)</th>
<th>Yield (L/s)</th>
<th>SWL (m)</th>
<th>Duration (hr)</th>
<th>Quality</th>
<th>EC</th>
<th>pH</th>
<th>Bottle No.</th>
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</thead>
<tbody>
<tr>
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**METHOD OF WATER BEARING BEDS**  
<table>
<thead>
<tr>
<th>Depth of Lift (m)</th>
<th>Duration (hr)</th>
<th>Completion SWL from GL</th>
<th>Completion Yield (L/s)</th>
<th>Method</th>
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<tbody>
<tr>
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<td>1</td>
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**STRATA / WATER SAMPLES**

<table>
<thead>
<tr>
<th>Have been</th>
<th>Will be</th>
<th>Completion Yield (L/s)</th>
<th>Method</th>
<th>Completion SWL from GL (m)</th>
<th>Depth of Lift (m)</th>
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</thead>
<tbody>
<tr>
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<td>☐</td>
<td>0.1</td>
<td>AIRLIFT</td>
<td>-8.41</td>
<td>20</td>
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</table>

**NOTE:** No company advertising is to be imprinted on this certificate apart from where requested.
LOCATION SKETCH OF BORE  RN: RN019067  LOCATION DESCRIPTION OF BORE

<table>
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<th>m/km</th>
<th>NW</th>
<th>North</th>
<th>NE</th>
</tr>
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<tbody>
<tr>
<td>West</td>
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<td></td>
</tr>
<tr>
<td>SW</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

OF:

FINAL CONSTRUCTION STATUS
- Capped
- Casing Pulled
- Left for Obs.
- Abandoned
- Equipped
- Backfilled
- Other

ADDITIONAL INFORMATION ABOUT THE BORE: (Include any information which may assist for future reference)
- BORE WAS CAPPED WITH A STEEL LOCKABLE LID PAINTED WHITE WITH A 1m SQUARE PAD 300mm THICK

Note: The holder of the NT licence shall submit the form to the Department within 28 days of completion of any works.

I certify that the information contained above is true and correct, and that I have complied with the bore licensing requirements and conditions of the Bore Construction Permit as issued if a Bore Construction Permit was required.

Name and licence number of driller: Michael Satchly  Signature and licence number of licensed driller:  Date: 15/8/14

FOR OFFICIAL USE ONLY

How Located: GPS  TST  Survey  Hand Plotted  Other

DESCRIPTION OF PROPERTY:
- Rural
- Mineral
- Pastoral
- Reserve
- VCL
- Other

Lease No: Lot No: Hundred of:

Portion No: Section No: Town of:

Class of Bore: Town  Domestic  Investigation  Agriculture  Mineral  Pastoral  Other

Use of Bore: Production  Investigation  Irrigation  Observation  Monitoring  Roads  None

Grid Reference: AMG  Clark  Zone: Scale:

Easting: Latitude: Map Name:

Northing: Longitude: Index Map Number:

Date Registered: Bore Plotted on the map? Yes  No

Dept Officer: Signature:

Remarks:
**THE NORTHERN TERRITORY OF AUSTRALIA**
**APPROVED FORM 21 (25/01/2011)**
**STATEMENT OF BORE**
As per Water Regulations (2009)

<table>
<thead>
<tr>
<th>Name of Owner:</th>
<th>LILLA CREEK STATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location/Address:</td>
<td>FINKE RIVER</td>
</tr>
<tr>
<td>Registration No.:</td>
<td>RN019066</td>
</tr>
<tr>
<td>BC Permit No:</td>
<td>NOT REQUIRED</td>
</tr>
<tr>
<td>Intended Use:</td>
<td>MONITORING</td>
</tr>
</tbody>
</table>

**GPS Location:**
- Zone: GDA94
- Other: Specify: 53J
- Easting: 435140
- Northing: 7182805

<table>
<thead>
<tr>
<th>From</th>
<th>To</th>
<th>Particulars of Strata</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>4</td>
<td>RED SANDS</td>
</tr>
<tr>
<td>4</td>
<td>10</td>
<td>LIGHT RED SANDY SOIL</td>
</tr>
<tr>
<td>10</td>
<td>12</td>
<td>OFF WHITE SANDY SOIL</td>
</tr>
<tr>
<td>12</td>
<td>17.1</td>
<td>COURSE GRAVEL</td>
</tr>
</tbody>
</table>

**Name of Drilling Company:** DRILLING SOLUTIONS

**Name of Driller:** JASON KIRK

**Name of supervising driller:** MICHAEL SOUTHBY

**Date Commenced:** 07/08/2014

**Date Completed:** 07/08/2014

**Depth Drilled:** 17.1 (m)

**Completion Depth:** 17.1 (m)

**METHOD OF DRILLING**
- Other: 
- Auger: 
- Rev. Circ.: 
- Rctary Air: 
- Rotary Mud: ✓

**HOLE DIAMETER**
- From (m) | To (m) | Dia. (mm) | Type |
- 0         | 2.1    | 280       | NONE |
- 1.9       | 17.1   | 80mm      | BIO-VIS |

**PARTICULARS OF CASING**
- From | To | Dia (ID) | Type |
- 0.5m | 2m | 219mm     | STEEL |
- .4m  | 14.1m | 80mm     | PVC |

**PARTICULARS OF PERFORATIONS OR SCREEN STRINGS**
- From | To | Dia (ID) | Type |
- 14.1 | 17.1m | 80mm     | PVC |

**Aperture**
- 0.5mm

**Casing Suspended:** Yes 

**Method:**

**Height of Casing above GL:** 0.3 m

**Top of Packer Set at:**

**Length of Packer:**

**Method of Packer Connection:**

**CEMENTING/GRAVEL PACKING**
- From | To | Type |
- 0    | 10 | GROUTE |
- 12.5 | 17.1 | GRAVEL |
- 10   | 12.5 | BENTONITE |

**WATER BEARING BEDS**
- Depth (m) | Yield (Ls) | SWL (m) | Duration (hr) | Quality | EC | pH | Bottle No. |
- 0         | 0.1       | 7.21    | 983        | 7.21    |

**STRA T A / WATER SAMPLES**
- Completion Yield: 0.1
- Method: AIRLIFT
- Duration: 1 HOUR
- Depth of Lift: 17 m

**Have been ✓ Will be ☐ Completion SWL from GL:** 7.21

**NOTE:** No company advertising is to be imprinted on this certificate apart from where requested.
LOCATION SKETCH OF BORE  RN: RN019066

<table>
<thead>
<tr>
<th>LOCATION DESCRIPTION OF BORE</th>
</tr>
</thead>
<tbody>
<tr>
<td>NW</td>
</tr>
<tr>
<td>West</td>
</tr>
<tr>
<td>SW</td>
</tr>
</tbody>
</table>

OF:

FINAL CONSTRUCTION STATUS

Capped  Casing Pulled  Left for Obs.  Abandoned  Equipped  Backfilled  Other

ADDITIONAL INFORMATION ABOUT THE BORE: (Include any information which may assist for future reference)
BORE WAS CAPPED WITH A STEEL LOCKABLE LID PAINTED WHITE WITH A 1m SQUARE PAD 300mm THICK

Note: The holder of the NT licence shall submit the form to the Department within 28 days of completion of any works.

I certify that the information contained above is true and correct, and that I have complied with the bore licensing requirements and conditions of the Bore Construction Permit as issued if a Bore Construction Permit was required.

