Pedirka Basin Aquifer Connectivity Investigation

DEWNR Technical report 2015/08

Government of South Australia
Department of Environment, Water and Natural Resources

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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

Acknowledgements

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- The owners and managers of Andado Station (Northern Territory) for allowing the development of the field site on their land and for providing access to water wells during the program.
- The Department of Land Resource Management (DLRM) drilling services group who successfully completed the drilling program in challenging and remote conditions.
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- The project technical advisory group for program oversight and review.

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Summary

The South Australian Department of Environment, Water and Natural Resources (DEWNR) was provided funding 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. In the western Lake Eyre Basin, DEWNR is undertaking three investigations including; the Lake Eyre Basin Rivers Monitoring Project, the Arckaringa Basin and Pedirka Basin Groundwater Assessment Project and the Lake Eyre Basin Springs Project. This report documents the investigation of hydraulic connection between the Pedirka Basin and overlying Great Artesian Basin (GAB) and forms a key component of the Arckaringa Basin and Pedirka Basin Groundwater Assessment.

In 2013, DEWNR completed a desktop review that identified several key knowledge gaps in the current understanding of the Pedirka Basin hydrogeology. These included the lack of groundwater investigation wells in the Pedirka Basin, and highlighted the uncertainty surrounding the inter-connectivity between the Pedirka Basin and the overlying GAB. To address these knowledge gaps DEWNR commissioned the Pedirka Basin aquifer connectivity investigation, which aims to deliver an improved understanding of intra-aquifer connectivity within the Pedirka Basin and inter-aquifer connectivity between the Permian formations and overlying GAB sequence.

The project involved the construction of a dedicated connectivity investigation site on Andado Station in the Northern Territory. A pilot hole was drilled to a depth of 531 m in the basal Permian Crown Point Formation. Information derived from wireline logging and drill cuttings provides a comprehensive and unprecedented picture of the hydrostratigraphy in this region of the Pedirka Basin. A nested piezometer site was completed with observation wells constructed in the Cadna-owie Formation (110 m), Algebuckina Sandstone (199 m), Purni Formation (242 m) and the Crown Point Formation (531 m). A multi-well 48-hour aquifer test was undertaken pumping the Purni Formation well to investigate the hydraulic connection throughout the profile. All nested wells were sampled for groundwater chemistry and environmental tracers.

On the basis of findings from the stratigraphic drilling and aquifer test program, it is concluded that the upper Purni Formation (Pedirka Basin) is highly connected to the J Aquifer (GAB) at the investigation site. This conclusion is based on the absence of an effective intervening aquitard between the formations and the rapid pressure response (14 minutes after test commencement) observed in the J Aquifer during the 48-hour pumping test in the upper Purni Formation. Aquifer tests also revealed a high level of hydraulic connection within the J Aquifer. Uncertainty remains regarding the level of connection between the Purni Formation and Crown Point Formation. The stress period in the 48-hour pumping test was most likely inadequate to produce a pressure response in the Crown Point Formation piezometer.

Aquifer parameter estimates were derived using analytical models and are presented as a range of probable values to best reflect the inherent uncertainty and non-unique nature of the solutions. The Purni Formation transmissivity is estimated to be between 176 and 264 m^2/d, which corresponds to a horizontal hydraulic conductivity ($K_{H)}$ of 4 to 6 m/d, while the storage coefficient is estimated to be between 5 x 10^{-5} and 1 x 10^{-4}. The cumulative transmissivity of the J Aquifer is estimated to be between 1 190 and 2 260 m^2/d (K_H 15 to 25 m/d) and storage coefficient between 1 x 10^{-3} and 1.9 x 10^{-3}. The transmissivity of the Crown Point Formation is estimated at 14 m^2/d with K_H ranging between 0.2 and 2.3 m/d. No estimate of storage coefficient was made for the Crown Point Formation due to the single well test format.

Water quality data, in particular the major ion signature, stable isotope and strontium isotope composition of groundwater in the GAB and Permian aquifers do not support a disconnected aquifer system. The apparent groundwater age, based on Carbon-14 concentration, is consistent across the three aquifers and indicates that modern recharge is not occurring at the site. This similarity in apparent groundwater age may indicate that palaeo-recharge to the Pedirka Basin and GAB Basin was contemporaneous in this area.

An evaluation of the lithology between the Permian coal measures and the GAB in 21 oil/gas/coal exploration wells suggests the Purni Formation and J Aquifer are connected, particularly in the north-west of the basin where the major coal resource is located. The connection is assessed as limited where the Purni Formation and J Aquifer are separated by a thick sequence of fine-grained Triassic sediments. Such sequences are considered spatially constrained to structural lows and basin depocentres such as the Madigan and Poolowanna Troughs.

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 coal seam gas and large coal mining 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 coal seam gas or large coal mining 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 coal seam gas and large coal mining 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 coal seam gas and large coal mining 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 coal seam gas and large coal mining 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 commissioned 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 Lake Eyre Basin bioregion, including the:

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

This report documents the investigation of hydraulic connection between the Pedirka Basin and overlying Great Artesian Basin (GAB); and forms a key component of the Arckaringa Basin and Pedirka Basin Groundwater Assessment.

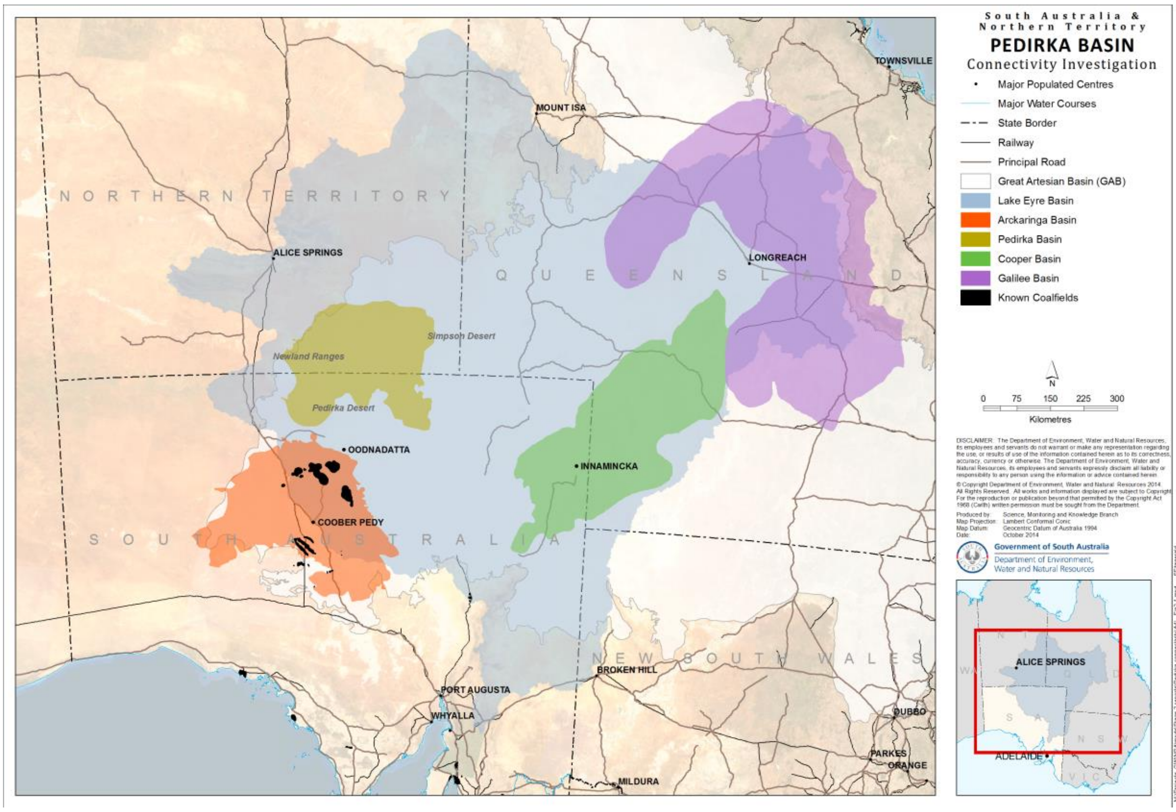


Figure 1-1 Lake Eyre Basin bioregion, showing coal bearing basins, known coalfields and the Great Artesian Basin

1.2 Pedirka Basin groundwater assessment

In 2013, DEWNR undertook a desktop assessment aimed at benchmarking the level of hydrogeological knowledge for the Arckaringa and Pedirka basins (Wohling et al. 2013). The review identified fundamental data gaps in the characterisation of the Pedirka Basin groundwater system, these include:

- Limited information on the hydrogeology and hydraulic behaviour of the two 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 is 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 address 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, focussed ephemeral river recharge and Dalhousie Springs discharge. This report details the findings from the aquifer connectivity investigation.

1.3 Aquifer connectivity investigation

In 2014, the IESC released a background review of aquifer connectivity within the Great Artesian Basin, and the Surat, Bowen and Galilee basins (Commonwealth of Australia, 2014). The report describes a range of scientific methods developed to measure and model aquifer connectivity including hydraulic, laboratory, geophysical and geochemical techniques, in addition to analytical and numerical modelling approaches. Where possible the review recommends the application of multiple approaches to improve confidence in the assessment of aquifer connectivity.

Existing information on the hydrogeology of the Pedirka Basin and its potential connection with the GAB is extremely limited. The absence of wells in the Purni Formation and the limited number of wells in the Crown Point Formation restrict the application of a number of methods described in the Commonwealth of Australia (2014) report. The Pedirka Basin groundwater assessment aims to address these fundamental data gaps by establishing a dedicated aquifer connectivity study site. The installation of targeted groundwater wells will allow for the application of hydraulic, geophysical and geochemical techniques to help characterise the inter-connection between the Pedirka Basin and GAB while also establishing a site for longer-term monitoring and future studies.

1.4 Objectives

The Pedirka Basin aquifer connectivity investigation aims to deliver an improved understanding of intra-aquifer connectivity within the Pedirka Basin and inter-aquifer connectivity between the Permian formations and overlying GAB sequence. The investigation aims to advance the conceptual understanding of basin hydrodynamic processes to inform future water resource and development activities. The assessment has the following specific objectives to:

- drill a pilot hole through the GAB and Pedirka Basin sequence in order to create a detailed hydrostratigraphic type section
- establish a dedicated aquifer connectivity investigation site with piezometers constructed in the Crown Point Formation and Purni Formation (Pedirka Basin) and the Algebuckina Sandstone and Rolling Downs Group (GAB)
- assess the inter-connectivity between the coal-bearing Permian sequence and overlying GAB aquifer (J Aquifer) and the intra-connectivity within the Pedirka Basin (i.e. between the Purni Formation and Crown Point Formation)
- provide estimates of aquifer parameters for the Purni Formation, and where possible, the J Aquifer and Crown Point Formation
- characterise water quality attributes and hydrochemistry of the Crown Point Formation, Purni Formation and J Aquifer
- evaluate site specific connectivity findings in the context of the greater Pedirka Basin.

2 Regional setting

The following section provides a summary of the location, physiography, geology and hydrogeology of the Pedirka subregion. The Pedirka subregion is one of four subregions comprising the LEB bioregion and is defined by the extent of the Pedirka geological basin. This is intended to provide context for the site specific investigations documented in this report, further detail can be found in the Arckaringa Basin and Pedirka Basin desktop assessment (Wohling et al. 2013).

2.1 Location and physiography

The Pedirka subregion is centred on the South Australia/Northern Territory border, approximately 860 km north–north-west of Adelaide and 160 km south-east of Alice Springs (Figure 3-1). The basin underlies a surface area of approximately 60 000 km^2 with roughly 60 % of the basin located in the Northern Territory and 40 % in South Australia. The topography is relatively flat-lying with an elevation range between 0 and 450 m AHD and a mean elevation of 144 m AHD. The physiography of the eastern and central regions of the basin is dominated by the longitudinal dune fields of the Simpson Desert. The western margin is characterised by highlands and plateaus of the Newland and Rodinga Ranges, which contain the only surface expression of the Pedirka subregion. Anastomosing rivers and creeks form wide, gently sloped valleys, swales and floodplains that provide much of the observed topographic variability in the west of the basin. Drainage in the region is characterised by a network of ephemeral rivers and creeks that fall concentrically east towards Kati Thanda-Lake Eyre. Major ephemeral drainage lines include the Finke and Hale Rivers as well as Goyder, Lilla, Coglin, Stevenson and Hamilton Creeks. Not all of these water courses drain directly into Kati Thanda-Lake Eyre; with rivers located in the Northern Territory terminating in ephemeral lakes and playas in the Simpson Desert.

2.2 Geology

Pedirka Basin

The Pedirka Basin is an intra-cratonic sedimentary basin comprising early to late Permian sediments and coal sequences. It is divided into two main units, the glacial Crown Point Formation and the overlying coal-bearing Purni Formation. The basin largely occurs subsurface at depths greater than 400 m and reaches a maximum depth of 3000 m in the south-east (Munson and Ahmad, 2012). The Crown Point Formation is a glaciofluvial to periglacial unit consisting of conglomerate, diamictite, pebbly coarse-grained sandstone, fine sandstone and thick claystone beds. A clean sand at the top of the Crown Point Formation is typically used as a marker for the end of glaciation; Ambrose and Heugh (2012) and Munson and Ahmad (2012) regard this sand unit as a distinct formation and have named it the Tirrawarra Sandstone, suggesting it is the equivalent of the Cooper Basin formation of the same name. The unit is not formally recognised in the Pedirka Basin and is considered in this report as a sub-unit of the Crown Point Formation. The Crown Point Formation unconformably overlies Amadeus Basin/Warburton Basin sediments (Figure 2-1) and, where these are absent, Proterozoic bedrock. It conformably underlies the Purni Formation and where absent unconformably underlies the Jurassic to Cretaceous Eromanga and Triassic Simpson Basins. The Crown Point Formation outcrops in the west of the Pedirka Basin on the Finke, Rodinga and Hale River 1:250 000 mapsheets. It is extensive across the Pedirka Basin and reaches a maximum recorded thickness of 504 m in drillhole Mount Hammersley-1 in South Australia.

The Purni Formation forms an alluvial/paludal sequence comprising beds of white kaolinitic sandstone, occasional thin conglomerates, thinly bedded grey shales, siltstones, coal and very carbonaceous shales (Youngs, 1975). The Purni Formation disconformably underlies the Simpson Basin and where absent, the Eromanga Basin; it conformably overlies the Crown Point Formation. The formation is widespread across the western Pedirka Basin and it is present on the Andado Shelf where this aquifer connectivity investigation site is located. The western extent of the Purni Formation is poorly constrained and it is presumed to pinch out subsurface to the west of the connectivity site. The Purni Formation reaches a maximum recorded thickness of 564 m in Blamore-1, which is located in the centre of the Pedirka Basin (Figure 3-1).

Simpson Basin

The subsurface Triassic Simpson Basin directly overlies the Permian formations in the central and eastern Pedirka Basin. The Simpson Basin comprises two sedimentary units: the Peera Formation and Walkandi Formation (Figure 2-1). The Peera Formation consists of shale, siltstone, fine to coarse grained sandstone and coal, and is most extensively developed in the Poolowanna Trough where it attains a maximum recorded thickness of 190 m at Walkandi-1 (Munson and Ahmed, 2012). The Walkandi Formation is a continental succession consisting of interbedded shale, siltstone and minor fine grained sandstone (Munson and Ahmed, 2012). The Walkandi Formation is thickest in the basin depocentres (see Keppel et al. 2013, Munson and Ahmed, 2012 for further detail) and attains a maximum recorded thickness of 247 m at Blamore-1.

Eromanga Basin (Great Artesian Basin)

The Jurassic to Cretaceous Eromanga Basin sequence directly overlies the Simpson Basin where present and where absent in the west of the basin Permian Purni and Crown Point formations. In this region the Eromanga Basin is synonymous with the Great Artesian Basin, it comprises a thick upper sequence of marine shales, siltstones and minor sandstones collectively named the Rolling Downs Group and a lower continental succession of massive cross-bedded quartz sandstone. The lower succession comprises the transitional Cadna-owie Formation, Algebuckina Sandstone and basal Poolowanna Formation.

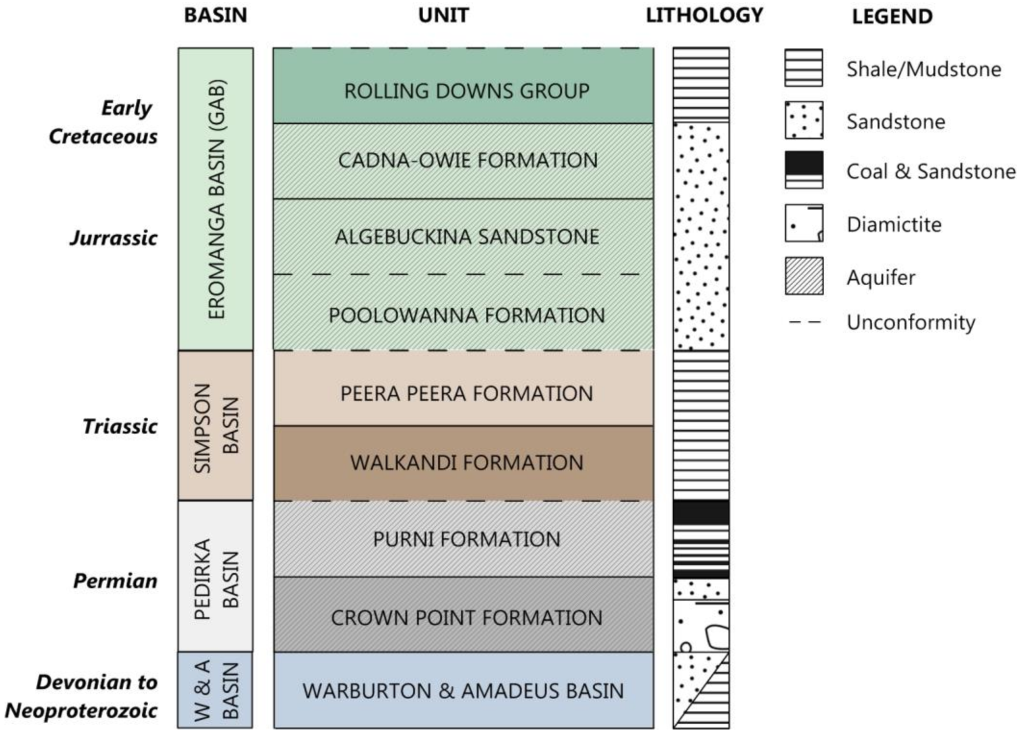


Figure 2-1 Simplified stratigraphic log for the Pedirka Basin and adjacent units

2.3 Hydrogeology

Crown Point Formation (Pedirka Basin)

There are limited groundwater data available for the Crown Point Formation as all wells are located on the western margin of the Pedirka Basin, where the formation outcrops and is used as a stock supply for pastoral enterprises. A total of 27 wells have been constructed in the Crown Point Formation; 12 of which are currently operational. Well depth ranges from 12 to 192 m and depth to water ranges from 5 to 159 m. The shallowest groundwater is found in wells immediately adjacent to the Finke River at depths of less than 10 m. Groundwater sampling undertaken by DEWNR in 2012 identified modern groundwater (post 1950) in these wells indicating active recharge (Wohling et al. 2013). Water quality is variable with Total Dissolved Solids (TDS) ranging from 93–7910 mg/L. The best quality groundwater is located adjacent to the Finke River and Goyder Creek where the resource is potable (< 500 mg/L) but the quality deteriorates away from these zones reaching almost 8000 mg/L in the north west of the basin. Porosity estimates for the Crown Point Formation range from 11–32 % from laboratory core analysis with permeability estimates between 91 and 1998 mD (equivalent hydraulic conductivity range of 0.08–1.66 m/d). There are no published estimates of aquifer transmissivity or storativity for the Crown Point Formation.

Purni Formation (Pedirka Basin)

No groundwater wells have been constructed in the Purni Formation and consequently there are no data available on groundwater levels, well yields, water quality attributes or aquifer parameters for this formation. Data collated from petroleum and gas well completion reports provide a porosity range of 4–32 % and a permeability range of 0.2–2529 mD (equivalent hydraulic conductivity of 0.0017–2.44 m/d).

J Aquifer (GAB)

The J Aquifer forms the principal GAB aquifer in the west of the basin, comprising the Cadna-owie Formation, Algebuckina Sandstone (also known in the Northern Territory as the De Souza Sandstone) and Poolowanna Formation. The aquifer is unconfined along the western basin margin and confined in the central and eastern portion of the Pedirka Basin where it reaches a maximum recorded thickness of 1000 m. The fractured sandstone aquifer is highly transmissive and exhibits dual porosity where unconfined (Fulton, 2013). Aquifer pumping tests conducted where the J Aquifer is confined yielded transmissivities of 2470–2600 m^2/d, storage coefficients from 6 x 10^{-4} to 1.2 x 10^{-3} and an average hydraulic conductivity of 11 m/d (Fulton, 2013). Porosity measurements for the J Aquifer range from 10–29 % with an average porosity of 23 % (Radke, 2000). Typical well yields are recorded at 0.1 to 6.0 L/s by Kellet (1999), though Fulton (2012) notes that well yields often reflect stock water requirements and yields of up to 100 L/s (McDills No. 1) have been reported where the basin is artesian. Detailed hydrogeological summaries of the western GAB can be found in Smerdon et al. (2012), Keppel et al. (2013), Love et al. (2013a) and Love et al. (2013b).