Name and licence number of driller: Signature and licence number of licensed driller: Date: 70  15 8 14

FOR OFFICIAL USE ONLY

How Located: GPS  TST  Survey  Hand Plotted  Other

DESCRIPTION OF PROPERTY:

Rural  Mineral  Pastoral  Reserve  VCL  Other

Lease No: Lot No: Hundred of:

Portion No: Section No: Town of:

Class of Bore: Town  Domestic  Investigation  Agriculture  Mineral  Pastoral  Other

Use of Bore: Production  Investigation  Irrigation  Observation  Monitoring  Roads  None

Grid Reference: AMG  Clark  Zone: Map Name: Scale:

Easting: Latitude: Northing: Longitude: Index Map Number:

Date Registered: Bore Plotted on the map? Yes  No

Dept Officer: Signature: Remarks:
**Name of Owner:** LILLA CREEK STATION  
**Registration No.:** RN0190701  
**Location/Address:** FINKE RIVER  
**BC Permit No.:** NOT REQUIRED  
**Intended Use:** MONITORING

**GPS Location:** Zone: GDA94 Other: Specify:  
- **53J**

**From** | **To** | **Particulars of Strata**  
--- | --- | ---  
0 | 4 | RED SANDS  
4 | 10 | LIGHT RED SANDY SOIL  
10 | 12 | OFFF WHITE SANDY SOIL  
12 | 26 | COURSE GRAVEL

**Easting:** 435860  
**Northing:** 7183330

**Name of Drilling Company:** DRILLING SOLUTIONS  
**Name of Driller:** JASON KIRK  
**Name of supervising driller:** MICHEAL SOUTHBY

**Date Commenced:** 08/08/2014  
**Date Completed:** 08/08/2014

**Depth Drilled:** 26.5 m  
**Completion Depth:** 26.4 m

**METHOD OF DRILLING**

Other Auger Rev. Circ. Rotary Air Rotary Mud  

**Specify:**

**HOLE DIAMETER**  
**From (m)** | **To (m)** | **Dia. (mm)** | **Type**  
--- | --- | --- | ---  
0 | 2.1 | 280 | NONE  
1.9 | 26 | 80 | NONE

**PARTICULARS OF CASING**  
**From** | **To** | **Dia (ID)** | **Type**  
--- | --- | --- | ---  
0.5m | 2m | 219mm | STEEL  
.4m | 20m | 80mm | PVC

**PARTICULARS OF PERFORATIONS OR SCREEN STRINGS**  
**From** | **To** | **Dia (ID)** | **Aperture** | **Type**  
--- | --- | --- | --- | ---  
20 | 26 | 80mm | 0.5mm | PVC

**Casing Suspended:** Yes  
**Method:**

**Height of Casing above GL:** 0.3 m

**Top of Packer Set at:** (m)  
**Length of Packer:** (m)

**Method of Packer Connection:**

**CEMENTING/GRAVEL PACKING**  
**From** | **To** | **Type**  
--- | --- | ---  
0 | 6 | GROUT
19 | 26 | GRAVEL  
17 | 19 | BENTONITE

**WATER BEARING BEDS**  
**Depth (m)** | **Yield (Ls)** | **SWL (m)** | **Duration (hr)** | **Quality** | **EC** | **pH** | **Bottle No.**
--- | --- | --- | --- | --- | --- | --- | ---
0 | 6 | -16.6 | 1 | 11868 | 7.06

**STRATA / WATER SAMPLES**  
**Completion Yield:** 1  
**Method:** AILIFT  
**Duration:** 1 HOUR

**Completion SWL from GL:** -16.6  
**Depth of Lift:** 20

**NOTE:** No company advertising is to be imprinted on this certificate apart from where requested.
LOCATION SKETCH OF BORE  RN: RN0190701
LOCATION DESCRIPTION OF BORE

<table>
<thead>
<tr>
<th>m/km</th>
<th>NW</th>
<th>North</th>
<th>NE</th>
<th>West</th>
<th>East</th>
<th>SW</th>
<th>South</th>
<th>SE</th>
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<tbody>
<tr>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

OF:

FINAL CONSTRUCTION STATUS

- Capped [ ]
- Casing Pulled [ ]
- Left for Obs. [ ]
- Abandoned [ ]
- Equipped [ ]
- Backfilled [ ]
- Other [ ]

ADDITIONAL INFORMATION ABOUT THE BORE: (Include any information which may assist for future reference)
BORE WAS CAPPED WITH A STEEL LOCKABLE LID PAINTED WHITE WITH A 1m SQUARE PAD 300mm THICK

Note: The holder of the NT licence shall submit the form to the Department within 28 days of completion of any works.

I certify that the information contained above is true and correct, and that I have complied with the bore licensing requirements and conditions of the Bore Construction Permit as issued if a Bore Construction Permit was required.

Michael Smith
Name and licence number of driller: 
Signature and licence number of licensed driller: 
Date: 15/8/14

FOR OFFICIAL USE ONLY

DESCRIPTION OF PROPERTY:

- Rural [ ]
- Mineral [ ]
- Pastoral [ ]
- Reserve [ ]
- VCL [ ]
- Other [ ]

- Lease No: [ ]
- Lot No: [ ]
- Hundred of: [ ]
- Section No: [ ]
- Town of: [ ]

Class of Bore:
- Town [ ]
- Domestic [ ]
- Investigation [ ]
- Agriculture [ ]
- Mineral [ ]
- Pastoral [ ]
- Other [ ]

Use of Bore:
- Production [ ]
- Investigation [ ]
- Irrigation [ ]
- Observation [ ]
- Monitoring [ ]
- Roads [ ]
- None [ ]

Grid Reference:
- AMG [ ]
- Clark [ ]
- Zone: [ ]
- Scale: [ ]

Easting: [ ]
Latitude: [ ]
Longitude: [ ]
Index Map Number: [ ]

Date Registered: [ ]
Bore Plotted on the map? Yes [ ] No [ ]

Dept Officer: [ ]
Signature: [ ]

Remarks: [ ]
Name of Owner: LILLA CREEK STATION  
Location/Address: FINKE RIVER  
Registration No.: RN019005  
BC Permit No.: NOT REQUIRED

**Particulars of Strata**

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<th>From</th>
<th>To</th>
<th>Stratum</th>
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<td>0</td>
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<td>RED SANDS</td>
</tr>
<tr>
<td>10</td>
<td>15</td>
<td>LIGHT GREY</td>
</tr>
<tr>
<td>15</td>
<td>18</td>
<td>GREY SLOP DUE TO WATER INJECTION</td>
</tr>
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**Name of Drilling Company:** DRILLING SOLUTIONS  
**Name of Driller:** JASON KIRK  
**Name of supervising driller:** MICHEAL SOUTHBY  
**Date Commenced:** 18/08/2014  
**Date Completed:** 18/08/2014  
**Depth Drilled:** 18 (m)  
**Completion Depth:** 18 (m)

**Method of Drilling**

- [ ] Other  
- [x] Auger  
- [ ] Rev. Circ.  
- [ ] Rotary Air  
- [ ] Rotary Mud  

**Hole Diameter**

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<th>To (m)</th>
<th>Dia. (mm)</th>
<th>Type</th>
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<tbody>
<tr>
<td>0</td>
<td>2.1</td>
<td>280</td>
<td>NONE</td>
</tr>
<tr>
<td>1.9</td>
<td>18</td>
<td>100</td>
<td>NONE</td>
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**Particulars of Casing**

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<th>Type</th>
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<tr>
<td>0.5m</td>
<td>2m</td>
<td>219mm</td>
<td>STEEL</td>
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<tr>
<td>4m</td>
<td>15m</td>
<td>100mm</td>
<td>PVC</td>
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**Particulars of Perforations or Screen Strings**

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<th>To</th>
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<th>Aperture</th>
<th>Type</th>
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<tr>
<td>15m</td>
<td>18m</td>
<td>100mm</td>
<td>0.5mm</td>
<td>PVC</td>
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**Casing Suspended:** Yes [ ] No [x]  
**Method:**  
**Height of Casing above GL:** 0.3 m

**Method of Packer Connection:**

<table>
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<th>From</th>
<th>To</th>
<th>Type</th>
<th>Depth (m)</th>
<th>Yield</th>
<th>SWL</th>
<th>Duration (hr)</th>
<th>Quality</th>
<th>EC</th>
<th>pH</th>
<th>Bottle No.</th>
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</thead>
<tbody>
<tr>
<td>0 m</td>
<td>6 m</td>
<td>GROUTE</td>
<td>0.1</td>
<td>10.4</td>
<td></td>
<td>12590</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>18</td>
<td>GRAVEL</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>12</td>
<td>BENTONITE</td>
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**Bottle No:**

- TBC

**Strata / Water Samples**

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<th>From</th>
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<th>Type</th>
<th>Depth (m)</th>
<th>Yield</th>
<th>SWL</th>
<th>Duration (hr)</th>
<th>Quality</th>
<th>EC</th>
<th>pH</th>
<th>Bottle No.</th>
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</thead>
<tbody>
<tr>
<td>0 m</td>
<td>6 m</td>
<td>GROUTE</td>
<td>0.1</td>
<td>10.4</td>
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<td>10</td>
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<td>BENTONITE</td>
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</table>

**Completion Yield:** 10.4  
**Method:** AIRLIFT  
**Duration:** 1 HOUR  
**Depth of Lift:** 17 m

**NOTE:** No company advertising is to be imprinted on this certificate apart from where requested.
LOCATION SKETCH OF BORE  RN: RN019005

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<tr>
<td>SW</td>
<td>South</td>
<td>SE</td>
</tr>
</tbody>
</table>

OF:

FINAL CONSTRUCTION STATUS

- [ ] Capped
- [ ] Casing Pulled
- [ ] Left for Obs.
- [ ] Abandoned
- [ ] Equipped
- [ ] Backfilled
- [ ] Other

ADDITIONAL INFORMATION ABOUT THE BORE: (Include any information which may assist for future reference)

BORE WAS CAPPED WITH A STEEL LOCKABLE LID PAINTED WHITE WITH A 1m SQUARE PAD 300mm THICK

Note: The holder of the NT licence shall submit the form to the Department within 28 days of completion of any works.

I certify that the information contained above is true and correct, and that I have complied with the bore licensing requirements and conditions of the Bore Construction Permit as issued if a Bore Construction Permit was required.

Name and licence number of driller: Michael Southby  Signature and licence number of licensed driller:  Date: 15/04/14

FOR OFFICIAL USE ONLY

<table>
<thead>
<tr>
<th>How Located:</th>
<th>GPS</th>
<th>TST</th>
<th>Survey</th>
<th>Hand Plotted</th>
<th>Other</th>
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DESCRIPTION OF PROPERTY:

- [ ] Rural
- [ ] Mineral
- [ ] Pastoral
- [ ] Reserve
- [ ] VCL
- [ ] Other

<table>
<thead>
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<th>Lease No:</th>
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<th>Hundred of:</th>
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<table>
<thead>
<tr>
<th>Class of Bore:</th>
<th>Town</th>
<th>Domestic</th>
<th>Investigation</th>
<th>Agriculture</th>
<th>Mineral</th>
<th>Pastoral</th>
<th>Other</th>
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</thead>
<tbody>
<tr>
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<table>
<thead>
<tr>
<th>Use of Bore:</th>
<th>Production</th>
<th>Investigation</th>
<th>Irrigation</th>
<th>Observation</th>
<th>Monitoring</th>
<th>Roads</th>
<th>Other</th>
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</thead>
<tbody>
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<td></td>
<td></td>
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</table>

Date Registered:  Bore Plotted on the map? Yes [ ] No [ ]

Dept Officer:  Signature:

Remarks:
**THE NORTHERN TERRITORY OF AUSTRALIA**  
**APPROVED FORM 21 (25/01/2011)**  
**STATEMENT OF BORE**  
*As per Water Regulations (2009)*

**Name of Owner:** LILLA CREEK STATION  
**Registration No.:** RN019075  
**Location/Address:** FINKE RIVER  
**BC Permit No.:** NOT REQUIRED  
**Intended Use:** MONITORING

**GPS Location:**  
- **Zone:** GDA94  
- **Other:** Specify  
- **Easting:** 439953  
- **Northing:** 7176555

<table>
<thead>
<tr>
<th>From</th>
<th>To</th>
<th>Particulars of Strata</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>10</td>
<td>RED SANDS</td>
</tr>
<tr>
<td>10</td>
<td>24</td>
<td>VERY COURSE GRAVELS</td>
</tr>
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**Name of Drilling Company:** DRILLING SOLUTIONS  
**Name of Driller:** JASON KIRK  
**Name of supervising driller:** MICHEAL SOUTHBY

<table>
<thead>
<tr>
<th>Date Commenced</th>
<th>Date Completed</th>
</tr>
</thead>
<tbody>
<tr>
<td>18/08/2014</td>
<td>19/08/2014</td>
</tr>
</tbody>
</table>

**Depth Drilled:** 24 (m)  
**Completion Depth:** 21 (m)

**METHOD OF DRILLING**  
- Other  
- Auger  
- Rev. Circ.  
- Rotary Air  
- Rotary Mud

**HOLE DIAMETER**  
<table>
<thead>
<tr>
<th>From (m)</th>
<th>To (m)</th>
<th>Dia. (mm)</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>2.1</td>
<td>280</td>
<td>NONE</td>
</tr>
<tr>
<td>1.9</td>
<td>24</td>
<td>100</td>
<td>NONE</td>
</tr>
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</table>

**PARTICULARS OF CASING**  
<table>
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<th>From</th>
<th>To</th>
<th>Dia (ID)</th>
<th>Type</th>
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<tbody>
<tr>
<td>0.5m</td>
<td>2m</td>
<td>219mm</td>
<td>STEEL</td>
</tr>
<tr>
<td>.4m</td>
<td>15m</td>
<td>100mm</td>
<td>PVC</td>
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**PARTICULARS OF PERFORATIONS OR SCREEN STRINGS**  
<table>
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<th>From</th>
<th>To</th>
<th>Dia (ID)</th>
<th>Aperture</th>
<th>Type</th>
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</thead>
<tbody>
<tr>
<td>15m</td>
<td>21m</td>
<td>100mm</td>
<td>0.5mm</td>
<td>PVC</td>
</tr>
</tbody>
</table>

**Casing Suspended:** Yes  
**Method:**  
**Height of Casing above GL:** 0.3 m  
**Top of Packer Set at:** (m)  
**Length of Packer:** (m)  
**Method of Packer Connection:**

**CEMENTING/GRAVEL PACKING**  
<table>
<thead>
<tr>
<th>From</th>
<th>To</th>
<th>Type</th>
<th>Depth (m)</th>
<th>Yield</th>
<th>SWL</th>
<th>Duration</th>
<th>Quality</th>
<th>EC</th>
<th>pH</th>
<th>Bottle No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 m</td>
<td>6 m</td>
<td>GROUTE</td>
<td>0.2</td>
<td>-8.43</td>
<td></td>
<td>1933</td>
<td>7.7</td>
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**WATER BEARING BEDS**  
| STRATA / WATER SAMPLES | Completion Yield | Method | Duration | Bottle No.
<table>
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<td></td>
<td>0.2</td>
<td>AIRLIFT</td>
<td>1 HOUR</td>
<td></td>
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**Completion SWL from GL:** 11 (m)  
**Death of Lift:** 20 (m)

**NOTE:** No company advertising is to be imprinted on this certificate apart from where requested.
<table>
<thead>
<tr>
<th>LOCATION SKETCH OF BORE</th>
<th>LOCATION DESCRIPTION OF BORE</th>
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<tr>
<td>SW □ South □ SE □</td>
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OF:

### FINAL CONSTRUCTION STATUS

- Capped □
- Casing Pulled □
- Left for Obs. □
- Abandoned □
- Equipped □
- Backfilled □
- Other □

### ADDITIONAL INFORMATION ABOUT THE BORE: (Include any information which may assist for future reference)

BORE WAS CAPPED WITH A STEEL LOCKABLE LID PAINTED WHITE WITH A 1m SQUARE PAD 300mm THICK

---

Name and licence number of driller: Michael Soothy
Signature and licence number of licensed driller: MJS
Date: 15/8/14