Other aquifers

Local aquifer systems have also been identified in Cenozoic sediments overlying the GAB sequence (Keppel et al. 2013), in fractured shale and sandstone interbeds within the Cretaceous Rolling Downs Group (Fulton, 2012) and in the Devonian Finke Group (Fulton, 2012, Lau and Jacobson, 1991), which forms part of the Warburton Basin that underlies the Crown Point Formation. No information is available for the hydrogeology of the Triassic Walkandi or Peera Formations.

3 Site establishment

3.1 Site selection

DEWNR completed a desktop review to identify a suitable site for the aquifer connectivity investigation drilling by applying the following selection criteria. The:

- Purni Formation, Crown Point Formation and J Aquifer underlie the site, are saturated and each have a minimum expected thickness of 20 m.
- expected depth to the Crown Point Formation is less than 500 m.
- site is located outside the artesian (flowing) portion of the GAB.
- site is located close to the known coal resource.
- site has an open, flat area of at least 10 000 m^2 and good access roads.
- site is within 5 km of an operational and equipped groundwater well.

Estimates of formation extents and thicknesses were drawn from the Pedirka Basin Hydrogeological Map, developed as part of the Arckaringa Basin and Pedirka Basin desktop assessment (Wohling et al. 2013). Information on expected artesian conditions within the J Aquifer was sourced from the South Australia and Northern Territory Hydrogeological Map of the Great Artesian Basin Part 2 (Sampson et al. 2012). No suitable sites were identified in the SA portion of the Pedirka Basin as the target formations were generally too deep to drill within program budget and were remote to the known coal resource. Two potential sites were identified on Andado Station in the NT: a southern site located approximately 25 km northwest of Andado Homestead and a northern site located approximately 30 km north-northwest of Old Andado Homestead. In June, 2013 a reconnaissance trip was undertaken to compare access, heritage clearance and proximity to water supply between the two sites. The northern site was selected as the preferred location for the connectivity drilling program.

3.2 Site location

The drilling site is located on Andado Station approximately 220 km south-east of Alice Springs (Figure 3-1). Access from Alice Springs is via Santa Teresa and the Old Andado Road. Southern access is from the Stuart Highway at Kulgera via Finke and Andado Homestead. The site is located on the Safari Bore access track approximately 10 km north of the junction with the Old Andado Road. The drilling pad (Figure 3-2) is situated on a small, rocky, gibber plain in the swale between two prominent sand dunes. The immediate area surrounding the drilling pad is flat lying, while the topography of the surrounding area has a gentle gradient to the southwest. The landscape is sparsely vegetated with Gidgee *(Acacia cambagei)*.

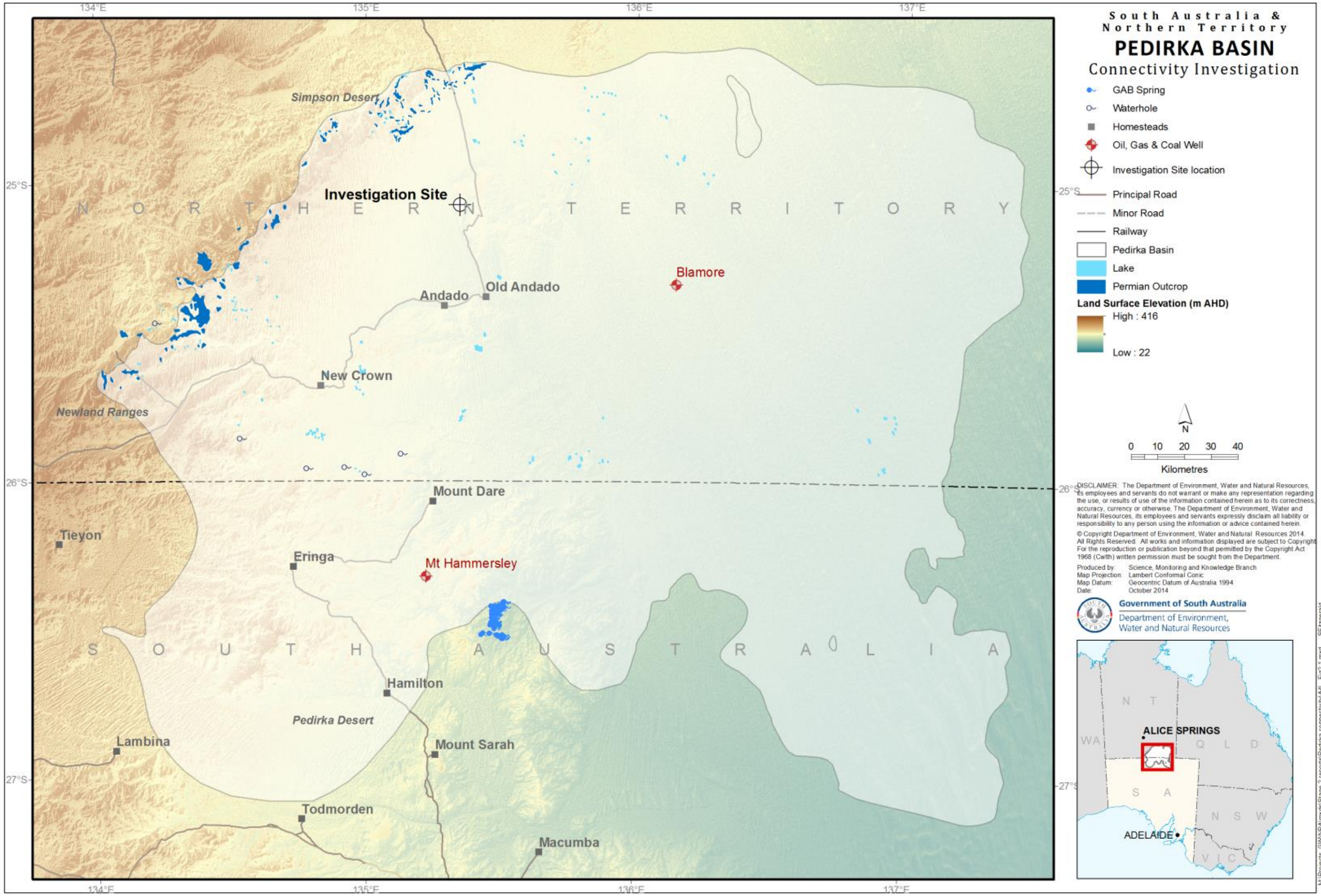


Figure 3-1 Location map

3.3 Drilling program overview

The drilling program commenced on 29 July 2013 and concluded ten weeks later on 4 October 2013. A total of 1326 m was drilled over 54 days of active drilling. The program included the construction of four monitoring wells and one test production well. The initial phase of works involved the drilling and geophysical logging of a pilot hole which was used to construct a detailed hydrostratigraphic profile for the site (Appendix A). This profile provided the control for the second phase of works, which involved the construction of a piezometer in the Crown Point Formation, drilling of the Purni Formation test production well, and drilling and construction of piezometers in the J Aquifer and Purni Formation. A summary of the drilling results is provided below in Table 3-1 and Figure 3-3**.**

Table 3-1 Summary of well completion and location details

Well ID	Easting GDA94 Z53	Northing GDA94 Z53	Completion date	Drilled depth (m)	Aquifer monitored	SWL m BGS*	RWL# m AHD
RN018915	534791	7227114	20-08-2013	531	Crown Point Formation	39.33	155.85
RN018916	534796	7227122	06-09-2013	111	J Aquifer (upper)	41.70	153.48
RN018917	534788	7227109	13-09-2013	199	J Aquifer (lower)	41.85	153.11
RN018918	534798	7227112	25-09-2013	242	Purni Formation	42.25	153.01
RN018919	534857	7227071	03-10-2013	243	Purni Formation	42.52	152.66

* Standing water level (SWL) taken on 06-03-2014 measured in metres below ground surface (m BGS)

\# Reduced water level (RWL), not corrected for density effects. Wells were surveyed using a laser level relative to the concrete pad on RN18918 and referenced to a local surface elevation of 195 m AHD sourced from the SRTM 1-Second Digital Terrain Model

The drilling works were completed under contract by the drilling services group from the Northern Territory Department of Land Resource Management (DLRM). Site supervision and logging was undertaken by a rotating team of hydrogeologists from DEWNR. The holes were drilled using a trailer mounted Ingersoll Rand T75 rig crewed by a team of four drillers under the supervision of site foreman, Ian McMasters. The Ingersoll Rand T75 is a top head drive equipped to drill using rotary air and rotary mud drilling methods. For this program the rig has a practical depth limit of 540 m. To maintain hole stability and circulation during drilling, AMC (Australian Mud Company) developed a custom mud program and provided onsite support during drilling of the pilot hole. Detail on the mud program and drilling conditions can be found in Appendix B. Water for the drilling process was sourced from stock well RN16954, located two kilometres west of the site.

Drill cuttings were collected every three metres (twice for each six metre drilling rod) and laid out in order of increasing depth for logging by the site hydrogeologist. Small cutting samples were collected in chip trays and larger bulk samples in white calico bags for future reference. The drillers also bagged samples every three metres and collected 1 L water samples during development, which were submitted to DLRM in accordance with well licensing conditions.

Figure 3-2 Ingersol Rand T75 and support vehicles during drilling of pilot hole (RN18915)

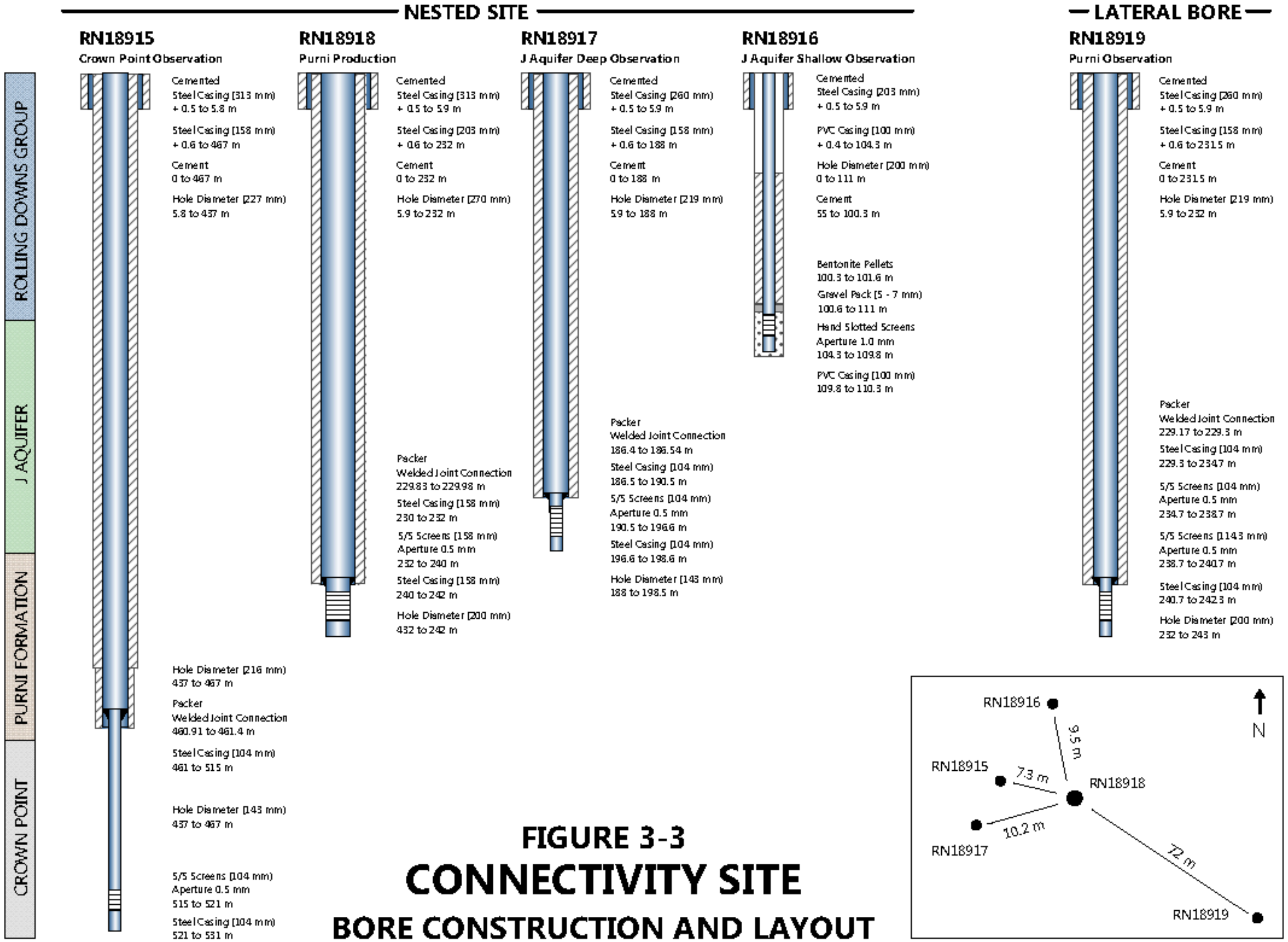


Figure 3-3 Connectivity site bore construction and layout

3.4 Drilling and construction

The aquifer connectivity investigation site consists of a piezometer nest with observation wells screening the Crown Point Formation (RN18915), the base of the J Aquifer (RN18917) and the transition between the Bulldog Shale and J Aquifer (RN18916), in addition to a test production well in the Purni Formation (RN18918). An observation well in the Purni Formation (RN18919) targeting the same sand/coal interval as RN18918 was drilled approximately 70 m south east of the nested site. All wells were constructed in accordance with minimum construction requirements (NUDLC, 2012) and completed with a steel standpipe set in a 1 m^2 concrete slab. On completion wells were developed using compressed air until field parameters stabilised. Well yield was estimated during air lifting using a v-notch weir. The elevation of the wells was referenced back to the concrete pad around RN18918 using an electronic level. Key well construction details are summarised in Table 3-2, additional construction detail and a site layout are provided in Figure 3-3. The *Statement of Bore*, containing the driller's well logs and construction records are provided in Appendix C.

Table 3-2 Summary of well construction

Well ID	Constructed depth (m)	Casing type ID (mm)	Casing from (m)	Casing to (m)	Screen type	Screen from (m)	Screen to (m)	Well yield (L/s)
RN18915	531	Steel (158)	+0.6	467	S/Steel	515	521	6
RN18916	110.3	PVC (100)	+0.42	110.3	PVC	104.3	109.8	5
RN18917	198.6	Steel (158)	+0.6	187.6	S/Steel	190.5	196.6	11
RN18918	242	Steel (203)	+0.6	231.7	S/Steel	232	240	32
RN18919	242.3	Steel (158)	+0.6	231.5	S/Steel	234.7	240.7	6

3.4.1 RN18915 Crown Point Formation observation well

Drilling of the pilot hole (RN18915) commenced with the installation of six metres of 273 mm steel surface casing in a 313 mm hole to depth of 5.9 m. The casing was cemented and allowed 24 hours to cure. Drilling continued with a 9 in blade bit and mud rotary methods to a depth of 467 m. Penetration rates dropped significantly between 454 and 467 m. The drill string was tripped out and inspection of the drill bit revealed the diameter had abraded from 9 to 7 in (Figure 3-4A). The worn drill bit was replaced with an 8.5" blade bit and the hole was reamed to 216 mm between 437 and 467 m. The drill string was removed and geophysical logging completed to a depth of 466 m. The hole was cased with 158 mm steel to 467 m and pressure cemented back to surface with a 20:1 cement/bentonite grout. The grout was allowed 48 hours to cure before the cement plug was reamed out and a 149 mm hole drilled to a total depth of 531 m. The drill string was tripped out and the hole re-logged with geophysical tools to a depth of 522 m. Six metres of 104 mm stainless steel screens were lowered into the hole targeting an interval with a lower gamma/higher neutron count between 515 and 521 m. The screen section was attached to a 10 m sump (104 mm steel) resting on the base of the hole and 54 m of steel casing (104 mm) which was suspended through the 158 mm steel casing using a K packer. The well was developed using compressed air which was surged through the drill string for 3.5 hours from a depth of 209 m. The flow rate was estimated at 6 L/s using a v-notch weir. Water quality was measured during development with a portable TPS unit which reported a water temperature of 41.8 °C, a pH of 7.45 and an electrical conductivity (EC) of 26.1 mS/cm. The standing water level at the completion of drilling was 39.16 m BGS.

Figure 3-4 (A) Abraded drill bit after 464 m drilling and (B) drill cuttings after 300 m drilling on RN18915

3.4.2 RN18916 upper J Aquifer observation well

Drilling of RN018916 commenced with the installation of 6 m of 203 mm steel surface casing cemented to a depth of 5.9 m. A 200 mm hole was drilled with air rotary to a depth of 100 m. No water intersections were recorded and drilling operations were suspended for an hour at 63 m and two hours at 100 m without any free water observed in the Bulldog Shale. Drilling recommenced and groundwater was intersected at 105 m in the transitional beds (Cadna-owie Formation) between the Bulldog Shale and Algebuckina Sandstone. The 200 mm hole was extended to 111 m and 100 mm Class 12 PVC casing was run to a depth of 110.3 m. The casing was perforated between 104 and 110 m with 1 mm horizontal slots. The annulus was filled with 3-5 mm gravel to a depth of 101.6 m, capped with bentonite pellets to 100.3 m and a 20:1 cement/bentonite grout to 55 m. The well was airlifted for 3.5 hours from a depth of 66 m at a flow rate of approximately 5 L/s. The temperature of the discharge water was 32 °C, the pH 7.97 and EC 6.67 mS/cm. The standing water level at completion was 41.97 m BGS.

3.4.3 RN18917 lower J Aquifer observation well

Observation well RN18917 was constructed in a basal sand unit of the J Aquifer immediately above the top of the Purni Formation. Drilling commenced with the installation of 260 mm steel surface casing to a depth of 5.9 m, the casing was cemented in place and left to cure for 24 hours. A 219 mm hole was drilled with mud to a depth of 187.6 m. Steel casing (158 mm diameter) was run to depth and pressure cemented to the surface with a 20:1 cement/bentonite grout. The cement plug at the base of the casing was drilled out and a 143 mm hole was drilled to a depth of 198.5 m. Six metres of 104 mm stainless steel screens (1 mm aperture) were lowered and positioned between 190.5–196.6 m. The screens were welded to a 2 m steel sump (104 mm) resting on the bottom of the hole and were attached to 4 m of 104 mm steel casing that was secured to the 158 mm casing with a K packer. The well was airlifted for 3 hours from a depth of 176 m and produced an estimated yield of 11 L/s. The discharge water recorded an EC of 9.1 mS/cm and a pH of 7.21. The water level at completion was 41.75 m BGS.

3.4.4 RN18918 Purni Formation test production well

RN18918 was constructed as a test production well in the Purni Formation and screens a thick sandstone sequence immediately above the first significant coal intersection (243–245 m). Drilling of the well commenced with the installation of six metres of 313 mm surface casing, which was cemented to a depth of 5.9 m in a 381 mm hole. A 270 mm hole was drilled using mud through the Rolling Downs Group, J Aquifer and upper Purni Formation to a depth of 231.7 m. Steel casing (203 mm) was run to depth and pressure cemented back to surface with a 20:1 cement/bentonite grout. The cement was allowed 36 hours to cure before drilling recommenced and a 200 mm hole was drilled through the cement plug to a depth of 242 m. A casing string comprising two metres of blank 158 mm steel, eight metres of 158 mm stainless steel screens (0.5 mm aperture) and a 2 m steel sump (158 mm) was lowered into the hole. The screens were set between 232 and 240 m and secured to the 200 mm casing with a K packer. The well was developed with air for 5 hours from a depth of 180 m at an estimated flow rate of 32 L/s. The EC of the discharge water was measured at 12.5 mS/cm and the pH at 7.2. The water level at completion of drilling was 41.88 m BGS.

3.4.5 RN18919 Purni Formation observation well

RN18919 was drilled to provide an observation well in the Purni Formation, it was constructed in the same sandstone interval as RN18918 at a horizontal distance of 72 m. Steel surface casing (260 mm) was cemented to 5.9 m in a 311 mm hole. A 219 mm hole was drilled with mud through the surface casing to 232 m and 158 mm steel casing was installed to a depth of 231.5 m. The casing was pressure cemented to surface with a 20:1 cement/bentonite grout and left for 24 hours to cure. The cement plug was reamed out and a 200 mm hole drilled to 243 m. A casing string comprising five metres of 104 mm steel blank, 6 m of stainless steel screens (0.5 mm aperture) and a 2 m steel sump (104 mm) was suspended in the 158 mm casing with a K-packer.

A large volume of sand was produced during development and the well depth was gauged at 182 m indicating the formation pressure had forced the screens up inside the 158 mm casing. The drilling crew removed the screens revealing the bottom 2 m were concertinaed, these were removed and replaced with an equivalent length of 114 mm stainless steel screen. The hole was reamed to 243 m to remove cuttings and sand. The 104 mm casing and screens were then lowered on the drill string and the screens positioned between 234.7 and 240.7 m. The completed well was air lifted from 121 m for a duration of 2.5 hours, the flow rate was estimated at 6 L/s. Only trace fine sand was produced during development. The groundwater recorded a temperature of 32.8 °C, an EC of 12.7 mS/cm and a pH of 7.42. The standing water level at completion was 42.27 m BGS.

3.5 Geophysical logging

Geophysical logging of the pilot hole was undertaken by the DEWNR Resource Monitoring Unit. An initial logging run was undertaken in the uncased pilot hole to a depth of 466 m. This run aimed to corroborate formation intersections estimated from the drill cuttings before the permanent casing was installed. Due to the malfunction of the depth encoder during logging results were only obtained for the gamma and neutron tools between 466 m and 320 m. The fault could not be resolved on site and the logging unit returned to Adelaide, SA for servicing.