---

FOR OFFICIAL USE ONLY

<table>
<thead>
<tr>
<th>How Located:</th>
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<th>Other</th>
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<td>VCL □</td>
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<td>Other □</td>
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<th>Investigation □</th>
<th>Agriculture □</th>
<th>Mineral □</th>
<th>Pastoral □</th>
<th>Other □</th>
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<td>Use of Bore:</td>
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<td>Observation □</td>
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<tr>
<td>Easting:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Northing:</td>
<td></td>
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</tr>
<tr>
<td>Latitude:</td>
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<td>Longitude:</td>
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<tr>
<td>Scale:</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Index Map Number:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Date Registered: Bore Plotted on the map? Yes □ No □
Dept Officer: Signature: 
Remarks:
THE NORTHERN TERRITORY OF AUSTRALIA
APPROVED FORM 21 (25/01/2011)
STATEMENT OF BORE
As per Water Regulations (2009)

| Name of Owner: | LILLA CREEK STATION |
| Registration No.: | RN019074 |
| BC Permit No.: | NOT REQUIRED |
| Location/Address: | FINKE RIVER |
| Intended Use: | MONITORING |

**GPS Location:**
- Zone: GDA94
- Other: Specify: 53J
- Easting: 436869
- Northing: 7184845

**From** | **To** | **Particulars of Strata**
--- | --- | ---
0 | 4 | RED SANDS
4 | 10 | LIGHT RED SANDY SOIL
10 | 12 | OFF WHITE SANDY SOIL
12 | 42 | RED SANDY SOIL

**Name of Drilling Company:** DRILLING SOLUTIONS
**Name of Driller:** JASON KIRK
**Name of supervising driller:** MICHEAL SOUTHBY
**Date Commenced:** 10/08/2014
**Date Completed:** 10/08/2014
**Depth Drilled:** 42 m
**Completion Depth:** 0 m

**METHOD OF DRILLING**
- Other: 
- Auger: 
- Rev. Circ.: 
- Rotary Air: ☑
- Rotary Mud: 
**Specify:**

**HOLE DIAMETER**
- From (m): 0
- To (m): 42
- Dia. (mm): 165
- Type: NONE

**PARTICULARS OF CASING**

**PARTICULARS OF PERFORATIONS OR SCREEN STRINGS**

**CEMENTING/GRAVEL PACKING**

**WATER BEARING BEDS**

<table>
<thead>
<tr>
<th>Depth (m)</th>
<th>Yield (L/s)</th>
<th>SWL (m)</th>
<th>Duration (hr)</th>
<th>Quality</th>
<th>EC</th>
<th>pH</th>
<th>Bottle No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
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</tr>
</tbody>
</table>

**STRATA / WATER SAMPLES**

**Completion Yield:**
**Method:**
**Duration:** HOUR
**Depth of Lift:**

**Height of Casing above GL:** 0.3 m

**Casing Suspended:**
- Yes: ☑
- No: 

**Top of Packer Set at:** (m)
**Length of Packer:** (m)
**Method of Packer Connection:**

**NOTE:** No company advertising is to be imprinted on this certificate apart from where requested.
**LOCATION SKETCH OF BORE**  RN: RN019074  **LOCATION DESCRIPTION OF BORE**

<table>
<thead>
<tr>
<th>NW</th>
<th>North</th>
<th>NE</th>
<th>West</th>
<th>East</th>
<th>SW</th>
<th>South</th>
<th>SE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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</tr>
</tbody>
</table>

**OF:**

---

**FINAL CONSTRUCTION STATUS**

- Capped [ ]
- Casing Pulled [ ]
- Left for Obs. [ ]
- Abandoned [ ]
- Equipped [ ]
- Backfilled [ √ ]
- Other [ √ ]

**ADDITIONAL INFORMATION ABOUT THE BORE:** *(Include any information which may assist for future reference)*

BORE WAS A DRY HOLE

---

**FOR OFFICIAL USE ONLY**

- **Name and licence number of driller:** Michael Southby
- **Signature and licence number of licensed driller:** [Signature]
- **Date:** 15/8/14

---

**DESCRIPTION OF PROPERTY**

- **How Located:** GPS [ ]
- **TST:** [ ]
- **Survey:** [ ]
- **Hand Plotted:** [ ]
- **Other:** [ ]

**Rural** [ ]  **Mineral** [ ]  **Pastoral** [ ]  **Reserve** [ ]  **VCL** [ ]  **Other** [ ]

- **Lease No:** [ ]
- **Lot No:** [ ]
- **Hundred of:** [ ]
- **Section No:** [ ]
- **Town of:** [ ]

**Class of Bore:**

- **Town** [ ]
- **Domestic** [ ]
- **Investigation** [ ]
- **Agriculture** [ ]
- **Mineral** [ ]
- **Pastoral** [ ]
- **Other** [ ]

**Use of Bore:**

- **Production** [ ]
- **Investigation** [ ]
- **Irrigation** [ ]
- **Observation** [ ]
- **Monitoring** [ ]
- **Roads** [ ]
- **None** [ ]

**Grid Reference:**

- **AMG** [ ]
- **Clark** [ ]
- **Zone:** [ ]
- **Scale:** [ ]

**Easting:** [ ]
**Latitude:** [ ]
**Northing:** [ ]
**Longitude:** [ ]
**Index Map Number:** [ ]
**Map Name:** [ ]

**Date Registered:** Bore Plotted on the map? Yes [ ]  No [ ]
**Dept Officer:** Signature: [Signature]

**Remarks:**
D. Aquifer test water level data
Data Set: F:...\B1A Falling 1.aqt
Date: 01/27/15 Time: 08:43:43

PROJECT INFORMATION
Company: S Fulton
Client: DEWNR
Location: Lilla Creek Pedirka Basin
Test Well: RT1
Test Date: 10/09/2014

AQUIFER DATA
Saturated Thickness: 10.93 m
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (B1A)
Initial Displacement: 1.62 m
Total Well Penetration Depth: 9.93 m
Casing Radius: 0.0385 m
Static Water Column Height: 9.93 m
Screen Length: 3. m
Well Radius: 0.1143 m

SOLUTION
Aquifer Model: Unconfined
Solution Method: Bouwer-Rice
\( K = 0.001145 \text{ m/day} \)

\( y_0 = 1.251 \text{ m} \)
### PROJECT INFORMATION

- **Company**: S Fulton
- **Client**: DEWNR
- **Location**: Lilla Creek Pedirka Basin
- **Test Well**: RT1
- **Test Date**: 10/09/2014

### AQUIFER DATA

- **Saturated Thickness**: 10.93 m
- **Anisotropy Ratio (Kz/Kr)**: 1.

### WELL DATA (B1A)

- **Initial Displacement**: 1.052 m
- **Total Well Penetration Depth**: 9.93 m
- **Casing Radius**: 0.0385 m
- **Static Water Column Height**: 9.93 m
- **Screen Length**: 3. m
- **Well Radius**: 0.1143 m

### SOLUTION

- **Aquifer Model**: Unconfined
- **Solution Method**: Bouwer-Rice
- **K**: 0.004582 m/day
- **y0**: 0.323 m
**PROJECT INFORMATION**

Company: S Fulton  
Client: DEWNR  
Location: Lilla Creek Pedirka Basin  
Test Well: RT1  
Test Date: 10/09/2014

**AQUIFER DATA**

Saturated Thickness: 10.46 m  
Anisotropy Ratio (Kz/Kr): 1

**WELL DATA (B5A)**

Initial Displacement: 1.68 m  
Total Well Penetration Depth: 9.96 m  
Casing Radius: 0.0385 m  
Static Water Column Height: 9.96 m  
Screen Length: 6.5 m  
Well Radius: 0.1143 m

**SOLUTION**

Aquifer Model: Unconfined  
Solution Method: Bouwer-Rice  
K = 0.2791 m/day  
y0 = 0.342 m
PROJECT INFORMATION

Company: S Fulton
Client: DEWNR
Location: Lilla Creek Pedirka Basin
Test Well: RT1
Test Date: 10/09/2014

AQUIFER DATA

Saturated Thickness: 10.46 m
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (B5A)