The logging unit remobilised to site on 17 August with drilling suspended at a depth of 531 m. The hole was logged to a depth of 522 m; the interval 522 to 466 m was open hole and the interval from 466 m to the surface was logged through cemented steel casing (158 mm). Two separate logging runs were completed, the first with gamma and neutron tools and the second with calliper, near density and far density tools.

Results of the geophysical logs are provided in the composite log in Appendix A. The gamma and neutron plots have been corrected to compensate for the dampened readings in the cased section of the log (0–466 m). The correction was based on the interval 320–466 m, which was logged open hole in the initial run and through casing in the second run.

4 Drilling results

4.1 Stratigraphy

The following section summarises the stratigraphy encountered during drilling of RN18915. A detailed compositional record providing a lithological description for each three meter interval can be found in tabular format in Appendix D and an interpretation of the sequence from both the drill cuttings and the geophysical logs is provided in a composite log in Appendix A.

QUATERNARY SEDIMENTS (0–3 m). Red-brown clayey sand of aeolian provenance, predominantly very fine to fine grained angular quartz sand with development of gibber cobbles at surface. The formation is unconsolidated and porous, the clay component shows iron oxide staining but displays no plasticity.

BULLDOG SHALE (3–103 m). Light green to grey-brown, silty shale with planar laminations and claystone. The upper 31 m is highly weathered and gypsiferous, and the shale is soft with no plasticity and low permeability. The formation is slightly weathered from 31 m and fresh below 61 m where the shale is darker grey in colour, firm with no plasticity and impermeable (see Figure 4-1). The formation has a predominantly clay mineralogy with traces of glauconite from 61 m giving a distinctive green colouration.

CADNA-OWIE FORMATION (103–109 m). Comprising a thin sandstone unit marking the transition between the marine Bulldog Shale and the continental Algebuckina Sandstone, the Cadna-owie Formation consists of a coarse grained, unconsolidated quartz sandstone. The formation was difficult to separate from the underlying Algebuckina Sandstone during drilling and was distinguished on the basis of its distinctive low gamma ray response.

ALGEBUCKINA SANDSTONE (109–197 m). Light to medium grey in colour, predominantly quartz in composition with sub-rounded to rounded grains ranging from fine sand to granule in grain size (Figure 4-1). The sandstone is highly porous and friable with no plasticity. The formation contains minor interbeds of planar laminated, silty shale.

PURNI FORMATION (197–474 m). The Purni Formation was picked at 197 m from the appearance of lignite in cuttings and an increase in gamma ray response. The formation is 277 m thick and has been informally divided into four distinct stratigraphic sequences:

1. Gradational Coal Bearing Sequence (197–258 m) comprising five fining upward sequences from fine to very coarse sandstone through to silty shale, claystone and minor coal. Colour varies from medium to dark grey. The thickness of the sequences ranges between 9 and 18 m and increases with depth. The coal is peaty, brown lignite, sub-fissile to fissile and predominantly dull with bright bands of black coal. The shale is silty and clayey. The sandstones are angular to sub-rounded, fine to very coarse grained and comprise predominantly a quartz mineralogy. The sediments are soft, with negligible to medium plasticity and range from low to highly permeable.

2. Carbonaceous Shale/Coal Sequences (258–405 m) comprising six fining up sequences from very fine to medium grained clayey sandstone to predominantly silty shale, claystone, carbonaceous shale and coal. Colour varies from medium to dark grey. The coal is dull, sub-fissile and brown to black in colour (Figure 4-1). The shale is micaceous with planar laminations and is variably carbonaceous. The sediments are soft, impermeable to low permeability and highly plastic.

3. Sandy Clay Sequence (405–441 m) marked by a lower/more uniform gamma ray response and the absence of coal seams. The sandy clay is medium grey in colour, the sand is very fine to medium grained, sub-rounded and predominantly quartz, with a fining upward trend. The clay is highly plastic and micaceous. The sediments are firm with a low permeability and contain bands of harder silicified shale.

4. Clayey Sand Sequence (441–474 m) comprising very fine to coarse grained sandstone with a fining upward trend and trace pyrite cement. The sand grains are rounded and predominantly quartz with minor lithic fragments of shale and siltstone. The clay is grey and micaceous with minor kaolinite. The sediments are predominantly soft but with minor hard bands of silicified clayey shale.

CROWN POINT FORMATION (474–531 m). The top of the sequence is pallid, underlying a dark grey mudstone. This abrupt transition is interpreted as a weathering horizon marking the top of the Crown Point Formation. Sandstone intervals are minor, very fine grained and predominantly quartz, but also contain minor lithic fragments of shale and siltstone. Bands of bladed gravel noted between 480-486 m and 516-519 m probably reflect a diamictite, which is characteristic of the Crown Point Formation but was not explicitly observed in the cuttings due to the rotary drilling technique. The clay is grey, kaolinitic and micaceous. Sediments are predominantly soft but with minor hard bands of silicified clayey shale.

Figure 4-1 Bulldog Shale (70 m), Algebuckina Sandstone (165 m) and Purni Formation Coal (290 m)

Table 4-1 summarises the intersection depth and thickness of each stratigraphic formation. The thickness of the Bulldog Shale and J Aquifer (Cadna-owie Formation/Algebuckina Sandstone) are 103 and 94 m respectively and closely correlate with the expected thickness of 100 m derived from the GAB Hydrogeological Map (Sampson et al. 2012). At 289 m the Purni Formation is 239 m thicker than predicted from the Pedirka Basin Hydrogeological Map (Sampson et al. 2013). This discrepancy reflects the paucity of water or mineral exploration wells that penetrate the Permian sequence along the western edge of the basin.

Table 4-1 Formation depths and thickness

Formation	Basin	Depth intersected (m)	Thickness (m)
QUATERNARY SEDIMENTS	Eyre Basin	Surface	3
BULLDOG SHALE	Eromanga Basin	3	100
CADNA-OWIE FORMATION	Eromanga Basin	103	6
ALGEBUCKINA SANDSTONE	Eromanga Basin	109	88
PURNI FORMATION	Pedirka Basin	197	289
CROWN POINT FORMATION	Pedirka Basin	474	> 57

4.2 Coal occurrence

A total of 47 m of coal seams over one metre in thickness were intersected in the Purni Formation during the drilling of RN18915. The first major seam was encountered between 243 and 245 m, directly below the screened interval for the test production well (RN18918). The largest continuous coal seam measured 17 m in thickness and was intersected between 287–304 m, while the last major coal seam was logged at a depth of 396 m. The coal seams were identified using the geophysical logs where they display a distinctive low gamma ray and neutron response in combination with low density readings. Figure 4-2 shows the coal seam intersected at 243 m and the characteristic drop in gamma, neutron and density response. The sequence with a low gamma ray count above the coal (233–243 m) represents a clean quartz sand unit in the Purni Formation and was the target interval for the construction of the Purni Formation test production well (RN18918).

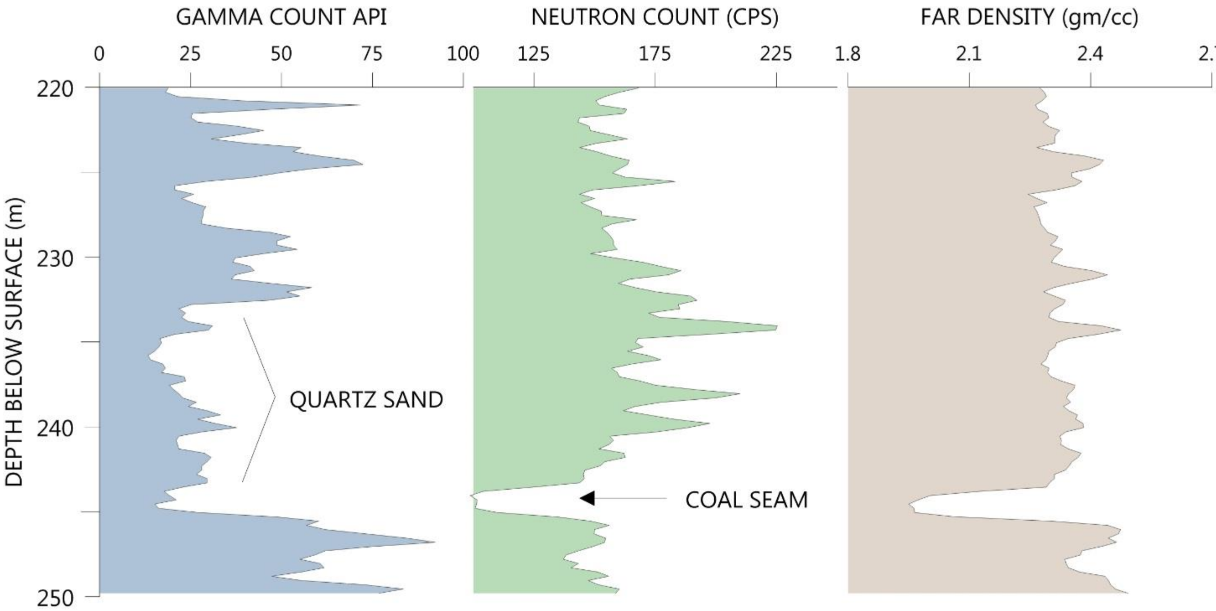


Figure 4-2 Combined gamma/neutron/far density plot showing coal signature

4.3 Hydrogeology

The shallowest piezometer in the nested site (RN18916) targeted the watertable, which was originally estimated to occur in the Bulldog Shale. To allow for better identification of groundwater horizons, RN18916 was drilled using air rotary rather than a mud drilling system. A fully penetrating hole was drilled through the Bulldog Shale without identifying any groundwater intersections and suggests the Bulldog Shale has a low permeability and limited development of secondary porosity at the site. Groundwater was first intersected in the Cadna-owie Formation at a depth of 105 m. RN18916 was constructed as a piezometer in the Upper J Aquifer and screens coarse quartz sand, shale and glauconitic sand between 104.3 and 109.8 m.

The Algebuckina Sandstone comprises the bulk of the J Aquifer at the site and is a highly permeable formation with clean quartz sands ranging in size up to fine gravel (2–4 mm diameter). Piezometer RN18917 targeted a thick sand unit at the base of the J Aquifer between 180–197 m with screens set between 190.5 and 196.6 m. A sieve test undertaken on a sample from the production zone (190 m) found 95% of material is greater than 1 mm in diameter (very coarse sand). The hydraulic conductivity of this sample is estimated at 49 m/d (Table 4-2) using the Korzeny-Carman equation (Korzeny, 1927, Carman, 1935, 1967).

$$K = \left(\frac{\rho g}{\mu}\right)\left[\frac{n^3}{(1-n)^2}\right]\left(\frac{d_{10}^2}{180}\right)$$

where: *K = derived hydraulic conductivity,*

ρ = density,

g = acceleration due to gravity,

μ = dynamic viscosity,

n = porosity,

d_{10} = 10% cumulative passing (geotechnical grain size distribution)

Drill cuttings and geophysical logs do not suggest any significant hydraulic barriers between the J Aquifer and the Purni Formation, with only a 4 m thick shale/clay bed separating the two units. Below this shale bed the upper sequence of the Purni Formation (197–255 m) comprises a series of upward fining sandstone sequences. Sieve tests from the production zone of RN18918 (232–240 m) suggest the Purni Formation is less permeable than the J Aquifer (30 % of sand retrained in a 1 mm sieve as opposed to over 95 % for the J Aquifer, Table 4-2). The hydraulic conductivity of this interval is estimated at between 2.4 and 11.8 m/d using the Korzeny-Carman equation. This finding is consistent with an increase in finer grained shale and clay in the Purni Formation relative to the Algebuckina Sandstone and is supported by airlift results from RN18917/RN18919 where flow rate estimates for the J Aquifer were 80% greater than the Purni Formation (noting that these wells have the same screen lengths, specification and construction).

Table 4-2 Comparison of field sieve test results for J Aquifer (195 m) and upper Purni Formation (240 m)

Formation	Percentage of sample retained			Hydraulic conductivity estimate*
	0.3 mm	0.6 mm	1.0 mm	m/d
J AQUIFER	> 99%	99 %	95 %	> 49
UPPER PURNI FORMATION	80 %	60 %	30 %	2.4–11.8

*Porosity values from core analysis, 16–25 % Purni Formation, 19 % Algebuckina Sandstone, assumes dynamic viscosity of 1.002.

The first significant coal horizon (243.5–245.5 m) is in direct connection with a thick sand sequence in the upper Purni Formation (233–243.5 m), which was targeted as the production zone for RN018918 and RN18919. Below this coal horizon the formation grades into a carbonaceous shale and coal sequence which contains less sand and has a lower permeability. This is reflected in the down-hole geophysics with a higher gamma ray response, which typically corresponds to an increase in clay content. Though it should be noted that an uncharacteristically high gamma ray response is observed in Purni Formation sandstones as a result of a K-feldspar mineralogy (Central Petroleum, 2010).

Piezometer RN18915 targets the Crown Point Formation and screens an interval between 516 and 521 m that corresponds with a marked drop in gamma ray response. Relative to the Upper Purni Formation and J Aquifer drill cuttings suggest the top sequence of the Crown Point Formation has limited permeability.

The reduced standing water level (RSWL) in each well has been density corrected to account for variable groundwater temperature and salinity through the profile. Corrections have been undertaken according to the following method detailed in Post et al. 2007.

$$h_{f,r} = z_r + \frac{\rho_i}{\rho_f}(h_i - z_i) - \frac{\rho_a}{\rho_f}(z_r - z_i)$$

where: $h_{f,r}$ = *freshwater head,*

h_i = *point water head measured relative to* z_r,

z_r = *reference level,*

z_i = *elevation head of the screen mid-point,*

ρ_a = *average water density between* z_i *and* z_r,

ρ_f = *freshwater density,*

ρ_i = *density of water surrounding the screen*

The corrected freshwater head values are presented with the uncorrected RSWL measurements in Table 4-3. The vertical groundwater gradient is downwards within the J Aquifer and upwards between the Pedirka Basin and GAB sequence. The correction process shifted the vertical gradient between the Purni Formation and the lower J Aquifer from a downward gradient of 0.002 to an upward gradient of 0.01. An upward gradient of 0.014 exists within the Pedirka Basin between the Crown Point Formation and Purni Formation.

Table 4-3 Density corrected reduced standing water levels

Well ID	Aquifer	Screen mid-point (m)	Uncorrected RWL (m AHD)	Corrected freshwater head (m AHD)	Direction of vertical groundwater flow
RN18916	J Aquifer (upper)	107	153.5	153.4	Downward
RN18917	J Aquifer (lower)	193	153.1	152.9	Upward
RN18918	Purni Aquifer	236	153	153.3	Upward
RN18915	Crown Point Aquifer	518	155.9	157.2	
RN18919	Purni Aquifer	238	152.7	153	N/A*

* Vertical gradients have not been calculated for the distant Purni Formation observation well (RN18919)

5 Aquifer tests

An aquifer test and groundwater sampling program was undertaken in December 2013 to assess the degree of hydraulic connection between the Purni Formation, J Aquifer and Crown Point Formation. Aquifer testing involves pumping a well whilst simultaneously monitoring drawdown, or decline in water level, inside the pumping well and at nearby observation wells. The shape of the resultant drawdown/time curve is a function of the type of groundwater flow (laminar or turbulent), the pumping rate, the size, geometry and orientation of the aquifer, and the characteristics (e.g. grain size, degree of sorting) of the material making up the aquifer.

Aquifer tests generally take the form of either a well performance test, used to assess optimal pump rates and settings in production wells, or a constant rate test, commonly used to determine aquifer parameters such as hydraulic conductivity, transmissivity and storage coefficients. Constant rate pumping tests also identify hydraulic boundaries, for example recharge boundaries, where pumping induces leakage from overlying or underlying aquifers or from surface water features. The connectivity test program focuses on constant rate testing because the site is designed for groundwater investigation rather than long term production. The key objectives of the pumping test program are to:

1. Investigate the level of hydraulic connection between the Permian formations and GAB sequence within the relatively short timeframe of the aquifer test
2. Test for the presence of aquifer boundary conditions, in particular recharge boundaries reflecting leakage from overlying formations
3. Provide estimates of aquifer parameters (transmissivity, storage coefficient, hydraulic conductivity) for the Purni Formation, and if possible the J Aquifer and Crown Point Formation
4. Collect representative groundwater samples to enable the hydrochemical and isotopic characterisation of the aquifer system.

5.1 Overview of test program

The aquifer test program comprised a 48-hour constant rate test in the Purni Formation (RN18918) with monitoring in all other wells and 8-hour constant rate tests in both the lower J Aquifer (RN18917) and Crown Point Formation (RN18915). Groundwater sampling was undertaken on the upper J Aquifer (RN18916) but an aquifer test was not attempted due to the limited yield of the sampling pump. The details and timing of the test program are summarised in Table 5-1. Raw water level data collected during the test are provided in Appendix E.

Table 5-1 Summary of aquifer test program

Well ID	Test	Production aquifer	Phase	Start	End	Duration (mins)*	Flow rate (L/s)	Drawdown (m)#
RN18918	48-hour Constant Rate	Purni Formation	Pumping	8:00 AM 05-12-2013	8:00 AM 07-12-2013	2880	25	23.93
			Recovery	8:00 AM 07-12-2013	8:00 AM 08-12-2013	1440 (4320)	-	- 23.91
RN18917	8-hour Constant Rate	Lower J Aquifer	Pumping	08:30 AM 08-12-2013	04:30 PM 08-12-2013	480	8	3
			Recovery	04:30 PM 08-12-2013	04:42 PM 08-12-2013	12 (492)	-	- 3
RN18915	8-hour Constant Rate	Crown Point Formation	Pumping	09:00 AM 09-12-2013	05:00 PM 09-12-2013	480	3	24.73
			Recovery	05:00 PM 09-12-2013	07:14 AM 10-12-2013	854 (1334)	-	- 24.46

* Duration in parenthesis represents cumulative duration from the commencement of pumping

Negative drawdown indicates recovery of water levels

5.2 System set up

The aquifer test program was undertaken by DEWNR Groundwater Technical Services. The Purni Formation production well was tested using a Grundfos SP95-9 electric submersible pump installed on a 100 mm steel column, set at a depth of 93 m. The initial water level in the well was 42.41 m BGS giving an available drawdown for the test of 50.59 m. The SP95-9 is a variable speed pump and the flow rate was controlled by adjusting the power input to the pump. The flow rate was measured using a Seimens SITRANS F M MAG 5000 flow meter connected into the discharge line. Groundwater was directed through 150 m of lay flat hosing and discharged into a small drainage feature to the south-west of the site.

The water level in the production well was measured manually using a "mega" system installed in PVC pipe. This system gauges drawdown using an electrical current, volt meter and water level tape. Drawdown was also recorded using a non-vented In-situ Level Troll 500 (60 m rating) suspended in the production well with stainless steel cable. Groundwater levels in the observation wells were logged using non-vented Solinst Level Loggers with back up readings taken manually using electronic water level tapes. Barometric pressure was recorded during the test using a separate high sensitivity Solinst Barologger Edge. Field parameters (electrical conductivity, pH, dissolved oxygen, temperature and redox potential) were recorded at regular intervals using a *YSI* water quality meter. Observations were also collected on the appearance, odour and sand content of the discharge water.

The 8-hour constant rate tests were conducted using a hydraulically-driven Legra variable speed pump, which was installed on 76 mm diameter hosing. The flow rate was measured using a Seimens SITRANS F M MAG 5100 flow meter. Water level and quality measurements were collected using the methods described above. The Upper J Aquifer well (RN18916) was sampled using a Grundfos SQE1-140 electric submersible pump. The flow rate was gauged manually during sampling at approximately 0.5 L/s. Table 5-2 provides a summary of the system set up for the pumping test program.

Table 5-2 Pumps, settings and available drawdown for aquifer test and groundwater sampling program

Well ID	Test/sampling pump	Screens (m BGS)	Pump setting (m BGS)	Water level pre-test (m BGS*)	Available drawdown (m)
RN18918	Grundfos SP95-9	232–242	93	42.41	50.59
RN18917	Legra	190.5–196.6	75	42.03	32.97
RN18915	Legra	515–521	70	39.25	30.75
RN18916	Grundfos SQE1-140	104–110	-	41.79	-

* Water levels reported as metres below ground surface and measured immediately before commencement of pump tests

5.3 Test results

5.3.1 Purni Formation 48-hour constant rate test

Production well

A 48-hour constant rate test was conducted on the Purni Formation production well RN18918 commencing at 8:00 am on 5 December 2013 and concluding two days later on 7 December 2013. Twenty-four hours of recovery data were collected after the completion of the pumping phase. The well was pumped at a constant rate of 25 L/s, incremental adjustments to the power input held the flow rate within a threshold of 0.1 L/s.

Water level in the production well showed a rapid decrease in early time data, with 23.1 m of drawdown recorded in the first 15 minutes of pumping; this accounts for over 96 % of the total drawdown observed in the test. After the initial drawdown response the water level dropped incrementally throughout the remainder of the test with a maximum drawdown of 23.93 m recorded after 1439 min of pumping.

The water level recovered rapidly once the pump was turned off with 99 % recovery (23.69 m) occurring within 120 min of the test completion, noting that the pump was not equipped with a non-return valve. Figure 5-1 shows the drawdown and recovery response in the production well over the test period.