Initial Displacement: 1.233 m
Total Well Penetration Depth: 9.96 m
Casing Radius: 0.0385 m
Static Water Column Height: 9.96 m
Screen Length: 6.5 m
Well Radius: 0.1143 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice

\[ K = 0.2695 \text{ m/day} \]
\[ y_0 = 0.3989 \text{ m} \]
Data Set: F:\...\B5A Rising 1.aqt
Date: 01/27/15
Time: 08:42:26

PROJECT INFORMATION
Company: S Fulton
Client: DEWNR
Location: Lilla Creek Pedirka Basin
Test Well: RT1
Test Date: 10/09/2014

AQUIFER DATA
Saturated Thickness: 10.46 m
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (B5A)
Initial Displacement: 1.029 m
Total Well Penetration Depth: 9.96 m
Casing Radius: 0.0385 m
Static Water Column Height: 9.96 m
Screen Length: 6.5 m
Well Radius: 0.1143 m

SOLUTION
Aquifer Model: Unconfined
K = 0.7903 m/day
Solution Method: Bouwer-Rice
y0 = 0.7308 m
**PROJECT INFORMATION**

Company: S Fulton  
Client: DEWNR  
Location: Lilla Creek Pedirka Basin  
Test Well: RT1  
Test Date: 10/09/2014

**AQUIFER DATA**

Saturated Thickness: 10.46 m  
Anisotropy Ratio (Kz/Kr): 1

**WELL DATA (B5A)**

Initial Displacement: 1.38 m  
Static Water Column Height: 9.96 m  
Total Well Penetration Depth: 9.96 m  
Screen Length: 6.5 m  
Casing Radius: 0.0385 m  
Well Radius: 0.1143 m

**SOLUTION**

Aquifer Model: Unconfined  
Solution Method: Bouwer-Rice  
K = 0.7065 m/day  
y0 = 0.9341 m
PROJECT INFORMATION

Company: S Fulton
Client: DEWNR
Location: Lilla Creek Pedirka Basin
Test Well: RT1
Test Date: 10/09/2014

AQUIFER DATA

Saturated Thickness: 10.38 m
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (B5B)

Initial Displacement: 0.8791 m
Total Well Penetration Depth: 6.62 m
Casing Radius: 0.0385 m
Static Water Column Height: 6.62 m
Screen Length: 3. m
Well Radius: 0.1143 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice
K = 0.06252 m/day
y0 = 0.7493 m
### PROJECT INFORMATION

- **Company:** S Fulton
- **Client:** DEWNR
- **Location:** Lilla Creek Pedirka Basin
- **Test Well:** RT1
- **Test Date:** 10/09/2014

### AQUIFER DATA

- **Saturated Thickness:** 10.38 m
- **Anisotropy Ratio (Kz/Kr):** 1

### WELL DATA (B5B)

- **Initial Displacement:** 0.9171 m
- **Total Well Penetration Depth:** 6.62 m
- **Casing Radius:** 0.0385 m
- **Static Water Column Height:** 6.62 m
- **Screen Length:** 3. m
- **Well Radius:** 0.1143 m

### SOLUTION

- **Aquifer Model:** Unconfined
- **Solution Method:** Bouwer-Rice
- **K:** 0.09339 m/day
- **y0:** 0.887 m
RT1 FALLING TEST 1

Data Set: F:\...\RT1 Falling 1.aqt
Date: 01/27/15
Time: 08:41:56

PROJECT INFORMATION

Company: S Fulton
Client: DEWNR
Location: Lilla Creek Pedirka Basin
Test Well: RT1
Test Date: 10/09/2014

AQUIFER DATA

Saturated Thickness: 10.31 m
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (RT1)

Initial Displacement: 1.208 m
Total Well Penetration Depth: 7.31 m
Casing Radius: 0.0385 m
Static Water Column Height: 7.31 m
Screen Length: 3. m
Well Radius: 0.1143 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice
K = 1.454 m/day
y0 = 0.7819 m
RT2 FALLING TEST 1

Data Set: F:\...\RT1 Falling 2.aqt
Date: 01/27/15
Time: 08:41:49

PROJECT INFORMATION

Company: S Fulton
Client: DEWNR
Location: Lilla Creek Pedirka Basin
Test Well: RT1
Test Date: 10/09/2014

AQUIFER DATA

Saturated Thickness: 10.31 m
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (RT1)

Initial Displacement: 1.305 m
Total Well Penetration Depth: 7.31 m
Casing Radius: 0.0385 m
Static Water Column Height: 7.31 m
Screen Length: 3. m
Well Radius: 0.1143 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice
K = 1.546 m/day
y0 = 0.7447 m
RT2 RISING TEST 1

Data Set: F:\...\RT1 Rising 1.aqt
Date: 01/27/15 Time: 08:41:39

PROJECT INFORMATION

Company: S Fulton
Client: DEWR
Location: Lilla Creek Pedirka Basin
Test Well: RT1
Test Date: 10/09/2014

AQUIFER DATA

Saturated Thickness: 10.31 m
Anisotropy Ratio (Kz/Kr): 1

WELL DATA (RT1)

Initial Displacement: 1.274 m
Total Well Penetration Depth: 7.31 m
Casing Radius: 0.0385 m
Static Water Column Height: 7.31 m
Screen Length: 3. m
Well Radius: 0.1143 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice

K = 2.024 m/day
y0 = 1.327 m
### PROJECT INFORMATION

- **Company:** S Fulton
- **Client:** DEWNR
- **Location:** Lilla Creek Pedirka Basin
- **Test Well:** RT1
- **Test Date:** 10/09/2014

### AQUIFER DATA

- **Saturated Thickness:** 10.31 m
- **Anisotropy Ratio (Kz/Kr):** 1.

### WELL DATA (RT1)

- **Initial Displacement:** 1.352 m
- **Total Well Penetration Depth:** 7.31 m
- **Casing Radius:** 0.0385 m
- **Static Water Column Height:** 7.31 m
- **Screen Length:** 3. m
- **Well Radius:** 0.1143 m

### SOLUTION

- **Aquifer Model:** Unconfined
- **Solution Method:** Bouwer-Rice
- **$K = 1.889$ $m/day**
- **$y_0 = 1.331$ m**
RT2A FALLING TEST 1

Data Set: F:\...\RT2a Falling 1.aqt
Date: 01/27/15 Time: 08:41:23

PROJECT INFORMATION

Company: S Fulton
Client: DEWNR
Location: Lilla Creek Pedirka Basin
Test Well: RT1
Test Date: 10/09/2014

AQUIFER DATA

Saturated Thickness: 11. m
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (RT2a)

Initial Displacement: 0.9041 m
Total Well Penetration Depth: 19.9 m
Casing Radius: 0.051 m
Static Water Column Height: 19.9 m
Screen Length: 6. m
Well Radius: 0.1143 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice

$K = \frac{0.009197}{\text{m/day}}$
$y_0 = 0.8356 \text{ m}$
RT2A RISING TEST 1

Data Set: F:\...\RT2a Rising 1.aqt
Date: 01/27/15
Time: 08:41:13

PROJECT INFORMATION

Company: S Fulton
Client: DEWNR
Location: Lilla Creek Pedirka Basin
Test Well: RT1
Test Date: 10/09/2014

AQUIFER DATA

Saturated Thickness: 11. m
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (RT2a)

Initial Displacement: 0.8599 m
Total Well Penetration Depth: 19.9 m
Casing Radius: 0.051 m
Static Water Column Height: 19.9 m
Screen Length: 6. m
Well Radius: 0.1143 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice
$K = 0.009234 \text{ m/day}$
$y_0 = 0.8098 \text{ m}$
PROJECT INFORMATION

Company: S Fulton
Client: DEWNR
Location: Lilla Creek Pedirka Basin
Test Well: RT1
Test Date: 10/09/2014

AQUIFER DATA

Saturated Thickness: 7 m
Anisotropy Ratio (Kz/Kr): 1

WELL DATA (RT2b)

Initial Displacement: 0.9041 m
Total Well Penetration Depth: 30.59 m
Casing Radius: 0.0385 m
Static Water Column Height: 30.59 m
Screen Length: 3 m
Well Radius: 0.1143 m