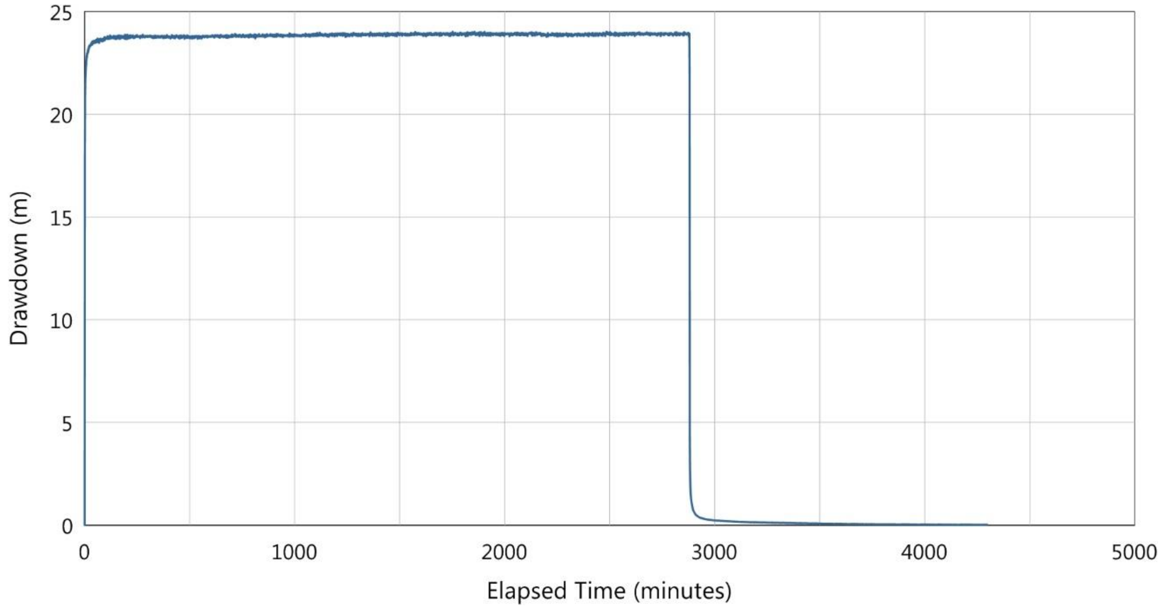


Figure 5-1 Production well drawdown, Purni Formation 48-hour constant rate test

Observation wells

A water level response consistent with the pumping well was observed in the Purni Formation observation well (RN18919) and in the nested lower and upper J Aquifer wells (RN18917 and RN18916). The drawdown curves are shown in Figure 5-2. Note water level data have been corrected to remove fluctuations caused by barometric pressure. Some small barometric effects remain, particularly in RN18916, where the magnitude of the drawdown response was small. The drawdown curves show a rapid hydraulic response in the lower J Aquifer well, which indicates there is a high degree of connection between the upper Purni Formation and the GAB sequence at this site. The drawdown response in the Crown Point well (RN18915) is not included in Figure 5-2 as no water level response was observed.

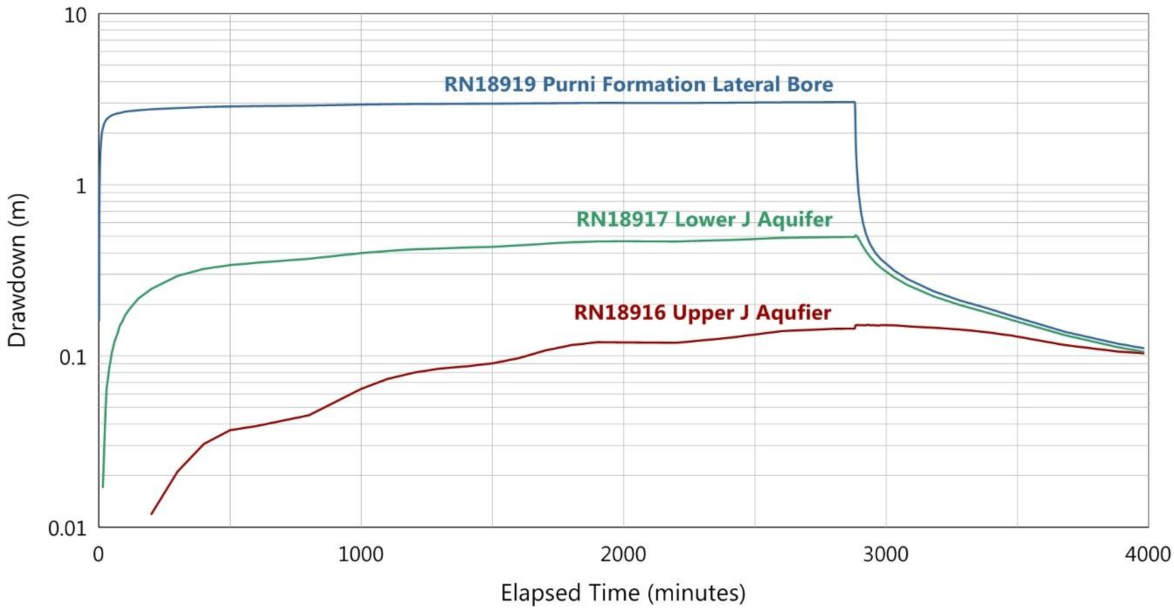


Figure 5-2 Observation well drawdown, Purni Formation 48 hour constant rate test

The greatest drawdown is observed in the Purni Formation lateral well (RN18919), which responded within the first minute of pumping and recorded a maximum drawdown of 3.04 m. When viewed as a semi-log plot (Figure 5-3), the Purni Formation drawdown curve flattens after 10 minutes and plots below the theoretical Theis curve matched to early time data. This flattening indicates an additional source of water; in this instance resulting from vertical leakage from the overlying sand sequences in the Upper Purni Formation and GAB sequence.

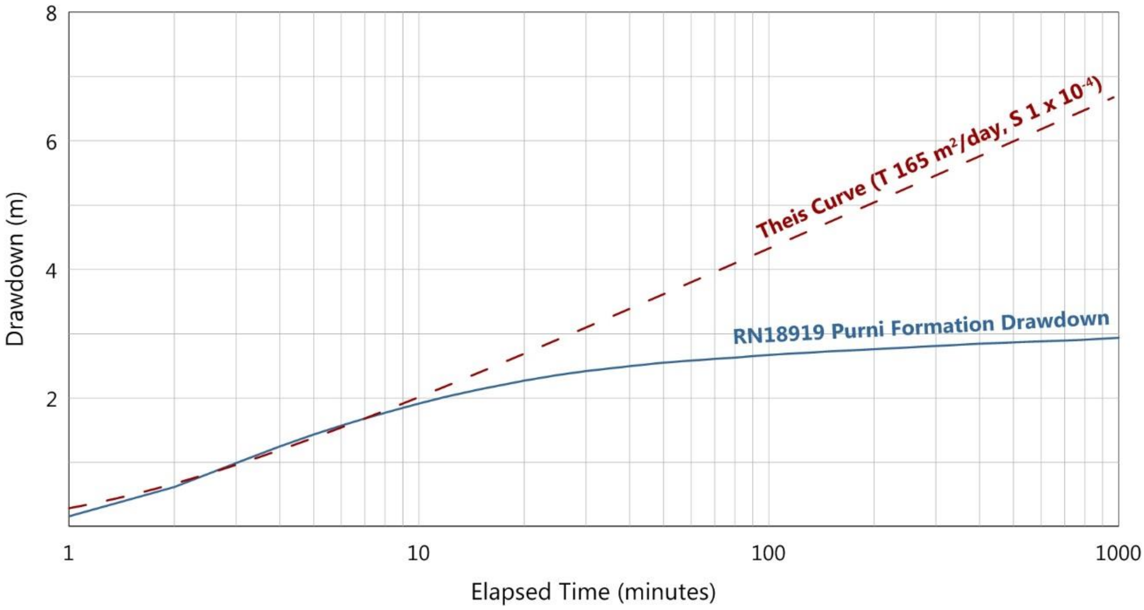


Figure 5-3 Drawdown curve for RN18919 and Theis curve

The water level in RN18917 (lower J Aquifer) responded after 14 minutes of pumping and recorded a maximum drawdown of 0.5 m. The water level in RN18916 (upper J Aquifer) was static until 200 minutes of pumping had elapsed and attained a maximum drawdown of 0.15 m. The water level in all three observation wells recovered to within 0.1 m of their initial pre-test level 4000 minutes after the test commenced (1120 minutes of recovery).

Water levels data collected for RN18915 (Crown Point Formation) did not display a pumping response but rather mirrored changes in barometric pressure. While this may suggest the hydraulic connection is limited between the Purni and Crown Point Formations, it is also a function of the greater intervening thickness between the screened units (280 m) and the limited test duration which may have been inadequate to produce a pressure response in the Crown Point Formation.

5.3.2 Lower J Aquifer 8-hour constant rate test

Production well

On 8 December 2013, an 8-hour constant rate test was undertaken on lower J Aquifer well (RN18917). Drawdown in the production well was monitored both manually and automatically with a vented In-situ Troll logger. Solinst loggers were also installed in the two Purni Formation wells (RN18918, RN18919) and in the upper J Aquifer Piezometer (RN18916).

The flow rate was initially set at 5 L/s but was increased after three minutes to 8 L/s and held at that rate for the remainder of the test. The water level in RN18917 showed a rapid drawdown and recovery response (Figure 5-4) with 2.9 m (95 %) of drawdown recorded in the first 5 minutes of the test. A maximum drawdown of 3 m was recorded at 180 minutes after which the water level stabilised for the remainder of the test. The production well water level recovered to pre-test levels within 12 minutes of the completion of the test.

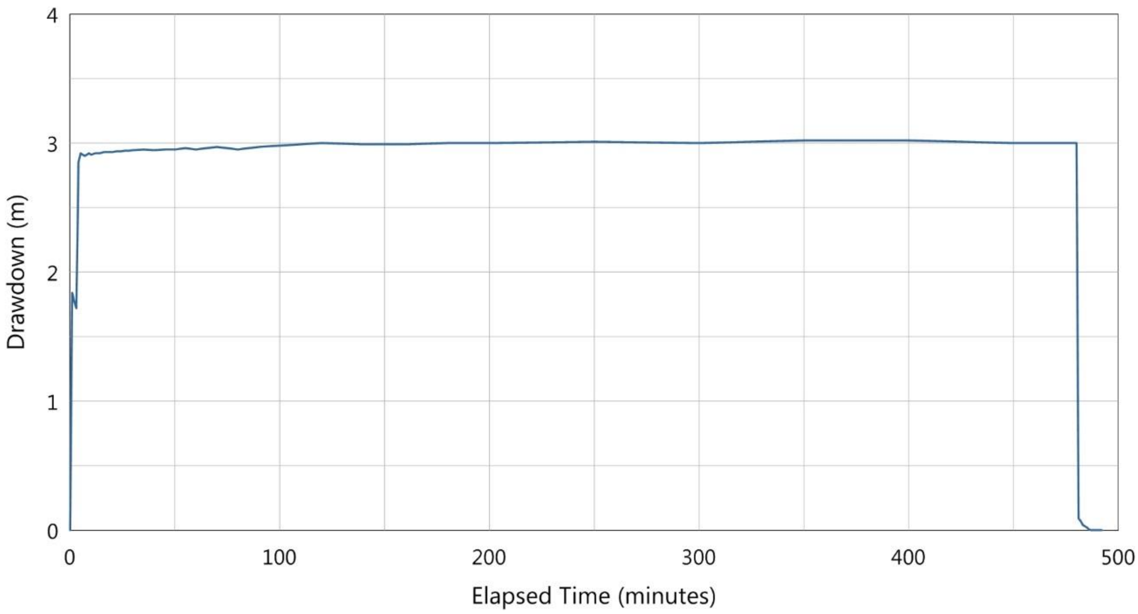


Figure 5-4 Production well drawdown (RN18917), Lower J Aquifer 8-hour constant rate test

Observation wells

Both wells screened in the Purni Formation show a water level response consistent with drawdown in the production well. The shape of the two drawdown curves is near identical (Figure 5-5), with the water level in both wells first responding 10 minutes after pumping commenced. The nested or close observation well (RN18918) recorded a total drawdown of 0.12 m. The drawdown in the far observation well (RN18919) showed a slightly more muted response, recording a maximum drawdown of 0.11 m. In light of the 72 m distance between the nested site and RN18919, the similarity in the magnitude and timing of the drawdown response suggests that groundwater flow within the Purni Formation is stratified and K_H (horizontal hydraulic conductivity) is significantly greater than K_V (vertical hydraulic conductivity).

No clear pumping response was observed in the upper J Aquifer (RN18916); the water level showed a net change of 0.04 m over the pumping test and mirrored the barometric pressure response for this period. When the test duration, flow rate and the 85 m of intervening GAB sequence between the two J Aquifer wells are considered the lack of a clear pumping response in the upper J Aquifer is not unexpected.

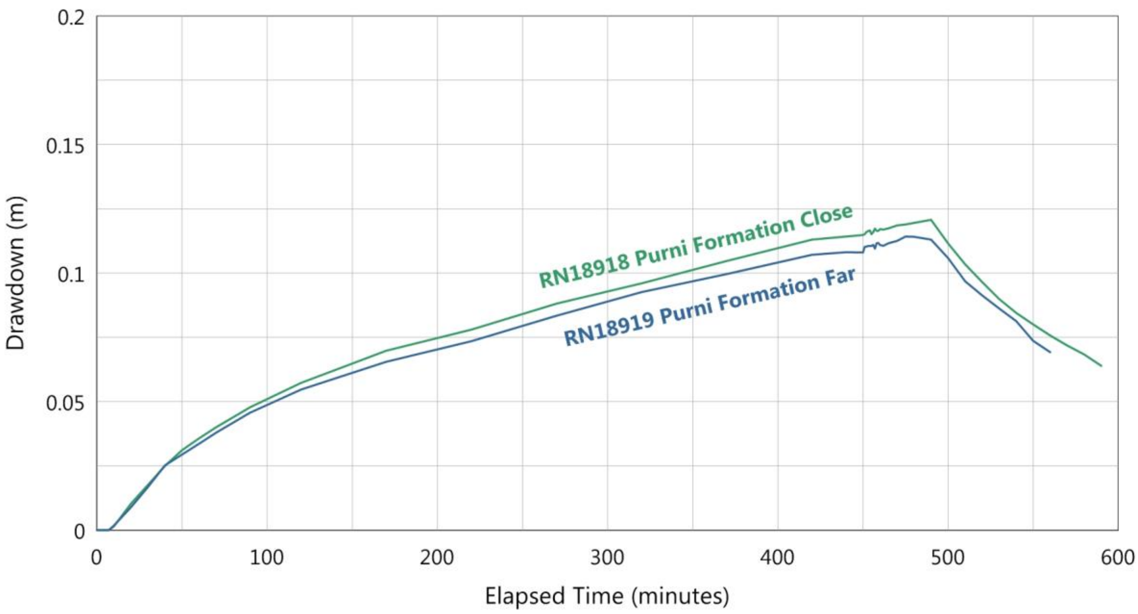


Figure 5-5 Purni Formation drawdown, Lower J Aquifer 8-hour constant rate test

5.3.3 Crown Point Formation 8-hour constant rate test

An 8-hour constant rate test was conducted on the Crown Point Formation monitoring well (RN18915) on 9 December 2013 commencing at 9:00 am with 854 minutes of recovery data collected after the completion of the test using an In-situ Troll 500. The test was conducted using a Legra pump operating at a constant flow rate of 3 L/s.

A maximum drawdown of 24.73 m was recorded in the production well during the test (Figure 5-6). When the logger was removed 854 minutes after the completion of the test, the water level had recovered to within 0.27 m of the pre-test level, corresponding to a 99% recovery.

Water levels were monitored using Solinst Level Loggers in RN18917, RN18918 and RN18919 but showed no response to pumping in the Crown Point Formation.

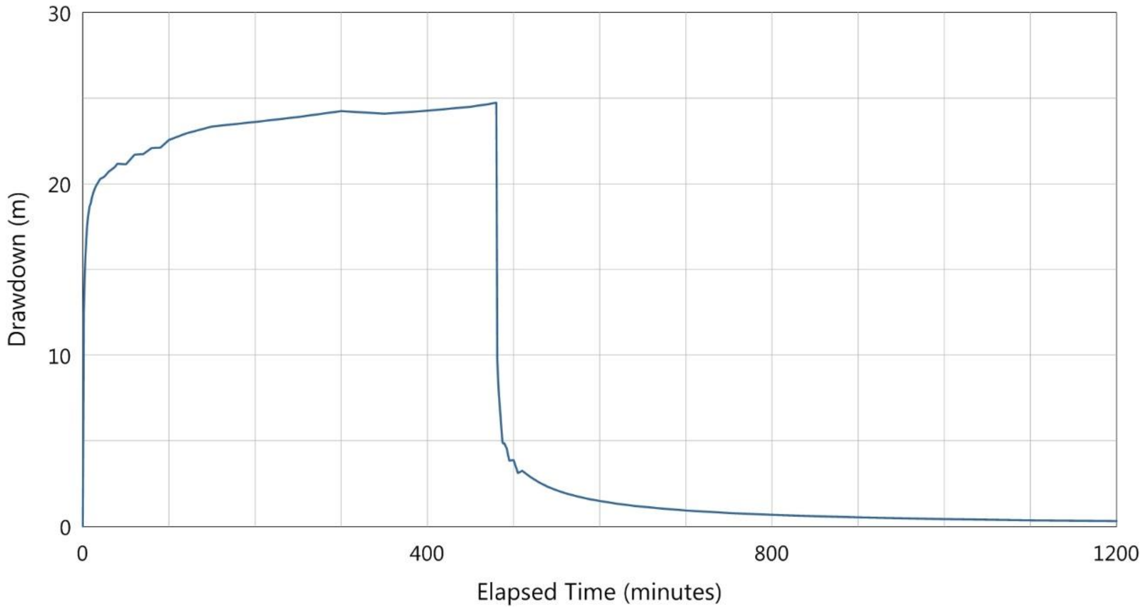


Figure 5-6 Production well drawdown (RN18915), Crown Point Formation 8-hour constant rate test

5.4 Test analysis

Pumping test analysis was undertaken using the aquifer test software MLU (Multi-Layer Unsteady State). MLU is an analytical groundwater modelling program used to compute hydraulic head and drawdown, and analyse a variety of aquifer test data in layered aquifer systems. In contrast to conventional curve fitting solutions, which generally assume one or two aquifers, MLU applies a single, generalised analytical solution for groundwater flow in layered or stratified aquifer systems. The hydraulic head computations are based on a multi-layer uniform well face drawdown solution (Hemker, 1999a) in which the groundwater system is divided into intermittent aquifer and aquitard layers. The solution assumes horizontal flow in the aquifers and vertical flow between aquifers through the intervening aquitard layers. Rather than relying on visual curve matching techniques, MLU computes drawdown using a parameter optimisation routine based on the Levenberg-Marquardt algorithm. The program allows for the optimisation of transmissivity and storativity in aquifer layers, and hydraulic resistance and storativity in aquitard layers. The transmissivity and hydraulic resistance are related back to horizontal and vertical hydraulic conductivity by specifying a thickness for the aquifer/aquitard layers.

MLU also allows for the optimisation of well loss in production wells in the form of a well skin factor. The MLU solution has a number of important and implicit assumptions including that aquifer and aquitard layers are isotropic, homogeneous and of infinite areal extent, that Darcy's law is valid, only saturated flow is considered and that observed drawdown is the result of groundwater extraction. Anisotropic flow conditions are observed in the Purni Formation wells, which is expected to increase uncertainty in the model results – modelled aquifer parameters are reported as ranges in order to acknowledge this uncertainty. A full list of assumptions and further detail on the theory behind the analytical solution can be found in Hemker and Maas (1987), Hemker (1999a) and Hemker (1999b).

While the computation of drawdowns is automated, the MLU modelling process involves several stages. Foremost is the development of a conceptual model to describe groundwater flow of the modelled system. The parameters optimised by MLU are not constrained by real world values, so a robust conceptual model is critical to ensuring the optimisation process produces meaningful results. The conceptual model describes the number of aquifer and aquitard layers, how the layers behave and interact, which parameters require optimisation and whether parameters are optimized singularly or as a group. Once these factors are determined, well data, drawdown observations and pumping rate data are entered into MLU. Initial estimates of hydraulic parameters are then entered and the modelling routine is run. MLU provides a range of statistics that measure the performance of the model and uncertainty of results. These can be assessed in combination with a visual assessment of observed and modelled drawdown to determine whether the model results adequately describe the groundwater flow system. The modelling process is iterative and adjustment to model parameters, further optimisation and potential refinement of the conceptual model may be required to obtain acceptable results.

5.4.1 Conceptual model and parameterisation

A number of conceptual models were trialled in MLU, ranging from low complexity where the whole upper Purni Formation/J Aquifer was characterised as a single aquifer, through to a high complexity multi-aquifer solution with seven discrete aquifers. A discussion of the sensitivity of the model results to the number of model layers is provided in Section 5.4.4. The optimal model has the least number of layers and parameters while still providing an accurate fit to observed water-level data. For the connectivity site the best performing and simplest conceptual model is a four aquifer model that incorporates the Bulldog Shale, the J Aquifer and the Upper Purni Formation. The Crown Point Formation is excluded from this model because no pumping response was observed during the 48 hour test. The 8-hour test on RN18915 is analysed separately in Section 5.4.5.

The Bulldog Shale forms the uppermost layer with a thickness of 104 m. This unit produced no free water during drilling and is characterised as an impermeable aquitard within the MLU model. Model runs undertaken with the Bulldog Shale set as a leaky aquitard to test this assumption found the Purni/J Aquifer hydraulic parameters are relatively insensitive to the hydraulic resistance of the Bulldog Shale, further discussion is provided in Section 5.4.4. The J Aquifer is divided into three separate aquifers (upper, middle, lower) separated by two clay/shale beds identified using the gamma ray response (Figure 5-7). The two main shale inliers, classified here as the Upper J Shale Bed and the Lower J Shale Bed, are 8 m and 6 m thick respectively and are conceptualised as leaking aquitards. It was necessary to include at least one resistive layer (aquitard) within the GAB sequence to enable the model to differentiate between the upper and the lower J Aquifer piezometers. The clay/shale inlier separating the J Aquifer and the Purni Formation (J/Purni Shale Bed) is 4 m thick and is also classified as a leaking aquitard.

The Upper Purni Formation, including the coal seam, has been conceptualized as a single aquifer unit 44 m thick. The shale beds apparent in the gamma log are not modelled as separate aquitard layers, primarily because the aim of the modelling exercise is to investigate the connection between the Purni Formation and J Aquifer, rather than the hydraulic behaviour within the Purni Formation. Unlike the J Aquifer, there are no drawdown data to support a further level of discretization within the Purni Formation. Below 245 m there is a distinct increase in gamma response in the Purni Formation marking a higher clay/shale content. This horizon has been taken as the top of the lower bounding aquitard, which is given a nominal thickness of 50 m in the MLU model. The hydraulic behaviour of this section of the Purni Formation is not well characterised so the layer has been assigned as a leaky rather than an impermeable aquitard and the hydraulic resistance of the layer has been optimized in the modelling process.

In order to reduce the number of parameters requiring optimisation several hydraulic parameters have been grouped together. This approach reduces model complexity and the likelihood of producing a non-unique solution. The transmissivity and storage coefficient of the three J Aquifer units were optimised as two separate groups. The hydraulic resistance of the two J Shale Beds formed a third parameter group. The transmissivity and storativity of the Purni Formation, and hydraulic resistance of the J/Purni Shale Bed and Purni Aquitard were optimized independently. A summary of the hydraulic parameters and optimisation approach for each model layer is provided below in Table 5-3.

MLU contains the functionality to estimate the storage coefficient of aquitard layers, however, in this modelling exercise storage coefficients for the aquitard layers have been set at zero and so do not require optimisation. Given the thin nature of the shale interbeds, vertical flow and leakage likely dominate the effects of aquitard storage. So the decision to set the aquitard storage to zero is unlikely to introduce significant uncertainty into the model results.

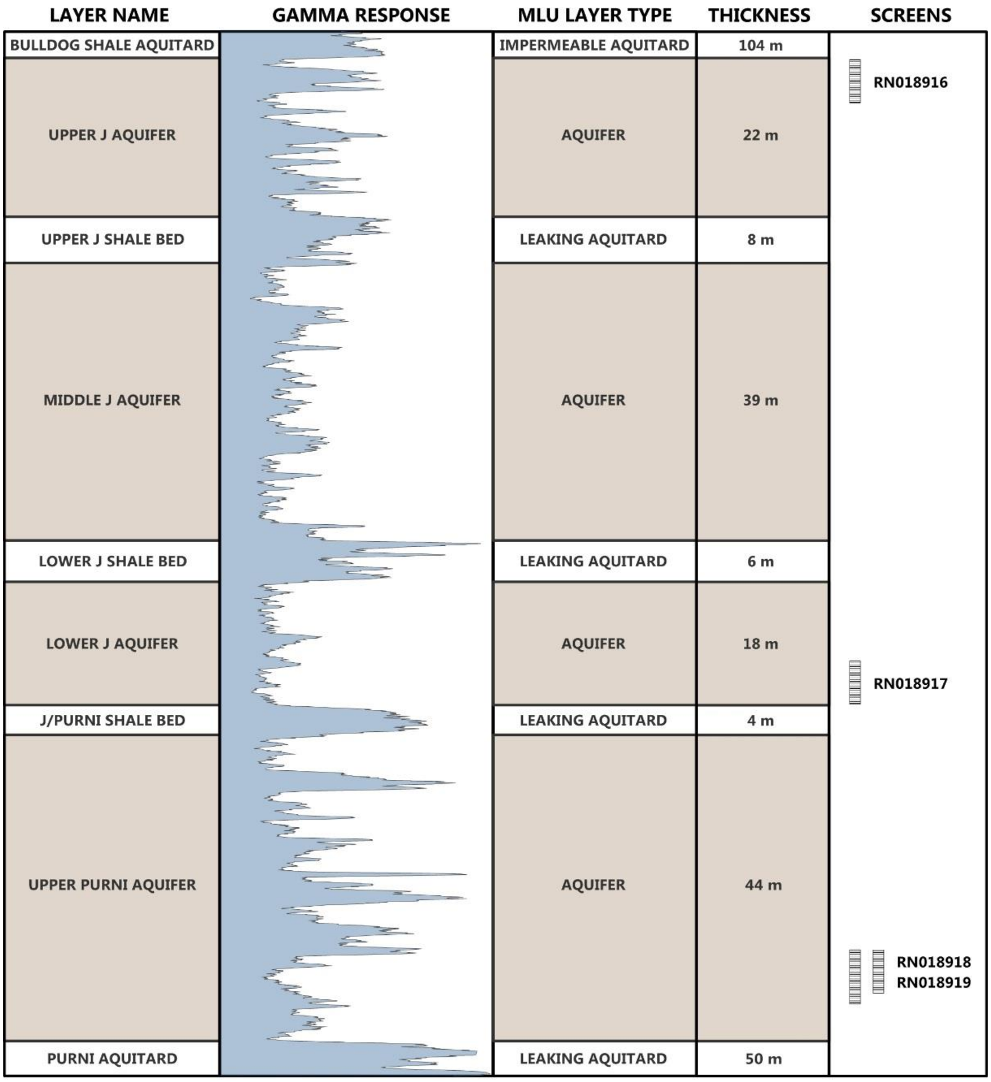


Figure 5-7 MLU conceptual model

Table 5-3 Model layers and parameter optimisation

Model layer	Hydraulic parameter	Optimisation no.*
Bulldog Shale Aquitard	-	-
Upper J Aquifer	Transmissivity	1
	Storativity	2
Upper J Shale Bed	Hydraulic resistance	3
Middle J Aquifer	Transmissivity	1
	Storativity	2
Lower J Shale Bed	Hydraulic resistance	3
Lower J Aquifer	Transmissivity	1
	Storativity	2
J/Purni Shale Bed	Hydraulic resistance	4
Upper Purni Aquifer	Transmissivity	5
	Storativity	6
Purni Aquitard	Hydraulic Resistance	7

* Parameters with the same number are optimised as a group

5.4.2 Model results

Results from the optimised MLU model showing observed drawdown (diamonds) and modelled drawdown (lines) are presented in Figure 5-8. The simulated drawdown closely matches observed drawdown for all four wells with only the early time model results for the J Aquifer showing minor deviation from observed water level response. Note that recovery data for the production well were not analysed because the test pump was not fitted with a non-return valve.

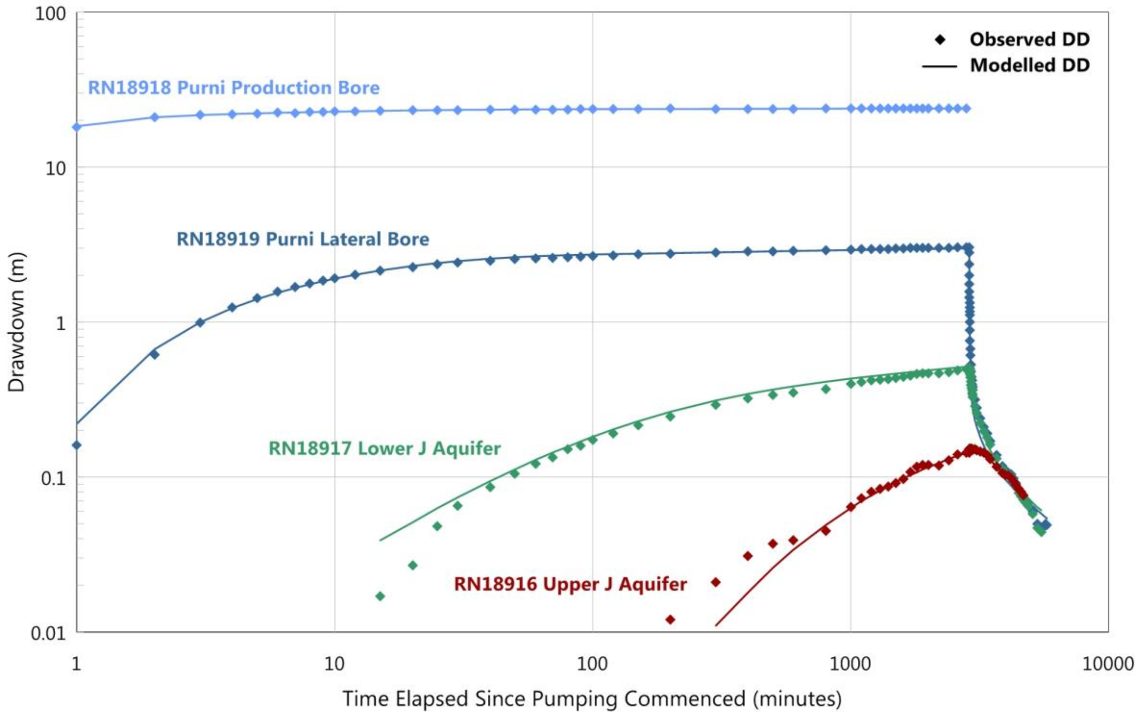


Figure 5-8 MLU optimised model results for 48-hour Purni Formation constant rate test

Table 5-4 presents optimised hydraulic parameters from the four aquifer model. Probable ranges for the primary parameters (transmissivity, storativity, hydraulic resistance) are presented as a ratio of the standard deviation to the optimal parameter value. The transmissivity of the Upper Purni Formation is estimated at 200 m/d and storativity at 5 x 10^{-5}. A cumulative transmissivity for the three J Aquifers is estimated at 1800 m^2/d, while the storage coefficient is estimated at 1 x 10^{-3}. The hydraulic resistance of the shale bed between the J Aquifer and Purni Formation is approximated at 450 days with a derived vertical hydraulic conductivity of 0.01 m/d. The hydraulic resistance for the Upper and Lower J Aquifer shale beds was calculated at 270 and 200 days respectively with a derived vertical hydraulic conductivity of 0.03 m/d.

Table 5-4 Optimised hydraulic parameters from MLU model

Layer	Thickness (m)	K-Horizontal (m/d)	K-Vertical (m/d)	Transmissivity (m^2/d)	Hydraulic resistance (d)	Storage coefficient
Upper J Aquifer	22	23	-	500 (5%)	-	1 x 10^{-3} (10%)
Upper J Shale Bed	8	-	0.03	-	270 (7%)	-
Middle J Aquifer	39	23	-	900 (5%)	-	1 x 10^{-3} (10%)
Lower J Shale Bed	6	-	0.03	-	200 (7%)	-
Lower J Aquifer	18	23	-	400 (5%)	-	1 x 10^{-3} (1%)
J/Purni Shale Bed	4	-	0.01	-	450 (1%)	-
Upper Purni Aquifer	44	5	-	200 (<1%)	-	5 x 10^{-5} (1%)

* Bracketed numbers provide the standard deviation as a ratio of the parameter value, this provides a probable range for each parameter

5.4.3 Model validation

Model parameters derived from the 48-hour test were applied to the 8-hour constant rate test conducted on RN18917 (Lower J Aquifer) to provide a separate validation of model results. In this scenario, all parameters were held constant with the exception of the production well (RN18917) skin factor, which was allowed to optimise to a value of 2. Figure 5-9 shows the observed and predicted drawdown for the two Upper Purni Formation well (RN18918 and RN18919). The model shows a good match with the simulated drawdown matching to within one centimetre of the observed drawdown in both wells.

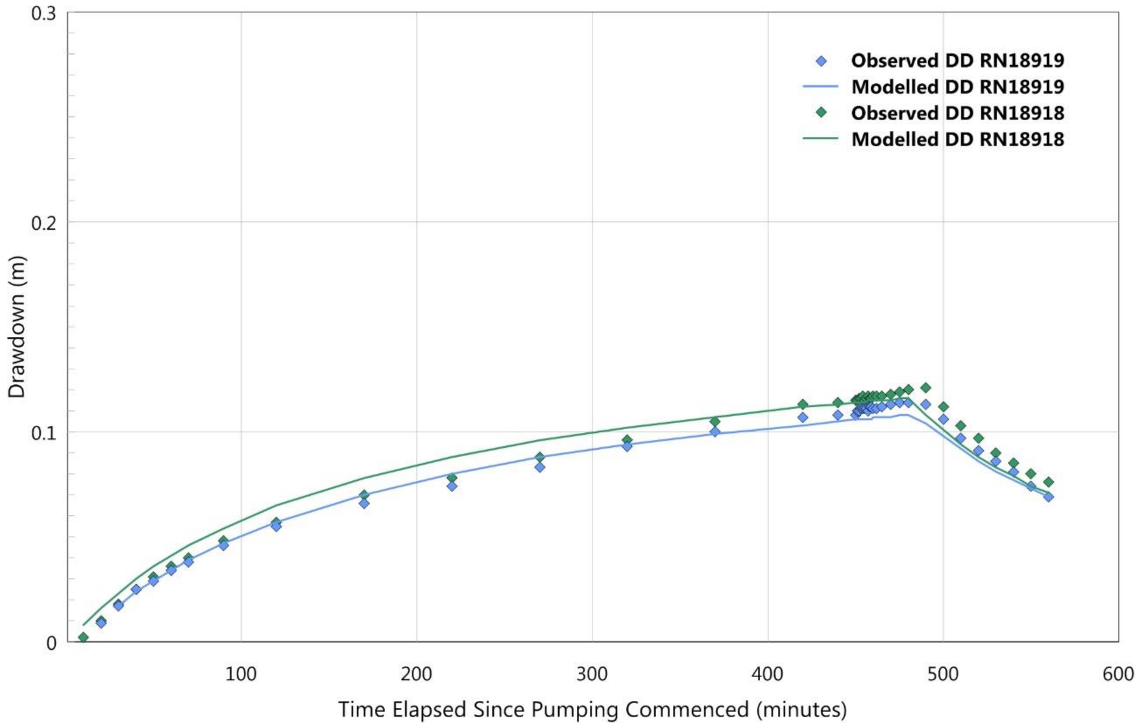


Figure 5-9 Observed and modelled drawdown for Upper Purni Formation, 8-hour Lower J Aquifer test

5.4.4 Model sensitivity testing

Separate model scenarios were run to investigate the sensitivity of the four aquifer model to changes in the transmissivity of the J Aquifer, the transmissivity and storage coefficient of the Upper Purni Formation and the aquitard status (leaking/impermeable) of the Bulldog Shale. A separate section is also included documenting the sensitivity of model results to the number of model layers.

J Aquifer transmissivity

To investigate model sensitivity, transmissivity/horizontal hydraulic conductivity (K_H) of the J Aquifer was held constant and the MLU model run allowing all other hydraulic parameters to optimise. Separate model scenarios were undertaken using K_H values of 5, 11, 15, 20 and 25 m/d. Figure 5-10 shows the simulation results against observed data for RN18917 (lower J Aquifer). Similar results were observed for RN18916 in the upper J Aquifer (see Appendix F, Figure F-1).

The largest difference in drawdown between the high and low K_H cases is 0.14 m suggesting the model is relatively insensitive to changes in J Aquifer K_H. When observing the general fit of these modelled data K_H = 20 m/d provides the best match to the drawdown and recovery response in RN18917. Allowing for measurement inaccuracy and the expected variation in K_H over the thickness of the J Aquifer, K_H = 15 m/d and K_H = 25 m/d also provide a reasonable match to observed drawdown data. However, the lower K_H simulations (K_H = 5 and 11 m/d) underestimate drawdown during pumping and overestimate the recovery response. Sensitivity testing was undertaken on the production well drawdown (RN18917) for the lower J Aquifer 8-hour constant rate test applying the same range of hydraulic conductivity. Results indicate that at K_H values of 15–25 m/d the model can fit the observed drawdown in RN18917, however, at K_H values of 5 m/d and 11 m/d the model overestimates drawdown in the production wells by 6.8 and 1.5 m respectively (see Appendix F, Figure F-2, for drawdown curves).

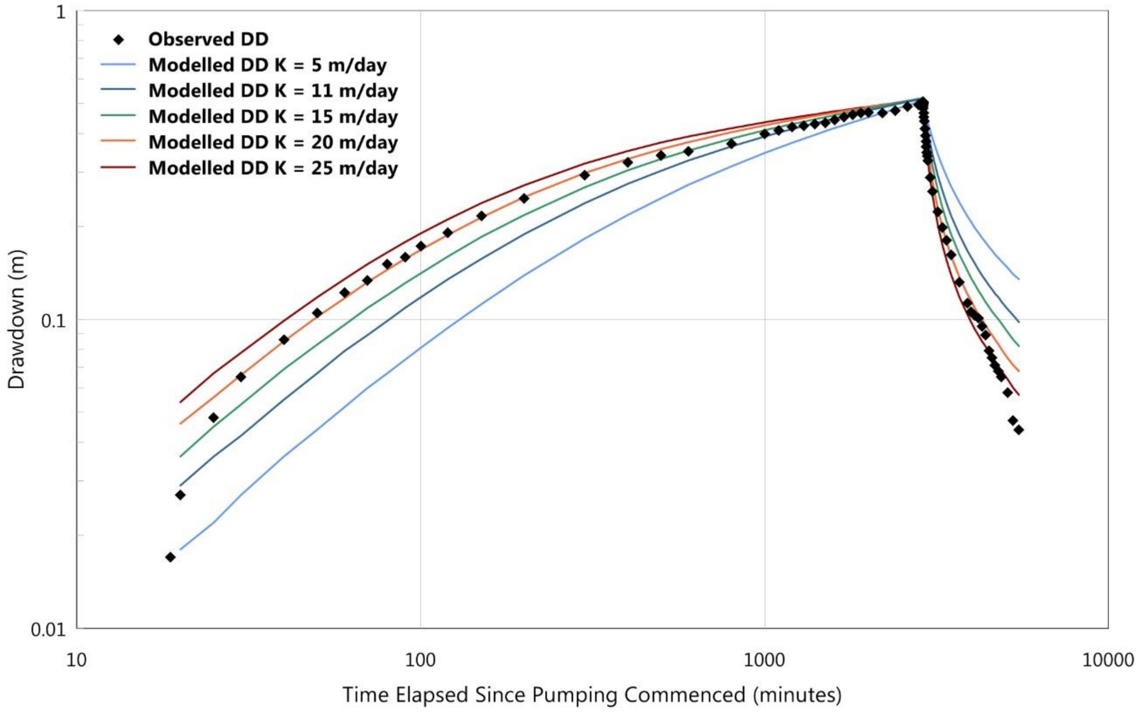


Figure 5-10 J Aquifer K_H sensitivity testing, RN18917 (lower J Aquifer) modelled and observed drawdown

Table 5-5 presents the optimised model parameters from the model simulations. The storage coefficient of J Aquifer shows the largest response to changes in the K_H of the J Aquifer varying by 90 % across the three best fit simulations (K_H = 15, 20, 25 m/d). In comparison, the transmissivity and storage coefficient of the Upper Purni Aquifer are relatively insensitive varying by only 2% respectively across the same three simulations.

Table 5-5 J Aquifer sensitivity testing – optimised model parameters

J Aquifer		**Upper Purni Aquifer**		**J/Purni Shale Bed**	**J Shale Beds**
K_H (m/d)	S	T (m^2/d)	S	K_V (m/d)	K_V (m/d)
5	4 x 10^{-3}	225	4.8 x 10^{-5}	0.006	0.050
11	2.5 x 10^{-3}	214	5 x 10^{-5}	0.007	0.045
15	1.9 x 10^{-3}	208	5 x 10^{-5}	0.008	0.041
20	1.4 x 10^{-3}	205	5 x 10^{-5}	0.009	0.034
25	1.0 x 10^{-3}	203	5.1 x 10^{-5}	0.009	0.027

Purni Formation transmissivity

To examine the model sensitivity to changes in the transmissivity of the Upper Purni Formation, five separate model scenarios were run with fixed K_H values of 2, 4, 6, 8 and 10 m/d. The model results for RN18919 are presented along with the observed drawdown in Figure 5-11. The best fit between modelled and observed drawdown is achieved when the K_H is fixed between 4 and 6 m/d (equivalent transmissivity between 166–272 m^2/d). At K_H values above and below this range, the modelled drawdown correlates poorly with the early time drawdown response.

This finding is supported by the Residual Sum of Squares (RSS), which is a measure of how well the modelled and observed data correlate. Lower RSS values indicate a greater correlation between modelled and observed data. The RSS provided by MLU is the sum of residuals for all modelled observation wells, not just the Purni Formation lateral well (RN18919) shown in

Figure 5-11. Scenarios with K_H of 4 and 6 m/d returned RSS values of 0.35 and 0.27 m, whereas the K_H of 2, 8 and 10 m/d scenarios returned RSS values of 1.9, 1.0 and 2.4 m respectively, suggesting a poorer correlation with observed drawdown data.