SOLUTION

Aquifer Model: Unconfined
K = 0.0003159 m/day
Solution Method: Bouwer-Rice
y0 = 1.45 m
Data Set: F:\...\RT2c Falling 1.aqt
Date: 01/27/15
Time: 08:40:56

PROJECT INFORMATION
Company: S Fulton
Client: DEWNR
Location: Lilla Creek Pedirka Basin
Test Well: RT1
Test Date: 10/09/2014

AQUIFER DATA
Saturated Thickness: 9. m
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (RT2c)
Initial Displacement: 1.43 m
Total Well Penetration Depth: 11.04 m
Casing Radius: 0.0385 m
Static Water Column Height: 11.04 m
Screen Length: 3. m
Well Radius: 0.1143 m

SOLUTION
Aquifer Model: Unconfined
Solution Method: Bouwer-Rice
K = 0.4006 m/day
y0 = 1.411 m
RT2C FALLING TEST 2

Data Set: F:\...\RT2c Falling 2.aqt
Date: 01/27/15 Time: 08:40:49

PROJECT INFORMATION

Company: S Fulton
Client: DEWR
Location: Lilla Creek Pedirka Basin
Test Well: RT1
Test Date: 10/09/2014

AQUIFER DATA

Saturated Thickness: 9. m
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (RT2c)

Initial Displacement: 1.468 m
Total Well Penetration Depth: 11.04 m
Casing Radius: 0.0385 m
Static Water Column Height: 11.04 m
Screen Length: 3. m
Well Radius: 0.1143 m

SOLUTION

Aquifer Model: Unconfined

Solution Method: Bouwer-Rice

$K = 0.4224 \text{ m/day}$

$y_0 = 1.483 \text{ m}$
### PROJECT INFORMATION

**Company:** S Fulton  
**Client:** DEWNR  
**Location:** Lilla Creek Pedirka Basin  
**Test Well:** RT1  
**Test Date:** 10/09/2014

### AQUIFER DATA

- **Saturated Thickness:** 9 m  
- **Anisotropy Ratio (Kz/Kr):** 1

### WELL DATA (RT2c)

- **Initial Displacement:** 1.64 m  
- **Total Well Penetration Depth:** 11.04 m  
- **Casing Radius:** 0.0385 m  
- **Static Water Column Height:** 11.04 m  
- **Screen Length:** 3 m  
- **Well Radius:** 0.1143 m

### SOLUTION

- **Aquifer Model:** Unconfined  
- **Solution Method:** Bouwer-Rice  
- **K:** 0.3408 m/day  
- **y0:** 1.07 m
RT3 FALLING TEST 1
Data Set: F:\...\RT3 Falling 1.aqt
Date: 01/27/15

PROJECT INFORMATION
Company: S Fulton
Client: DEWNR
Location: Lilla Creek Pedirka Basin
Test Well: RT1
Test Date: 10/09/2014

AQUIFER DATA
Saturated Thickness: 9.45 m
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (RT3)
Initial Displacement: 1.6 m
Total Well Penetration Depth: 7.46 m
Casing Radius: 0.0385 m
Static Water Column Height: 7.46 m
Screen Length: 3. m
Well Radius: 0.1143 m

SOLUTION
Aquifer Model: Unconfined
Solution Method: Bouwer-Rice
K = 4.954 m/day
y0 = 0.7806 m
RT3 FALLING TEST 2

Data Set: F:\..\RT3 Falling 2.aqt
Date: 01/27/15  Time: 08:40:13

PROJECT INFORMATION

Company: S Fulton
Client: DEWNR
Location: Lilla Creek Pedirka Basin
Test Well: RT1
Test Date: 10/09/2014

AQUIFER DATA

Saturated Thickness: 9.45 m  Anisotropy Ratio (Kz/Kr): 1

WELL DATA (RT3)

Initial Displacement: 2.384 m  Static Water Column Height: 7.46 m
Total Well Penetration Depth: 7.46 m  Screen Length: 3. m
Casing Radius: 0.0385 m  Well Radius: 0.1143 m

SOLUTION

Aquifer Model: Unconfined  Solution Method: Bouwer-Rice
K = 4.789 m/day  y0 = 0.7847 m
RT3 RISING TEST 1

Data Set: F:\...\RT3 Rising 1.aqt
Date: 01/27/15
Time: 08:40:04

PROJECT INFORMATION

Company: S Fulton
Client: DEWR
Location: Lilla Creek Pedirka Basin
Test Well: RT1
Test Date: 10/09/2014

AQUIFER DATA

Saturated Thickness: 9.45 m
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (RT3)

Initial Displacement: 1.47 m
Total Well Penetration Depth: 7.46 m
Casing Radius: 0.0385 m
Screen Length: 3. m
Static Water Column Height: 7.46 m
Well Radius: 0.1143 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice
K = 5.984 m/day
y0 = 1.46 m
RT3 RISING TEST 2

Data Set: F:\...\RT3 Rising 2.aqt
Date: 01/27/15
Time: 08:39:54

PROJECT INFORMATION

Company: S Fulton
Client: DEWNR
Location: Lilla Creek Pedirka Basin
Test Well: RT1
Test Date: 10/09/2014

AQUIFER DATA

Saturated Thickness: 9.45 m
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (RT3)

Initial Displacement: 1.14 m
Total Well Penetration Depth: 7.46 m
Casing Radius: 0.0385 m
Static Water Column Height: 7.46 m
Screen Length: 3. m
Well Radius: 0.1143 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice
K = 6.29 m/day
y0 = 1.163 m
Data Set: F:\...\RT4 Falling 1.aqt
Date: 01/27/15  Time: 08:39:45

PROJECT INFORMATION
Company: S Fulton
Client: DEWNR
Location: Lilla Creek Pedirka Basin
Test Well: RT1
Test Date: 10/09/2014

AQUIFER DATA
Saturated Thickness: 10.31 m  Anisotropy Ratio (Kz/Kr): 1

WELL DATA (RT4)
Initial Displacement: 1.48 m  Static Water Column Height: 9.21 m
Total Well Penetration Depth: 9.21 m  Screen Length: 3. m
Casing Radius: 0.0385 m  Well Radius: 0.1143 m

SOLUTION
Aquifer Model: Unconfined  Solution Method: Bouwer-Rice
K = 0.0346 m/day  y0 = 1.149 m
**PROJECT INFORMATION**

Company: S Fulton  
Client: DEWNR  
Location: Lilla Creek Pedirka Basin  
Test Well: RT1  
Test Date: 10/09/2014

**AQUIFER DATA**

Saturated Thickness: 10.31 m  
Anisotropy Ratio (Kz/Kr): 1.

**WELL DATA (RT4)**

Initial Displacement: 1.56 m  
Total Well Penetration Depth: 9.21 m  
Casing Radius: 0.0385 m  
Static Water Column Height: 9.21 m  
Screen Length: 3. m  
Well Radius: 0.1143 m

**SOLUTION**

Aquifer Model: Unconfined  
Solution Method: Bouwer-Rice  
K = 0.02859 m/day  
y0 = 1.326 m
RT5 FALLING 1

Data Set: F:\...\RT5 Falling 1.aqt
Date: 01/27/15 Time: 08:39:16

PROJECT INFORMATION
Company: S Fulton
Client: DEWNR
Location: Lilla Creek Pedirka Basin
Test Well: RT1
Test Date: 10/09/2014

AQUIFER DATA
Saturated Thickness: 12.11 m Anisotropy Ratio (Kz/Kr): 1

WELL DATA (RT5)
Initial Displacement: 1.48 m Static Water Column Height: 10.91 m
Total Well Penetration Depth: 10.91 m Screen Length: 3. m
Casing Radius: 0.0385 m Well Radius: 0.1143 m

SOLUTION
Aquifer Model: Unconfined Solution Method: Bouwer-Rice
K = 0.05739 m/day y0 = 1.277 m
Data Set: F:\...\RT5 Rising 1.aqt
Date: 01/27/15 Time: 08:38:41

PROJECT INFORMATION

Company: S Fulton
Client: DEWNR
Location: Lilla Creek Pedirka Basin
Test Well: RT1
Test Date: 10/09/2014

AQUIFER DATA

Saturated Thickness: 12.11 m
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (RT5)

Initial Displacement: 1.57 m
Total Well Penetration Depth: 10.91 m
Casing Radius: 0.0385 m
Static Water Column Height: 10.91 m
Screen Length: 3. m
Well Radius: 0.1143 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice
K = 0.05016 m/day
y0 = 1.298 m
E. Groundwater sampling and analysis methods

The methods described below were used to measure the relevant water quality parameters. For all sampling, care was taken to minimise air entrapment or excessive water agitation to minimise off-gassing of the chemical constituents. Groundwater was sampled in accordance with national guidelines and specific laboratory requirements.