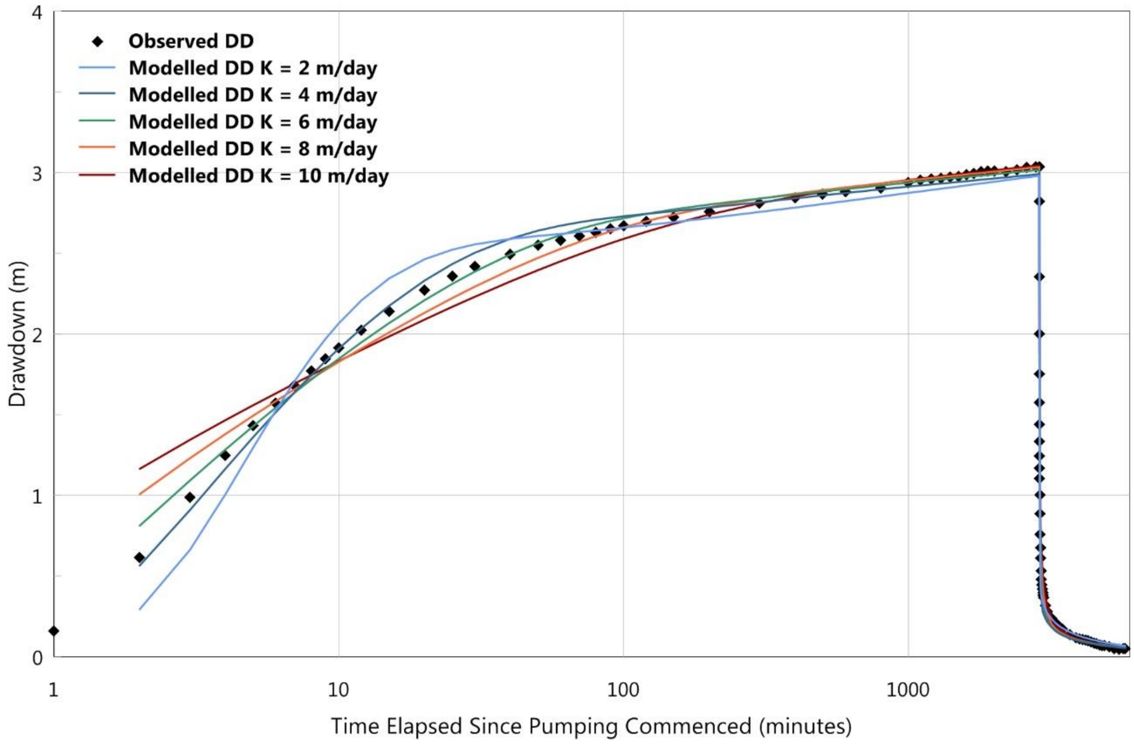


Figure 5-11 Upper Purni Aquifer K_H sensitivity testing, RN18919 modelled and observed drawdown

Table 5-6 shows the optimised model parameters from the five Upper Purni Aquifer K_H scenario tests. Changes in storativity in the Purni Formation and K_H of the J Aquifer are of a similar or smaller magnitude to the change in Purni Formation K_H. Both these parameters decrease as the Purni Formation K_H is increased. The largest changes are observed in the shift in storativity in the J Aquifer and vertical hydraulic conductivity (K_V) of the shale beds. The change in these parameters is over an order of magnitude. At higher transmissivity values less vertical leakage is required to match drawdown in the Purni Formation. The model achieves this by reducing the K_V of the aquitard layers and the storage coefficient of the J Aquifer.

Table 5-6 Upper Purni K_H sensitivity testing – Optimised model parameters

Upper Purni Aquifer		J Aquifer		J/Purni Shale Bed	J Shale Beds
K_H (m/d)	*S*	*K_H (m/d)*	*S*	*K_V (m/d)*	*K_V (m/d)*
2	6×10^{-5}	28	7×10^{-3}	0.03	0.16
4	6×10^{-5}	24	2×10^{-3}	0.012	0.045
6	4×10^{-5}	21	4×10^{-4}	0.004	0.01
8	2×10^{-5}	20	1×10^{-4}	0.001	0.003
10	1×10^{-5}	21	2×10^{-5}	0.0003	0.0006

Purni Formation storage

To investigate the sensitivity of the four aquifer model to changes in the storage coefficient of the Upper Purni Formation, four scenarios were run with fixed storativity values of 5×10^{-5}, 1×10^{-4}, 2×10^{-4} and 5×10^{-4}. The model results for RN18919 are presented along with the observed drawdown in Figure 5-12. Observed drawdown data are best matched at the lowest storativity value (5×10^{-5}). At higher storativity values, particularly those above 10^{-4}, the model provides a poor fit with the observed drawdown in RN18919. This is reflected more broadly in the correlation between modelled and observed drawdown across all Purni Formation and J Aquifer wells. The RSS increases from 0.2 m at a storativity of 5 x 10^{-5} to 3.1 m for the 10^{-4} scenario, and 16 m and 46 m for the 2 x 10^{-4} and 5 v 10^{-4} scenarios respectively.

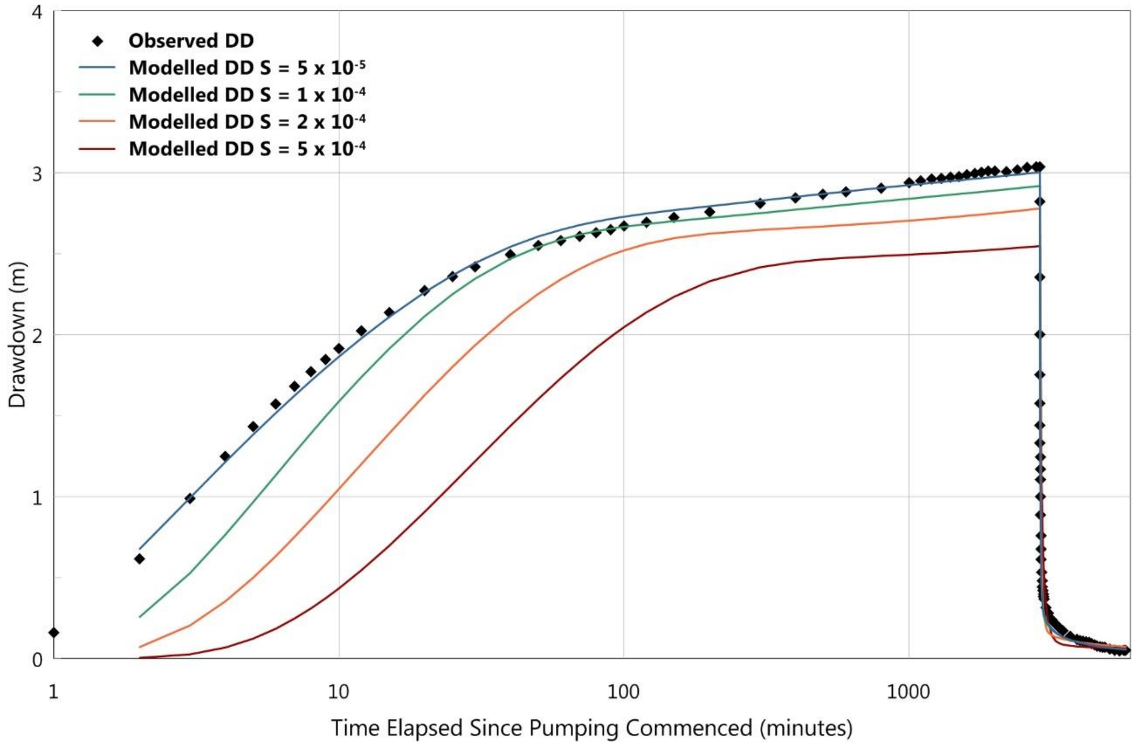


Figure 5-12 Upper Purni Aquifer storativity sensitivity testing, RN18919 modelled and observed drawdown

Table 5-7 shows optimised model parameters from the four Upper Purni Aquifer storativity scenario tests. The storage coefficient of the J Aquifer and the K_V of the shale beds within the J Aquifer were the most sensitive to changes in the Purni Formation storativity. Increasing the Purni Formation storativity above 10^{-4} resulted in modelled J Aquifer storativities well above 5 x 10^{-3}, the text book upper limit for confined aquifers (Todd, 1959, Fetter, 1986).

Table 5-7 Upper Purni storativity sensitivity testing – Optimised model parameters

Upper Purni Aquifer		J Aquifer		J/Purni Shale Bed	J Shale Beds
S	*Kh (m/d)*	*Kh (m/d)*	*S*	*Kv (m/d)*	*Kv (m/d)*
5 x 10^{-5}	5	22	9 x 10^{-4}	0.01	0.02
1 x 10^{-4}	3	22	4 x 10^{-3}	0.02	0.1
2 x 10^{-4}	3	17	0.01	0.02	0.2
5 x 10^{-4}	3	2	0.05	0.02	0.5

Bulldog Shale aquitard status

Additional model runs were undertaken to test the sensitivity of model results to the assumption that the upper aquitard layer (Bulldog Shale) is impermeable. The status of the Bulldog Shale aquitard in the four-aquifer model was set to "leaky" and the KV of this layer was given an initial value of 0.1 m/d. When allowed to optimise the KV of the aquitard resolved at 0.001 m/d and model results were identical to the runs where the Bulldog Shale aquitard layer was set to impermeable.

A second model scenario was undertaken in which the KV of the Bulldog Shale aquifer was fixed at 0.03 m/d – the optimised KV value of the J Aquifer Shale beds. Changing the leakage status of the Bulldog Shale Aquitard and fixing the KV did not have a significant impact on model results with change only observed in the KH of the J Aquifer which decreased by approximately 8% (Table 5-8).

Table 5-8 Optimised model results comparing scenarios where the Bulldog Shale is an impermeable/leaking aquitard

Bulldog Shale Aquitard		Upper Purni Aquifer		J Aquifer	
Layer Status	*K_V (m/d)*	*K_H (m/d)*	*S*	*K_H (m/d)*	*S*
Impermeable	-	5	5×10^{-5}	23	1×10^{-3}
Leaking	0.03	5	5×10^{-5}	21	1×10^{-3}

Sensitivity of conceptual model (number of model layers)

Several conceptual models were tested in MLU ranging from a simple one-layer model through to a complex seven-aquifer model. The best performing and simplest conceptual model was found to be a four aquifer model that split the J Aquifer into three discrete aquifer layers and conceptualised the upper Purni Aquifer as a single layer (see Section 5.4.1 for further detail). To investigate the uncertainty associated with the number of aquifer layers in the conceptual model, key results from the conceptual model trials are presented in Table 5-9. Note that aquifer transmissivity rather than K_H is compared because the aquifer thickness is not consistent between the different conceptual models.

Relative to the four-layer model, the Transmissivity of the upper Purni Aquifer ranged by 70 % and storativity (s) by 20 % across the other conceptual models. The greatest difference is observed in the seven-layer model, in which the Purni Formation was broken into three discrete aquifers. Where the Purni Formation was modelled as a single layer (two to four layer models) the variation in T and S between the models is less than 5%. Model results for the J Aquifer showed greater sensitivity to the number of model layers with T varying by 40 % and S by 80 %.

Table 5-9 Sensitivity of MLU model results to the number of model layers

Conceptual Model	Upper Purni Aquifer		J Aquifer	
	T (m^2/d)	*S*	*T (m^2/d)*	*S*
Two Aquifer Layers	190	5×10^{-5}	1670	4×10^{-4}
Three Aquifer Layers	200	5×10^{-5}	2590	1.2×10^{-3}
Four Aquifer Layers	200	5×10^{-5}	1810	1.1×10^{-3}
Seven Aquifer Layers	340	4×10^{-5}	1510	5×10^{-4}

5.4.5 Crown Point Formation 8-hour constant rate test

The 8-hour constant rate test undertaken on the Crown Point Formation observation well was analysed as a single well pumping test using AQTESOLV® pumping test analysis software (Hydrosolve, 2006). Based on a conceptualisation of the Crown Point Formation as a confined porous media aquifer it was viewed that the Theis (1935) method of analysis was appropriate for the prevailing hydrogeological conditions.

Without an additional observation well in the Crown Point Formation the storage coefficient of the aquifer cannot be accurately determined. For this analysis, the Crown Point Formation storage coefficient has been estimated at 3.2×10^{-4} using an approximation based on the aquifer thickness (64 m) and the compressibility of water (5×10^{-6} m). Results for the observed and modelled drawdown are presented in Figure 5-13, note that recovery data have not been included in the analysis because the test pump was not fitted with a non-return valve.

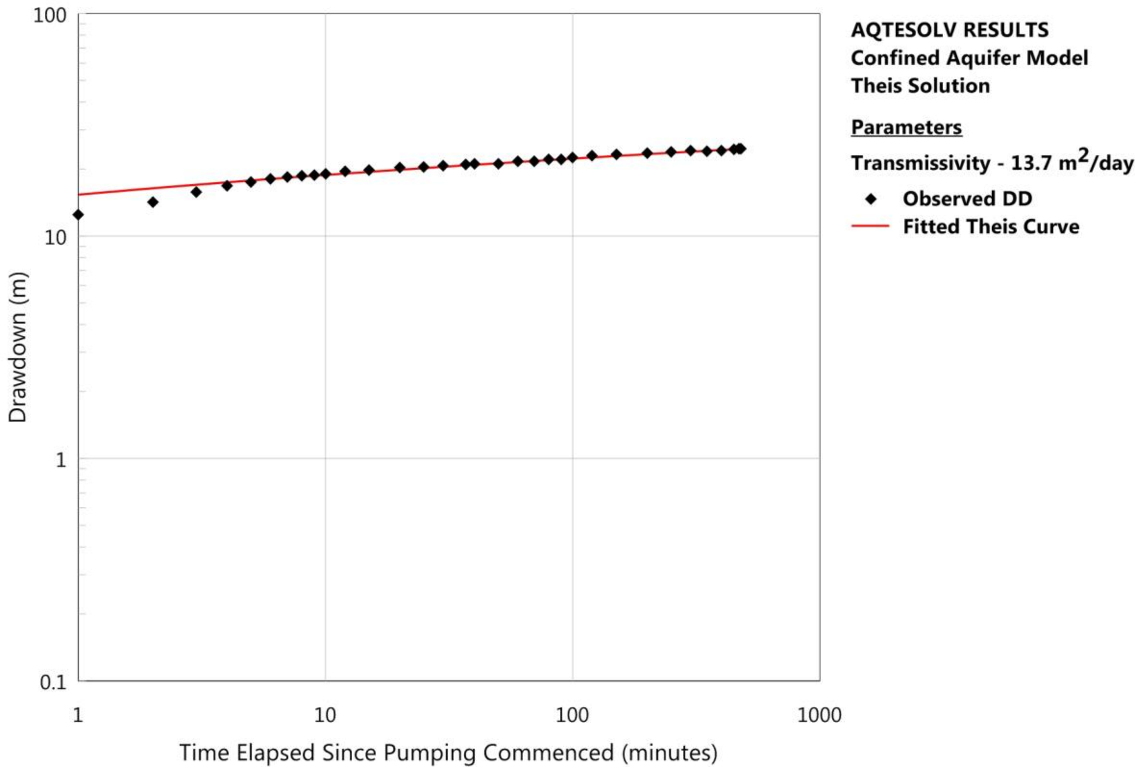


Figure 5-13 Crown Point Formation 8-hour test analysis - Theis curve

The Theis curve overestimates drawdown in early time data due to the effect of well storage, however, during the main phase of the test it is considered the Theis curve provides a reasonable approximation of the observed drawdown in RN18915. Based on the analysis, a transmissivity of 14 m^2/d was obtained. The well has a screen length of six metres, however the casing string on which the screens are attached is open to the aquifer for 64 m between a depth of 467 m and 531 m. As it is not apparent how much of the aquifer is providing flow to the well, these thicknesses provide an upper and lower range for the hydraulic conductivity of the Crown Point Formation, which is estimated to be between 0.2 and 2.3 m/d.

5.4.6 Discussion

Table 5-10 provides a summary of the aquifer parameters derived from the pump test analysis and modelling. The best estimate reflects the parameters from the optimised MLU model, with the exception of the Crown Point Formation parameters which are derived from a separate analysis. The upper and lower ranges are drawn from the sensitivity testing and reflect parameter sets that showed a plausible fit with observed water level data.

Table 5-10 Summary of aquifer parameters and expected ranges from pump test analysis

Formation	Parameter	Best estimate	Lower range	Upper range
J Aquifer	Transmissivity (m^2/d)	1800	1190	2260
	Hydraulic Conductivity K_H (m/d)	23	15	25
	Storage Coefficient	1.1×10^{-3}	1.0×10^{-3}	1.9×10^{-3}
Upper Purni Aquifer	Transmissivity (m^2/d)	204	176	264
	Hydraulic Conductivity K_H (m/d)	4.6	4	6
	Storage Coefficient	5×10^{-5}	5×10^{-5}	1×10^{-4}
Crown Point Formation Aquifer	Transmissivity (m^2/d)	14	-	-
	Hydraulic Conductivity K_H (m/d)	-	0. 2	2.3
J Aquifer/Purni Shale Bed	Hydraulic Conductivity K_V (m/d)	0.01	0.004	0.02
J Aquifer Shale Beds	Hydraulic Conductivity K_V (m/d)	0.03	0.01	0.1

The Upper Purni Aquifer transmissivity reported a modelled range between 176 and 264 m^2/d and an optimal value of 204 m^2/d. The corresponding K_H ranged from 4 to 6 m/d with a best estimate of 4.6 m/d. There are no published aquifer parameters for the Purni Formation, however, results are consistent with K_H estimated from the grain size analysis using the Korzeny-Carman equation (2.4–11.8 m/d). The model reported a storage coefficient for the Upper Purni Aquifer of between 5×10^{-5} and 1×10^{-4} with the best estimate at the bottom end of the range. These values are at the lower limit of the typical storativity range for a confined aquifer (5×10^{-3} to 5×10^{-5}, Kruseman and de Ridder (1994)). Approximating the storage coefficient of the aquifer using the formation thickness (44 m) and the compressibility of water (5×10^{-6}) yields a value of 2.2×10^{-4} which is more than twice the upper limit estimated by the model. Geophysical logging indicates that the Upper Purni Aquifer is stratified and characterising the unit as a single, homogeneous aquifer is likely to oversimplify the hydraulic behaviour of the system. The sand horizon over which the production well is screened has a thickness of 10 m, which multiplied by the compressibility of water corresponds to a storativity of 5×10^{-5}, a value consistent with the model results. This suggests that although vertical leakage is apparent throughout the profile, groundwater flow within the Upper Purni Aquifer is anisotropic.

The cumulative transmissivity for the J Aquifer ranges between 1190 and 2260 m^2/d with a best estimate of 1800 m^2/d. These values are consistent with previous test results in the region which report a transmissivity of 2467 to 2599 m^2/d for the J Aquifer (Fulton, 2013). The derived K_H ranges from 15–25 m/d with a best estimate of 23 m/d. The modelled result is twice the K_H (11 m/d) reported from aquifer testing at New Crown homestead 80 km to the south-west of the test site (Fulton, 2013). However, the K_H vales from the model are consistent with the high permeability estimated from the grain size analysis of drill cuttings (49 m/d) and with the K_H reported from regional studies of the GAB aquifer: 0.5–22 m/d (Berry and Armstrong, 1997), 1–73 m/d (Audibert, 1973). The modelled storage coefficient reported a range between 1×10^{-3} and 1.9×10^{-3} with a best estimate of 1.1×10^{-3}. Results compare favourably with storativity range of 1.2×10^{-3} to 6×10^{-4} reported in Fulton (2013).

The modelled K_V of the shale/clay bed separating the J Aquifer from the Upper Purni Aquifer is estimated at 0.01 m/d with a range of 0.004–0.02 m/d. The values fall within the reported laboratory derived permeability range for Purni Formation Sandstones 0.002–2.4 m/d (Wohling et al. 2013). By comparison, the best estimate K_V of the shale bed (0.01 m/d) is over two orders of magnitude greater than the K_V of the silty-clay layer (8.6×10^{-5}) that separates the GAB sequence from the Permian Mount Toodina Formation in the analogous Arckaringa Basin and four orders of magnitude greater than the laboratory derived K_V for the regional Bulldog Shale aquitard (2.1×10^{-6} m/d, Love et al. 2013a). Results suggest that the model derived K_V for the clay/shale bed between the Purni Formation and the GAB sequence is more consistent with the K_V of an aquifer unit than a true aquitard. The layer provides limited hydraulic resistance and at this site it can be considered that there is no effective aquitard separating the Upper Purni Aquifer from the J Aquifer.

5.5 Prediction of long-term impacts of pumping

Due to the practical constraints imposed by the remote site location, the aquifer test undertaken on the Purni Formation was limited to a 48-hour duration. This pumping period is significantly shorter than the prolonged extraction regime that would likely accompany a CSG or LCM development. To investigate the drawdown response in the Purni Formation and J Aquifer over longer extraction periods and at higher extraction rates, a series of forward prediction scenarios were run using the four aquifer-layer MLU model. The model was attributed with the best estimate parameters (see Table 5-10) and three scenarios run applying pumping rates of 25, 50 and 100 L/s from the Purni Production Well over a ten year stress period. Comparable to the 48-hour test results, there is a higher level of uncertainty associated with the forward predictions because the long term leakage response of the aquitard units may not have been captured in the 48-hour stress period. Consequently the drawdown predictions provided in Table 5-11 should be viewed as indicative.