Water level and bore depth

Depth to groundwater is used to indicate flow direction when corrected to a common datum (m AHD). Well depth indicates to what extent the well has filled with silt or collapsed. This was measured using a Solinst water level meter probe prior to pumping. For existing wells, these measurements were made where the configuration of the well headworks allowed without need for significant alteration.

Well purging

Wells were pumped for at least three well volumes and until field parameters including temperature, salinity and pH had stabilised prior to being sampled.

Temperature, EC, pH, DO, TDS

Temperature is a standard parameter that can be used to correct water level for density differences. Electrical conductivity (EC) is a proxy for salinity. Total dissolved solids (TDS) is calculated based on EC. pH indicates whether the water is basic or acidic. Dissolved oxygen (DO) is the concentration of oxygen dissolved in the groundwater. These parameters are measured using a YSI handheld multiparameter meter fitted to a closed cell sampling chamber. The parameters were checked regularly to ensure that they had stabilised during the extraction of three well volumes of water. EC and pH were calibrated at least daily against standard solutions for a precision of ±0.5 % and ±0.1 units respectively. DO was calibrated at least daily to an accuracy of ±0.2 mg/L (<20 mg/L) and ±0.6 mg/L (>20 mg/L).

Alkalinity

Alkalinity is a measure of CaCO₃ (calcium carbonate) concentration via titration. It is used to calculate the anion and cation balance from laboratory analyses. Alkalinity (CaCO₃) was determined in the field using a Hach digital titrator and reagents with a relative precision of ±5 %. A 100 ml groundwater sample was taken, to which a satchel of Bromocresol Green–Methyl Red indicator was added. Sulfuric acid was then titrated into the sample from which the distinctive colour change could be used to estimate the sample’s alkalinity concentration. Alkalinity was also analysed at CSIRO Land and Water laboratory, Adelaide.

Anions and cations

Ions are an indicator of water quality. Cations were filtered through a 0.45 μm membrane filter into rinsed samples bottles and acidified with nitric acid to pH <2. pH indicator strips were used to measure sample pH following acidification. Anions were field filtered and chilled. Samples were analysed at CSIRO Land and Water laboratory, Adelaide using a Metrohm Ion Chromatograph to a precision of ±2 % and a Varian Vista ICP-AES to a precision of ±2 %.

Stable isotopes δ¹⁸O and δ²H

Isotopes are those elements with the same number of protons however a different number of neutrons and therefore a different atomic mass. For the current study, stable isotopes of the water molecule, expressed as the ³H (rare) to ¹H (common) ratio (δ³H) and ¹⁸O (rare) to ¹⁶O (common) ratio (δ¹⁸O) were used to infer hydrological processes, such as recharge mechanisms and flow paths. An unfiltered sample was collected in a 28 ml McCartney jar. Care was taken to ensure no air bubbles were trapped in the sample and the lids were crimped tightly and taped to ensure no evaporative enrichment occurred. Stable isotope ratios (δ³H, δ¹⁸O) were measured at UC Davis Stable Isotope Facility (SIF) in California. The SIF provides simultaneous analysis of ¹⁸O/¹⁶O and D/H isotope ratios in liquid water samples using a Laser Water Isotope Analyzer V2 (Los Gatos Research, Inc., Mountain View, CA, USA). Sample isotope ratios are standardized using a range of working standards that have been calibrated against IAEA standard reference materials (VSMOW, GISP, and SLAP). Precision for water samples at natural abundance is typically ≤0.3 permil for ¹⁸O and ≤0.8 permil for D/H. Final ¹⁸O/¹⁶O and D/H values are reported relative to VSMOW.
**Strontium (87Sr/86Sr)**

Dissolved strontium is present in small quantities in most natural waters. When combined with other hydrochemical data, the ratio of two naturally occurring strontium isotopes, 87Sr and 86Sr, is a powerful indicator of water-rock interaction, mixing relationships and geochemical processes such as ion exchange (Shand et al. 2009; Clark and Fritz, 1997).

At the time of rock formation, minerals in igneous and metamorphic rocks have identical 87Sr/86Sr isotope ratios, which differ with age owing to the decay of 87Rb to 87Sr. Older rocks generally have higher Sr isotope ratios than younger rocks (Shand et al. 2009; Capo et al. 1998). Sr isotope ratios in groundwater are controlled initially by atmospheric inputs (Sr dissolved in rainfall and dust deposition), followed by soil and rock mineralogy along a flow path, and the mineral dissolution characteristics and residence time within the host rock (McNutt 2000).

Strontium isotopes have advantages over other isotope tracers as they are not affected by mass fractionation or gases in the unsaturated zone, and the 87Sr/86Sr signature essentially reflects the signature of aquifer minerals (Dogramaci & Herczeg 2002).

Strontium samples were filtered through a 0.45 µm membrane filter and collected in rinsed sample bottles. Strontium concentrations were measured by the CSIRO laboratory as described above in the section 'Anions and Cations'. 87Sr/86Sr ratios were measured at The University of Adelaide (Mawson Laboratory) on a Finnigan MAT 262 thermal ionisation mass spectrometer. Strontium was extracted from water samples by evaporating water to leave a solid precipitate, which was then re-dissolved in hydrochloric acid and filtered through columns of Biorad cation exchange resin to isolate SrCl2 from the precipitate.

**Chlorofluorocarbons (CFC-11 and CFC-12)**

Chlorofluorocarbon gases (CFCs) were produced between the 1930s and 1980s for industrial applications such as refrigeration, air conditioning and aerosol propellant. Since the Montreal Protocol in 1987 atmospheric concentrations have been decreasing (IAEA 2006). Detectable concentrations of CFCs can be used to estimate groundwater ages up to approximately 50 years (Scanlon et al. 2002). The presence of CFCs provides an indication of modern recharge.

Three 125 mL glass bottles, with metal-foil lid liners, were filled in a glass jar placed inside a stainless steel bucket continually filled with groundwater to minimise the surface area in contact with the atmosphere. Each sample bottle was flushed and filled with the groundwater sample and capped while submerged in the glass jar/bucket. Care was taken to ensure no air bubbles were trapped in the sample and the lids crimped tightly and taped to ensure no atmospheric contamination of the sample during transport. This method is outlined in greater detail in IAEA (2006). The samples were sent to CSIRO Isotopic Service unit for analysis.

**Radiocarbon dating (14C)**

Radiocarbon (carbon-14 or 14C) is a radioactive isotope of carbon with a known decay rate and a half-life of 5730 years. It is produced naturally in the atmosphere by interactions of nitrogen and cosmic rays, where it is quickly oxidised to CO2, mixed into the lower atmosphere and assimilated in the biosphere and hydrosphere (Kalin 2000). The record of natural variation in atmospheric 14C content over the last 24 000 years as measured in tree rings, provides a useful reference to estimate groundwater ages between 200 to 20 000 years (Scanlon et al. 2002). Since 1950 nuclear testing nearly doubled the amount of radioactive isotopes in the atmosphere (Kalin 2000). This peak provides a useful event marker in hydrogeological studies and is used as the zero year for 14C activity, the year 1950 is considered to have 100 Percent Modern Carbon (pmC). 14C activities less than 100 pmC are interpreted to be pre-1950, and 14C activities of greater than 100 pmC are post-1950.