The drawdown response from the MLU forward prediction scenarios are presented in Table 5-11. The drawdown in the Lower J Aquifer ranges from 1.1 to 4.3 m at the nested site. The drawdown cone extends radially from the connectivity site within the J Aquifer with the 0.5 m drawdown contour predicted to extend over 3 km in the 25 L/s scenario to over 30 km in the 100 L/s scenario.

Table 5-11 Maximum simulated drawdown after 10-years pumping at 25, 50 and 100 L/s

Pumping rate (L/s)	Maximum simulated drawdown (m)			
	Purni Formation (RN018918)	*Purni Formation (RN018919)*	*Lower J Aquifer (RN18917)*	*Upper J Aquifer (RN18916)*
25	25	3.6	1.1	0.8
50	49	7.2	2.3	1.5
100	98	14.4	4.6	3.1

6 Water quality

The analysis and comparison of environmental tracers from multiple wells/aquifers can provide important insights into aquifer connectivity (IESC, 2014). For the aquifer connectivity investigation site, groundwater samples were collected from each of the nested wells immediately before the completion of aquifer testing, with the exception of the upper J Aquifer, which was sampled after field chemistry stabilised. Groundwater samples were also collected from the Purni Aquifer during the 48-hour test at 120, 360, 600, 1440, 2040 and 2880 minute intervals.

Electrical conductivity (EC), pH, temperature, dissolved oxygen (DO) and redox potential (ORP) were measured with a *YSI Professional Plus* water quality meter. Carbonate alkalinity ($CaCO_3$) was determined in the field using a Hach digital titrator. Samples were collected and analysed for the following parameters: major cations and anions, trace metals, stable isotopes of water (δ^2H and $\delta^{18}O$), strontium isotopes ($^{87}Sr/^{86}Sr$) and carbon isotopes (^{14}C and ^{13}C). Further detail on sample preparation and preservation methods, laboratory details, analysis methods and accuracies are documented in Appendix G. The following section discusses the environmental tracer results across the nested site; time series data collected from the Purni Formation during the 48-hour test are discussed separately in Section 6.2.

6.1 Connectivity site

6.1.1 Field chemistry

Final field chemistry readings collected during the aquifer testing and sampling of aquifer connectivity investigation site wells are presented in Table 6-1. The EC of groundwater increases with depth through the profile reaching a maximum of 28.2 mS/cm in the Crown Point Formation; more than three times greater than the EC recorded from the upper J Aquifer. The EC of the J Aquifer is fairly uniform across the formation (8.8 and 9.9 mS/cm for upper and lower J Aquifer respectively). Groundwater temperature ranges from 33.5 °C in the upper J Aquifer to 47.2 °C in the Crown Point Formation. Temperatures recorded in the upper/lower J Aquifer and Purni Formation plot along a straight line against depth giving a local geothermal gradient of 2.4 °C/100 m. The pH of groundwater is neutral in all samples and ranges between 6.8 and 7.1, while redox potential (ORP) is uniformly negative indicating the dominance of reducing conditions.

Table 6-1 Connectivity site field chemistry

Well	Aquifer	EC (mS/cm)	Temp (° C)	pH	DO (mg/L)	ORP (mV)	Alkalinity (mg/L)*
RN18916	upper J Aquifer	8.8	33.5	6.8	3.04	-230	137
RN18917	lower J Aquifer	9.9	35.5	6.9	3.43	-327	185
RN18918	upper Purni Aquifer	14.2	36.6	6.9	1.77	-195	137
RN18915	Crown Point	28.2	47.2	7.1	2.34	-299	190

* Reported as $CaCO_3^-$ Alkalinity

6.1.2 Major ion chemistry

The relative cationic and anionic composition of the connectivity investigation site wells is plotted with regional groundwater samples for the J and Crown Point aquifers in Figure 6-1. The regional Crown Point samples are sourced from the DLRM HYDRSTA database and Stage 1 sampling results. The regional J Aquifer samples are sourced from Love et al. 2013, Matthews, 1998 and Radke et al. 2000. The major ion composition of groundwater is Na-Cl dominated in both J Aquifer samples and the Permian aquifers. The Crown Point Formation sample plots within the domain of regional groundwater for this aquifer, though it has a higher relative proportion of Na-Cl ions than most Crown Point Formation groundwater. The Lower J Aquifer, Purni Aquifer and Crown Point Formation samples cluster closely on the Piper diagram indicating they have a similar chemical signature. The fact that the Lower J Aquifer and Purni aquifer have similar chemistries is also consistent with high connectivity inferred from aquifer pumping test analysis.

The chemical fingerprint of the four samples is also presented in the inset as a Schoeller plot. In this diagram the major ion concentration of each sample is plotted on a logarithmic scale. Groundwater of similar composition plot along parallel lines with the separation distance simply indicating a dilution or concentration of the water type. With the exception of HCO_3 in the lower J Aquifer, which is higher relative to the Purni and Crown Point formations, the three formations have a similar ionic fingerprint. In contrast, the upper J Aquifer has a higher relative concentration of Mg and Cl and a lower relative concentration of Ca and SO_4.

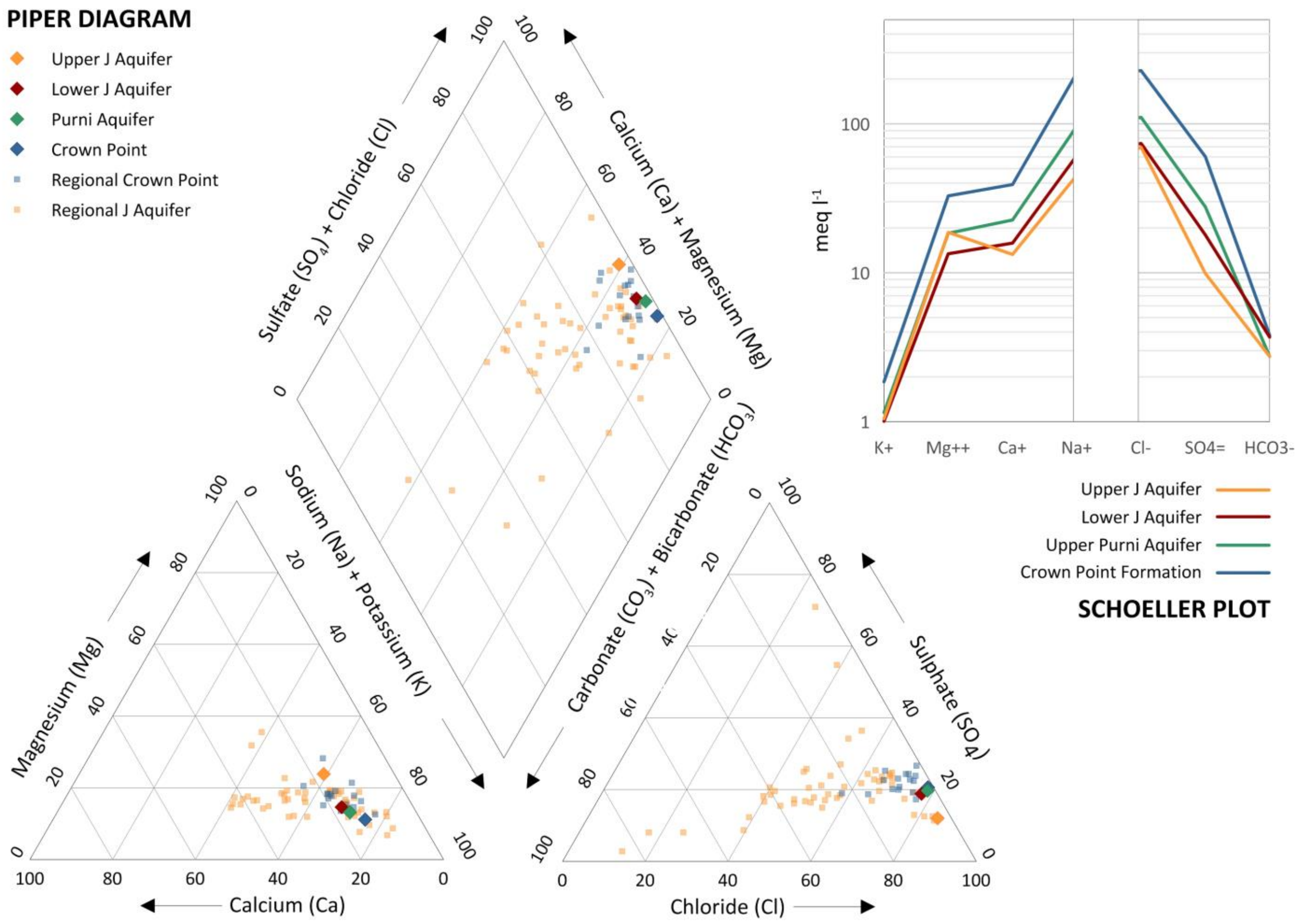


Figure 6-1 Piper diagram and Schoeller plot showing ionic composition of groundwater from the connectivity site

Chloride/bromide ratios in precipitation are very homogenous and prove a powerful tool for tracing the evolution of waters in groundwater systems. The Cl/Br ratio for the connectivity site ranges from 1427 to 2756 and increases with sampling depth through the profile (Figure 6-2A). All samples are significantly elevated above the Cl/Br ratio of oceanic derived precipitation (550 to 700, Herzceg et al. 1991), suggesting the addition of chloride or removal of bromide from the groundwater system. These high ratios are consistent with elevated Cl/Br ratios observed in regional groundwater from both the J Aquifer and the Crown Point Formation (Figure 6-2B). Groundwater actively dissolving halite is characterised by Cl/Br ratios of between 2250 and 22 500 (Davis et al. 1998). RN18915 has a Cl/Br ratio of 2 756 which suggests the possibility of halite dissolution in the Crown Point Formation. This is supported by a Na/Cl ratio of 0.97, which is close to the 1:1 molar ratio associated with halite dissolution (Figure 6-2C). Values for the Lower J and Purni aquifers are close to the atmospheric ratio of 0.86. A Na/Cl ratio of 0.65 in RN18916 suggests the addition of chloride/removal of sodium to the Upper J Aquifer.

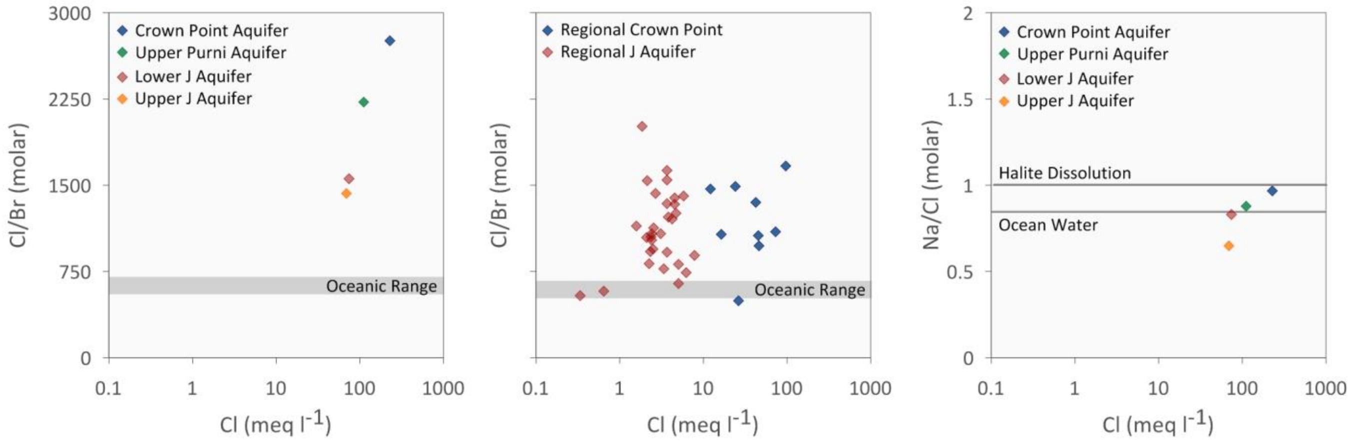


Figure 6-2 (A) Connectivity site Cl/Br vs Cl, (B) Regional Cl/Br vs Cl and (C) Connectivity Site Na/Cl vs Cl

6.1.3 Stable isotopes (δ^2H & $\delta^{18}O$)

Stable isotopes of water (δ^2H and $\delta^{18}O$) provide insight into the geochemical evolution and recharge characteristics of groundwater. The δ^2H and $\delta^{18}O$ results are presented in Figure 6-3 along with the Alice Springs Local Meteoric Water Line (LMWL) which is based on analysis of Alice Springs rainfall from the Global Network of Isotopes in Precipitation project (GNIP). For context the plot also presents other regional Crown Point Formation samples from the first stage of the project and regional J Aquifer samples (Love et al. 2013, Matthews, 1998 and Radke et al. 2000).

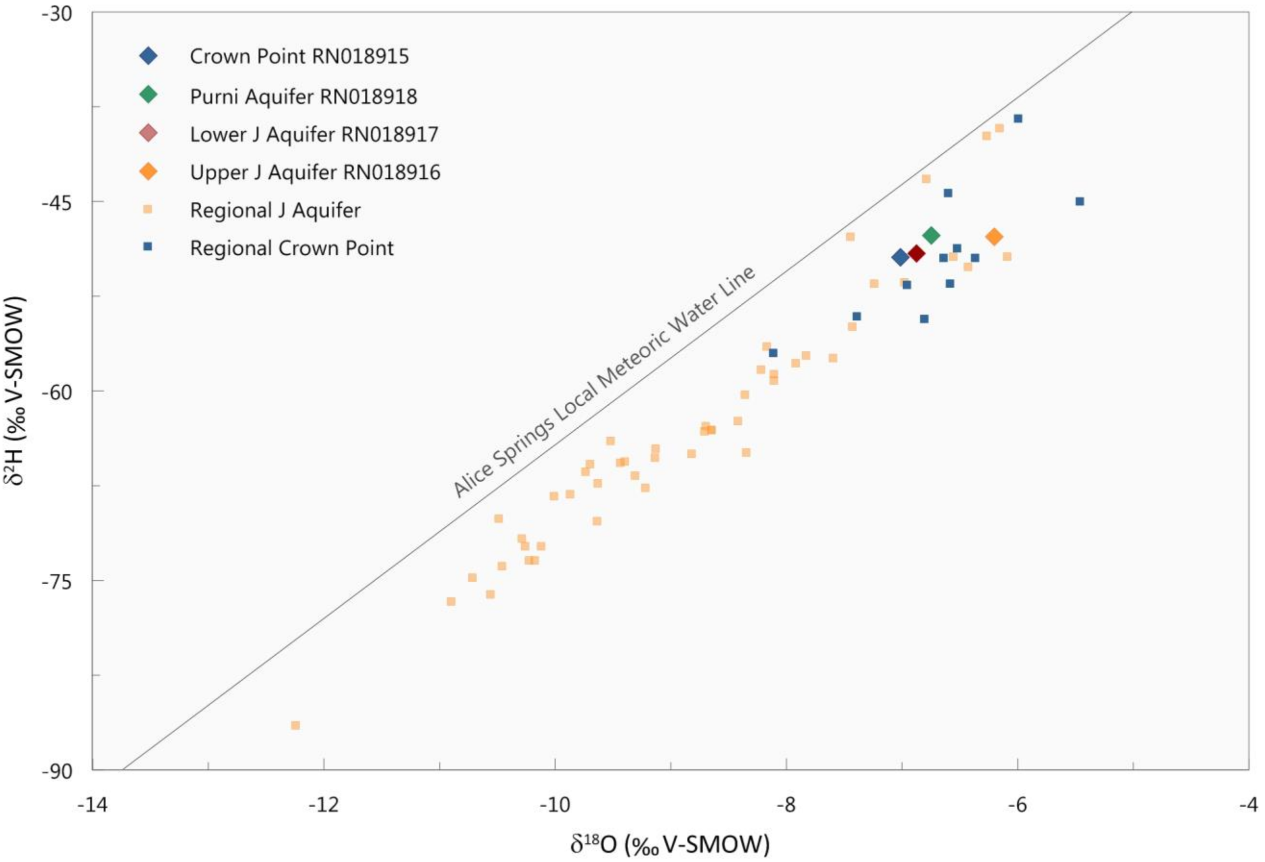


Figure 6-3 Stable isotopes (δ^2H vs $\delta^{18}O$) for connectivity site, regional aquifers and Alice Springs rainfall

The deeper aquifer connectivity investigation samples (lower J Aquifer, Purni Formation and Crown Point Formation) plot in a cluster suggesting the groundwater has a similar meteoric origin and evolution. The upper J Aquifer sample plots to the right of the three deeper samples, this displacement is consistent with groundwater having undergone a degree of evaporative fractionation. Regional samples from the J Aquifer form a trend slightly offset from the Alice Springs LMWL. The more depleted J Aquifer samples have been linked to large recharge events linked to the rapid infiltration of flood water from the Finke River (Love et al. 2013). The aquifer connectivity investigation site samples plot amongst the least depleted J Aquifer samples and within the domain of regional Crown Point groundwater. The greater enrichment of δ^2H and δ^{18}O of these samples suggests a recharge mechanism associated with smaller, less intense rainfall events.

6.1.4 Carbon-14

Carbon-14 (^{14}C) is a radionuclide with a known decay rate and a half-life of 5730 years. Carbon is near ubiquitous in groundwater, making ^{14}C a useful and commonly employed tracer in hydrogeological investigations where groundwater residence times are less than 30 000 years (Clark and Fritz, 1997). Carbon-14 is conventionally reported as percent modern carbon (pmC) which is defined as the absolute percent modern relative to the NBS oxalic acid standard, corrected for decay since 1950 (Stuiver and Polach, 1977). The year 1950 is taken as the zero year for modern ^{14}C activity: values less than 100 pmC are therefore interpreted to be pre-1950 and samples which have an activity greater than 100 pmC are post-1950 (Kalin, 1999).

To convert the ^{14}C concentration in pmC to an apparent groundwater age it is necessary to know the initial activity (A_O) of the carbon in groundwater when it first enters the aquifer. The ^{14}C activity of atmospheric CO_2 prior to 1950 has varied between 97 and 140 pmC over the last 25 000 years (Clark and Fritz, 1997). All apparent groundwater ages reported in Table 6-2 assumes A_O of 135 pmC, which is the atmospheric ^{14}C concentration 20 000 years BP and is sourced from the southern hemisphere atmospheric radiocarbon calibration curve SHCal04 (McCormac et al. 2004). Additional sources of dead carbon to groundwater, from soil CO_2 or calcite dissolution, can lead to the dilution of initial groundwater carbon concentrations and result in an overestimate of the apparent groundwater age. Three correction methods have been applied in Table 6-2 to account for the addition of dead carbon to the groundwater system. Tamers (1975) is based on chemical dilution, while the Ingerson and Pearson (1964) and Fontes and Garnier (1975) methods use Carbon-13 concentration to account for isotope dilution.

The ^{14}C activities in groundwater increase with depth and range from 6.8 pmC in the upper J Aquifer through to 10.6 pmC in the Crown Point Formation. The corrected apparent groundwater ages suggest a maximum groundwater residence time of between 19 500 years (upper Purni Aquifer) and 23 100 years (lower J Aquifer). The apparent groundwater ages reported in Table 6-2 reveal fossil groundwater occurs throughout the Pedirka/GAB aquifer sequence. Results may indicate palaeo-recharge to the Pedirka Basin and GAB Basin was contemporaneous in this area.

Table 6-2 Connectivity site ^{14}C concentrations, uncorrected and corrected apparent groundwater ages

Well	Aquifer	^{14}C (pmC)	δ^{13}C (‰)	Uncorrected apparent age (years BP)	Tamers Correction (years BP)	Pearson Correction (years BP)	Fontes & Garnier Correction (years BP)
RN18916	Upper J Aquifer	6.8	-10.2	24 700	20 200	17 500	17 800
RN18917	Lower J Aquifer	7.6	-15.2	23 700	18 100	23 100	22 700
RN18918	Upper Purni Aquifer	8.3	-10.6	23 000	19 500	16 600	16 900
RN18915	Crown Point	10.6	-15.6	21 000	16 900	20 700	20 400

6.1.5 Strontium isotopes (^{87}Sr/^{86}Sr)

Strontium and two of its naturally occurring isotopes ^{87}Sr and ^{86}Sr are powerful indicators of water–rock interaction and can provide information on the movement, evolution and the origin of dissolved salts in groundwater (Clark and Fritz, 1997). The ^{87}Sr/^{86}Sr ratios of groundwater from the four connectivity-site wells are presented in Figure 6-4 with samples from the regional Crown Point aquifer. The ^{87}Sr/^{86}Sr ratio ranges from 0.7136 to 0.7163 across the connectivity site samples; with the lower J Aquifer and Upper Purni Aquifer having similar ratios (0.7163 and 0.7162 respectively), and the Crown Point Formation (0.7146) and upper J Aquifer (0.7136) having slightly lower ratios. Regionally, groundwater from the Crown Point Formation is more radiogenic ranging from 0.7162 to 0.7201. Both the aquifer connectivity investigation site and the regional Crown Point Formation samples are more radiogenic compared to the ^{87}Sr/^{86}Sr ratio of modern seawater (0.709) and plot in the range consistent with ^{87}Sr enriched crustal rocks (0.710–0.740) (Clark and Fritz, 1997).