A 1 L unfiltered sample was collected in a white opaque PET bottle. δ13C and δ14C were measured by Accelerator Mass Spectrometry (AMS) at the Rafter Radiocarbon Laboratory, GNS Science National Isotope Centre, Gracefield, New Zealand. CO2 was generated by phosphoric acid evolution and was converted to graphite by reduction with hydrogen over iron catalyst before analysis by AMS.
F. Groundwater ion plots

Figure 6.1 Major ions plotted against chloride for groundwater in the study area
Figure 6.2  Ion ratios v. chloride plots
Figure 6.3  Major ion to chloride ratios plotted against chloride

These plots help to identify controls on groundwater composition. A horizontal trend suggests evapoconcentration; a curved trend suggests rock/mineral interaction and/or ion exchange.
## G. Well survey data

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<th>Registered number</th>
<th>Bore ID</th>
<th>Easting</th>
<th>Northing</th>
<th>Top of steel casing (m AHD)</th>
<th>Top of PVC stand pipe (m AHD)</th>
<th>Top of concrete pad (m AHD)</th>
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<tr>
<td>RN019066</td>
<td>RT1</td>
<td>435013</td>
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<td>265.262</td>
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RN019074 (B1B) easting and northing recorded by DEWNR using Garmin hand-held GPS accuracy ±4 m

Survey company: Fyfe Surveying

Date: 14/10/2014

Surveyor: Brett Richardson

Equipment: NTGL10 (R8)

Coordinate Datum: MGA94 Zone 53

Level Datum: AHD (Ausgeoid 09)

Local Authority: Lilla Creek 1 BM (AUSPOS)

Report reference: 40188-1-2
H. Geological figures
Figure 6.4 Adjoining geological basins (Wohling et al. 2013)
7 Units of measurement

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

<table>
<thead>
<tr>
<th>Name of unit</th>
<th>Symbol</th>
<th>Definition in terms of other metric units</th>
<th>Quantity</th>
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<tbody>
<tr>
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<td>d</td>
<td>24 h</td>
<td>time interval</td>
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<tr>
<td>gigalitre</td>
<td>GL</td>
<td>$10^6$ m³</td>
<td>volume</td>
</tr>
<tr>
<td>gram</td>
<td>g</td>
<td>$10^{-3}$ kg</td>
<td>mass</td>
</tr>
<tr>
<td>hectare</td>
<td>ha</td>
<td>$10^4$ m²</td>
<td>area</td>
</tr>
<tr>
<td>hour</td>
<td>h</td>
<td>60 min</td>
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</tr>
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<td>kg</td>
<td>base unit</td>
<td>mass</td>
</tr>
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<td>kilolitre</td>
<td>kL</td>
<td>1 m³</td>
<td>volume</td>
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<tr>
<td>kilometre</td>
<td>km</td>
<td>$10^3$ m</td>
<td>length</td>
</tr>
<tr>
<td>litre</td>
<td>L</td>
<td>$10^{-3}$ m³</td>
<td>volume</td>
</tr>
<tr>
<td>megalitre</td>
<td>ML</td>
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<td>volume</td>
</tr>
<tr>
<td>metre</td>
<td>m</td>
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<tr>
<td>microgram</td>
<td>µg</td>
<td>$10^{-6}$ g</td>
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<td>microliter</td>
<td>µL</td>
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<tr>
<td>milligram</td>
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<tr>
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</tr>
<tr>
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<td>base unit</td>
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</tr>
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<td>tonne</td>
<td>t</td>
<td>1000 kg</td>
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<tr>
<td>year</td>
<td>y</td>
<td>365 or 366 days</td>
<td>time interval</td>
</tr>
</tbody>
</table>

7.2 Shortened forms

~ approximately equal to
bgs below ground surface
EC electrical conductivity (µS/cm)
K hydraulic conductivity (m/d)
L/s Litres per second
Ma Million years
m AHD metres Australian Height Datum
m/d metres per day
mg/L milligrams per litre
pH acidity
pmC percent of modern carbon
8 Glossary

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

Aquifer, confined — Aquifer in which the upper surface is impervious (see ‘confining layer’) and the water is held at greater than atmospheric pressure; water in a penetrating well will rise above the surface of the aquifer

Aquifer test — A hydrological test performed on a well, aimed to increase the understanding of the aquifer properties, including any interference between wells, and to more accurately estimate the sustainable use of the water resources available for development from the well

Aquifer, unconfined — Aquifer in which the upper surface has free connection to the ground surface and the water surface is at atmospheric pressure

Aquitard — A layer in the geological profile that separates two aquifers and restricts the flow between them

Artesian — An aquifer in which the water surface is bounded by an impervious rock formation; the water surface is at greater than atmospheric pressure, and hence rises in any well which penetrates the overlying confining aquifer

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

Bore — See ‘well’

$^{14}$C — Carbon-14 isotope (percent modern Carbon; pmC)

Confining layer — A rock unit impervious to water, which forms the upper bound of a confined aquifer; a body of impermeable material adjacent to an aquifer; see also ‘aquifer, confined’

δD — Hydrogen isotope composition, measured in parts per thousand ($\text{permil}$)

DEWNR — Department of Environment, Water and Natural Resources (Government of South Australia)

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

Ephemeral river recharge — the process of indirect recharge to aquifers resulting from episodic flow events in arid zone rivers. The process relates to recharge occurring through the base of a river bed and does not include any localised recharge that results from overbank flooding. Also called indirect or focussed recharge.

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

Floodout — An area where channelised flow ceases and floodwaters spill across adjacent alluvial plains

Focussed recharge — see ephemeral river recharge.

GAB — Great Artesian Basin.

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

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

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

Hydraulic conductivity (K) — A measure of the ease of flow through aquifer material: high K indicates low resistance, or high flow conditions; measured in metres per day.

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

Indirect recharge — see ephemeral river recharge.

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

LMWL — Local meteoric water line.

m AHD — Defines elevation in metres (m) according to the Australian Height Datum (AHD).
Model — A conceptual or mathematical means of understanding elements of the real world that allows for predictions of outcomes given certain conditions. Examples include estimating storm run-off, assessing the impacts of dams or predicting ecological response to environmental change.

Monitoring — (1) The repeated measurement of parameters to assess the current status and changes over time of the parameters measured (2) Periodic or continuous surveillance or testing to determine the level of compliance with statutory requirements and/or pollutant levels in various media or in humans, animals and other living things.

$\delta^{18}$O — Oxygen isotope composition, measured in parts per thousand (‰).

Observation well — A narrow well or piezometer whose sole function is to permit water level measurements.

Palaeochannels — Ancient buried river channels in arid areas of the state. Aquifers in palaeochannels can yield useful quantities of groundwater or be suitable for ASR.

Permeability — A measure of the ease with which water flows through an aquifer or aquitard, measured in m²/d or millidarcies.

Piezometer — see ‘Observation well’.

Potentiometric head — The potentiometric head or surface is the level to which water rises in a well due to water pressure in the aquifer, measured in metres (m); also known as piezometric surface.

Production well — The pumped well in an aquifer test, as opposed to observation wells; a wide-hole well, fully developed and screened for water supply, drilled on the basis of previous exploration wells.

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

Specific storage ($S_s$) — Specific storativity; the amount of stored water realised from a unit volume of aquifer per unit decline in head; it is dimensionless.

Specific yield ($S_y$) — The volume ratio of water that drains by gravity, to that of total volume of the porous medium. It is dimensionless.

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

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

Tertiary aquifer — A term used to describe a water-bearing rock formation deposited in the Tertiary geological period (1–70 million years ago).

Transmissivity ($T$) — A parameter indicating the ease of groundwater flow through a metre width of aquifer section.

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

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

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

Water quality standard — A law or regulation that consists of the beneficial designated use or uses of a water body, the numerical and narrative water quality criteria that are necessary to protect the use or uses of that particular water body, and an anti-degradation statement.

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