Figure 6-6A shows a plot of 1/Sr vs $^{87}Sr/^{86}Sr$. The aquifer connectivity investigation site samples cluster close to the Y axis, indicating a relatively high strontium concentration, while the regional Crown Point Formation samples form a trend of increasing $^{87}Sr/^{86}Sr$ and decreasing strontium indicative of the mixing of two water components. Figure 6-6B plots the $^{87}Sr/^{86}Sr$ ratio against the sample distance from the Finke River recharge zone, an area of active recharge to the Pedirka Basin identified in Stage 1 of the investigation (Wohling et al. 2013). The plot reveals that groundwater close to the Finke River has a higher $^{87}Sr/^{86}Sr$ ratio and groundwater at distance from the river has a lower $^{87}Sr/^{86}Sr$ ratio. When viewed with Figure 6-4A, this may suggest there are two recharge sources to the Permian aquifers: a more radiogenic water associated with flood recharge from the Finke River and a second less radiogenic recharge source occurring at distance from the Finke River.

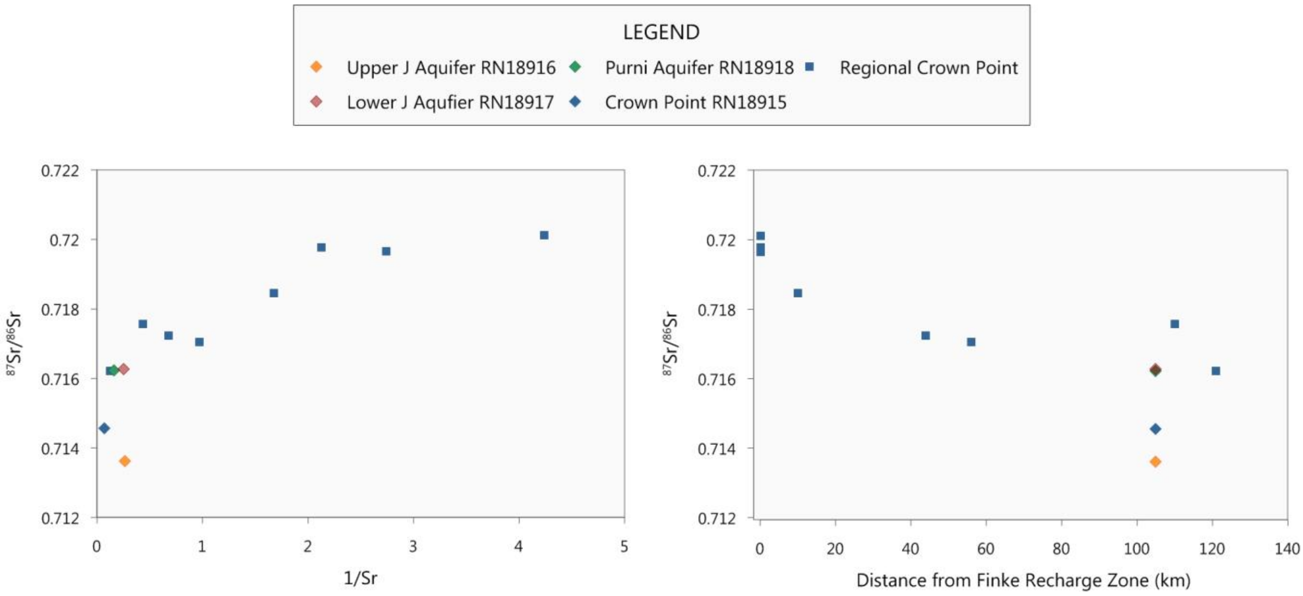


Figure 6-4 Regional Crown Point and connectivity site: (A) 1/Sr vs $^{87}Sr/^{86}Sr$ and (B) Distance from Finke River vs $^{87}Sr/^{86}Sr$

6.2 Purni formation 48-hour aquifer test time series

6.2.1 Field chemistry

Field chemistry remained largely constant throughout the 48-hour constant rate test (Figure 6-5) with an average alkalinity of 160 mg/L, pH of 6.9, DO content of 2 mg/L, groundwater temperature of 36.6 °C and EC of 14 200 µs/cm. Groundwater EC showed an increase of 300 µs/cm (2% of absolute reading) over the first 800 minutes of the test before trending back to within 100 µs/cm of the initial conductivity before the conclusion of the pumping period.

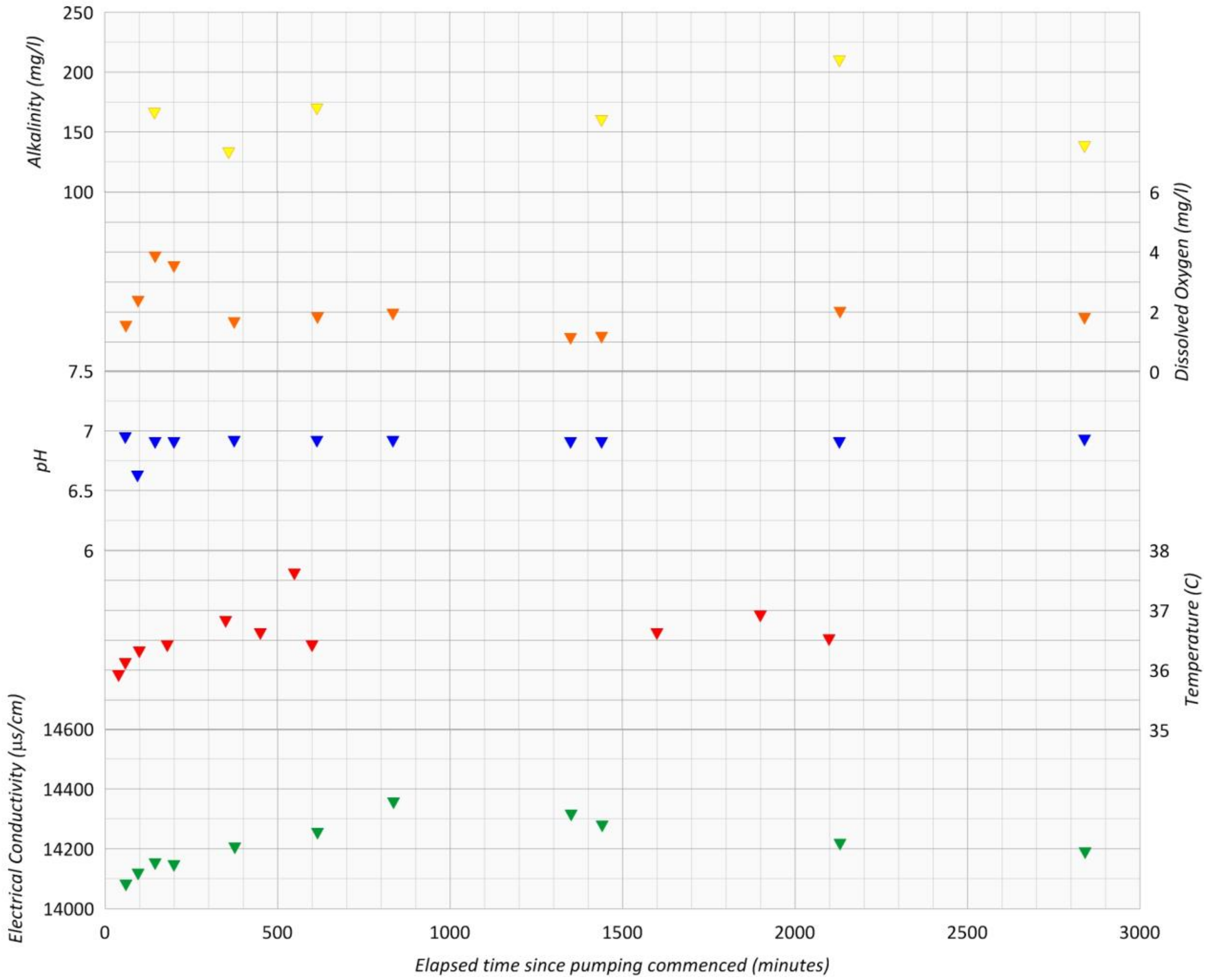


Figure 6-5 Purni Formation time series field chemistry observed during 48-hour aquifer test (RN18918)

6.2.2 Major ions and isotopes

The mean, minimum and maximum concentrations recorded for each major ion are summarised in the Table 6-3 with a comment on the observed trend. Graphs for major ion fluctuations against pumping time are provided in Appendix H.

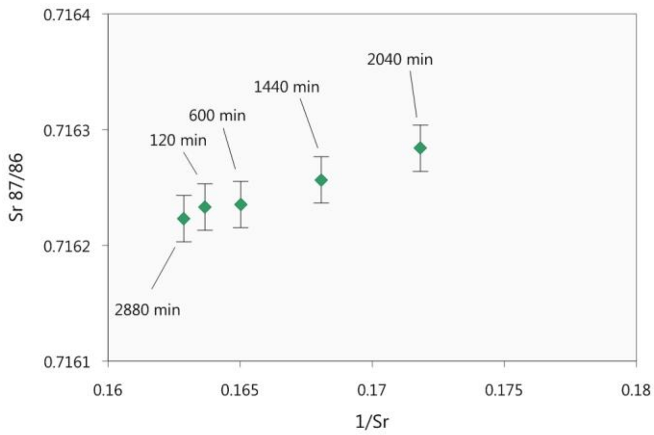
Table 6-3 Purni Formation major ion concentration range and observed trends over 48-hour test

Analyte	Mean conc. (mg/L)	Min. conc. (mg/L)	Max. conc. (mg/L)	Comment
Cl^-	3 940	3 900	3 990	No trend, scatter shows inverse relationship with HCO_3^-
HCO_3^-	197	161	255	No trend, scatter shows inverse relationship with Cl^-
SO_4^{2-}	1 330	1 300	1 340	No trend
Na^+	2 190	2 110	2 240	Decreasing trend until 2 040 min, spike at 2 880
Ca^{2+}	451	446	458	Slight decreasing trend 120 – 2040 min
Mg^{2+}	222	214	226	Slight decreasing trend 120 – 2 040 min, spike at 2 880 min
K^+	45	43	46	Slight decreasing trend 120 – 2 040 min, spike at 2 880 min

There is no apparent trend in chloride, sulfate or bicarbonate concentrations over the test period. Minor fluctuations occur in the concentration of chloride and bicarbonate which appear inversely correlated. Sodium shows a decreasing trend with a drop of around 5% (100 mg/L) from the start of the test to the 2040 minute mark before increasing 150 mg/L for the last reading.

This pattern (decreasing trend to 2040 minutes with a concentration spike in the final reading) is also observed for the other major cations (calcium, magnesium, potassium).

The decreasing trend in cation concentrations over the test suggests there is local variation in water quality within the Purni Formation aquifer. This is supported by a comparison of 1/Sr versus the strontium isotope ratio of $^{87}Sr/^{86}Sr$ (Figure 6-6A). The time series samples plot along a straight line which indicates the mixing of two distinct water components. As the test progresses the samples move along the mixing line until the last sample at 2880 minutes when the strontium isotope ratio return to near the initial value. A possible explanation may be a mixing of horizontal and vertical groundwater flow as the test progresses. This is supported in part by a comparison of the deuterium excess (*d*) from the Purni Formation time series with samples from other aquifers at the connectivity site. The Purni Formation samples collected during the aquifer test show a trend of decreasing *d* from 8.7 to 5.3 until the sample at 2880 min which reports a value of 6.3. The nested wells show a strong trend of increasing *d* with increasing depth in the profile (1.8 in the upper J Aquifer through to 6.7 in the Crown Point Formation). The decreasing trend observed in Purni Formation time-series data may result from the vertical leakage of low *d* water higher in the profile.



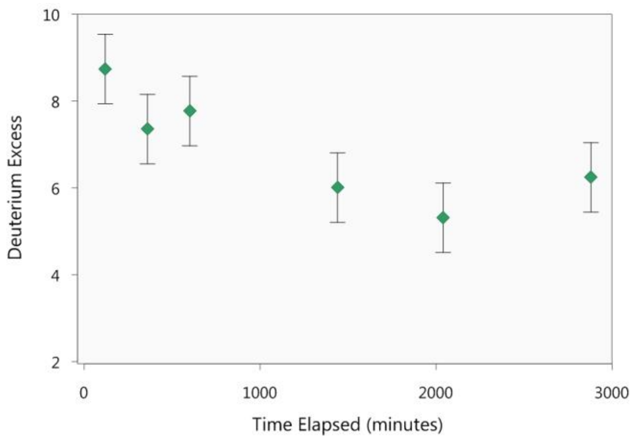


Figure 6-6 (A) 48-hour test, 1/Sr vs $^{87}Sr/^{86}Sr$ and (B) Time elapsed vs Deuterium excess

The ^{14}C activity of groundwater also shows notable variation over the test period, ranging from an initial concentration of 4.6 pmC and trending down to 1.6 pmC after 1440 minutes before increasing to 8.6 pmC at the end of the aquifer test (Figure 6-7). These results correlate to a corrected apparent groundwater age range of between 16 600 and 32 400 years. Reliance on these apparent groundwater ages should be avoided as groundwater in large sedimentary systems is comprised of a distribution of water of different ages. However, the results support the Purni Aquifer as a system with locally variable water quality and in combination with the hydraulic assessment may suggest that groundwater quality and flow is stratified within the aquifer under natural conditions.

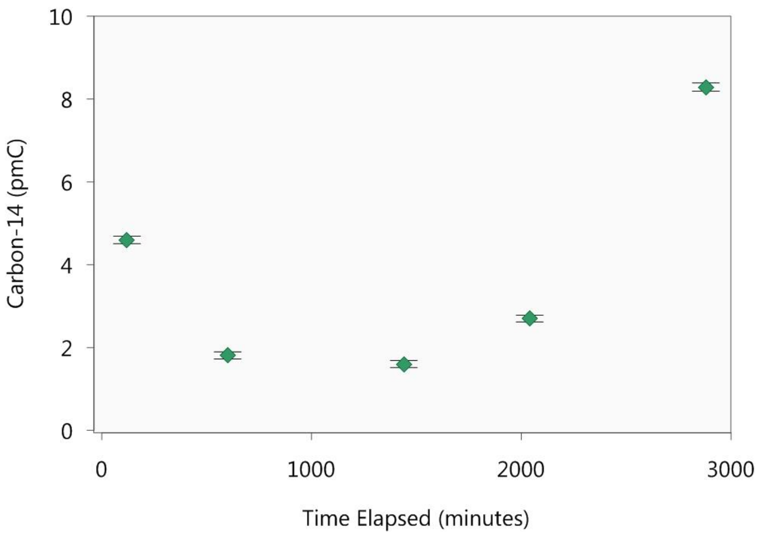


Figure 6-7 48-hour test: Carbon-14 vs Time elapsed

7 Up-scaling of connectivity site results

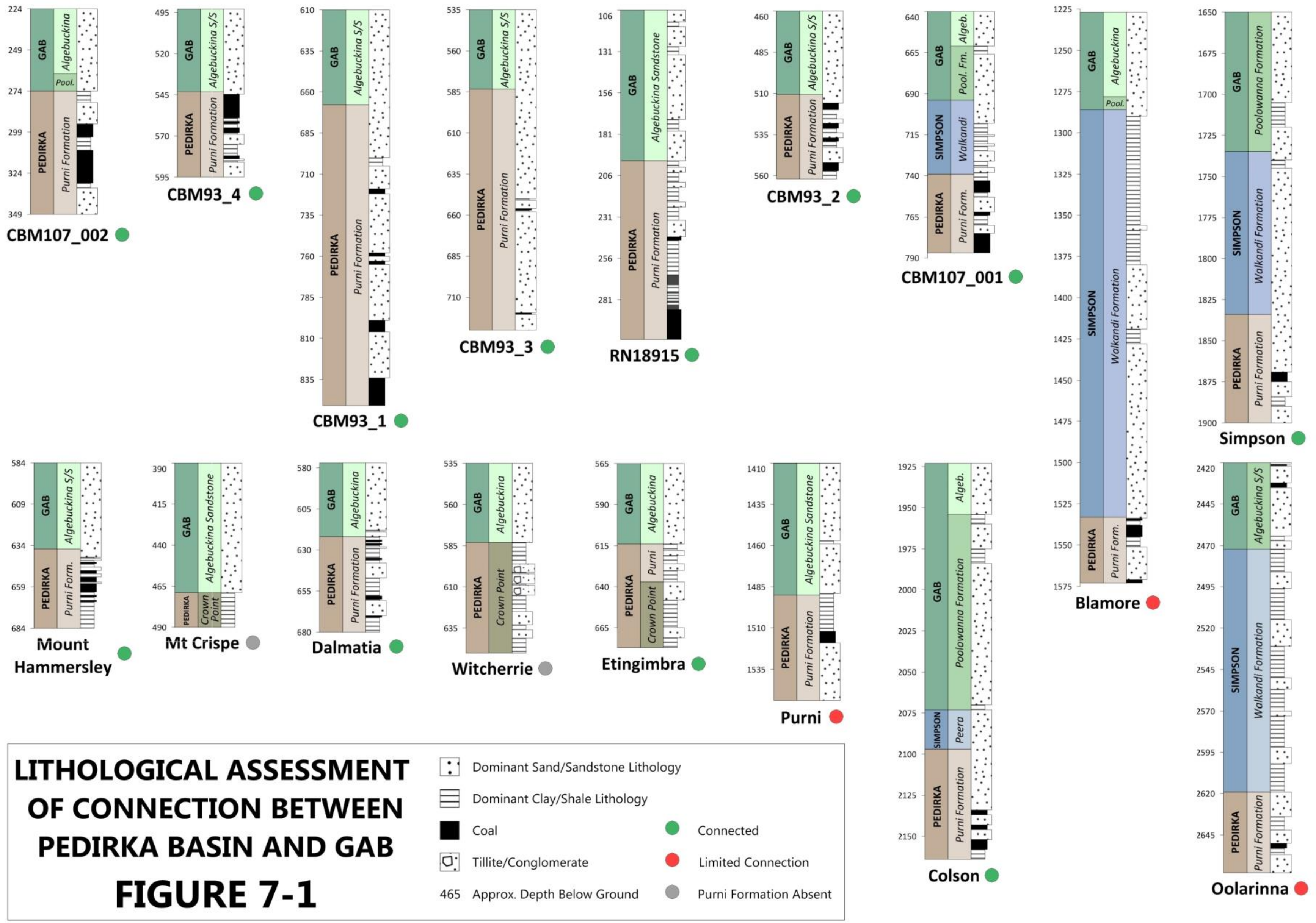
The drilling and aquifer testing program provides insight into the inter-connectivity between the Pedirka Basin and the GAB at a field scale. Translating these local findings to a regional level is necessary if the results are to be applied in other areas of the Pedirka Basin. The IESC connectivity report (Commonwealth of Australia, 2014) documents several approaches for assessing aquifer connectivity at a regional scale including the use of geophysical methods, environmental tracers and numerical modelling. A comparison between the aquifer connectivity investigation site results and regional environmental tracer data has been undertaken in Section 6, however, the approach is limited by data coverage which is restricted to the north-west of the basin. A numerical model for the Pedirka Basin has been developed by DEWNR (Peat and Yan, 2015) but insight provided by the model is also limited by the paucity of calibration data. In light of these data limitations this study adopts an upscaling method based on available lithological logs. Down-hole geophysics and detailed cutting descriptions from oil, gas and coal well completion reports have been used to make a basic assessment of regional aquifer connectivity based on the dominant lithology profile at each well site. The approach has limitations as it relies on a restricted number of field scale measurements, however, when viewed in concert with the formation coverages from the GAB Hydrogeological Map (Sampson et al. 2012) and Pedirka Basin Hydrogeological Map (Wohling et al. 2013) the results provide a level of insight into regional aquifer connectivity.

7.1 Assessment of lithological connection

Well completion reports from 21 oil, gas and coal exploration wells in the Pedirka Basin were reviewed to develop a series of lithological profiles classified according to sand/clay content. This analysis focused on the stratigraphic profile from the basal J Aquifer (Algebuckina sandstone/Poolowanna Formation) through to the first significant coal sequence in the Purni Formation. Five well completion reports (McDills No.1, Hale River, Mokari 1, Glen Joyce 1 and Macumba 1) contain insufficient information to construct a lithological profile at the required scale. In a further two wells, Mount Crispe 1 and Witcherrie 1, the Purni Formation is absent and the profile is characterised by the basal Crown Point Formation and GAB sequence.

A range of information including detailed cutting descriptions, mud logs and down hole geophysical logs were used to divide the profile into three key lithology groups: sand dominated (sand, sandstone and gravel), clay dominated (clay, claystone, mudstone and shale) and coal. A fourth group of conglomerate/tillite was included where the Crown Point Formation was present. Where a percentage composition was provided in the well completion report the sand dominated category was considered where sand/sandstone was >50% of the lithological composition and clay dominated where sand/sandstone was ≤50%. The lithology profiles are presented below in Figure 7-1 along with an assessment of the potential connection between the Purni Formation and GAB sequence. Profiles that have a predominant sand lithology (Figure 7-2) and do not contain a continuous intervening clay/shale clay in excess of 10 m between the coal measures and GAB sequence are classed as connected. Profiles that do not meet these criteria are categorised as having a limited connection. The spatial location of each well, connectivity assessment, formation extents and key geological structures are provided in Figure 7-3.

A key assumption in drawing inferences of hydraulic connectivity from the lithology profiles is that sand dominated lithology correlates with higher permeability/connectivity and clay dominated lithology correlates with low permeability/connectivity. The connectivity categories are made for the express purpose of comparing different sites across the Pedirka Basin. As this approach does not consider variation in permeability within sandstones, the effect of secondary porosity or preferential flow through fractured rocks; categories provided in Figure 7-1 should not be relied on for any site specific assessment of aquifer connectivity.



LITHOLOGICAL ASSESSMENT OF CONNECTION BETWEEN PEDIRKA BASIN AND GAB

FIGURE 7-1

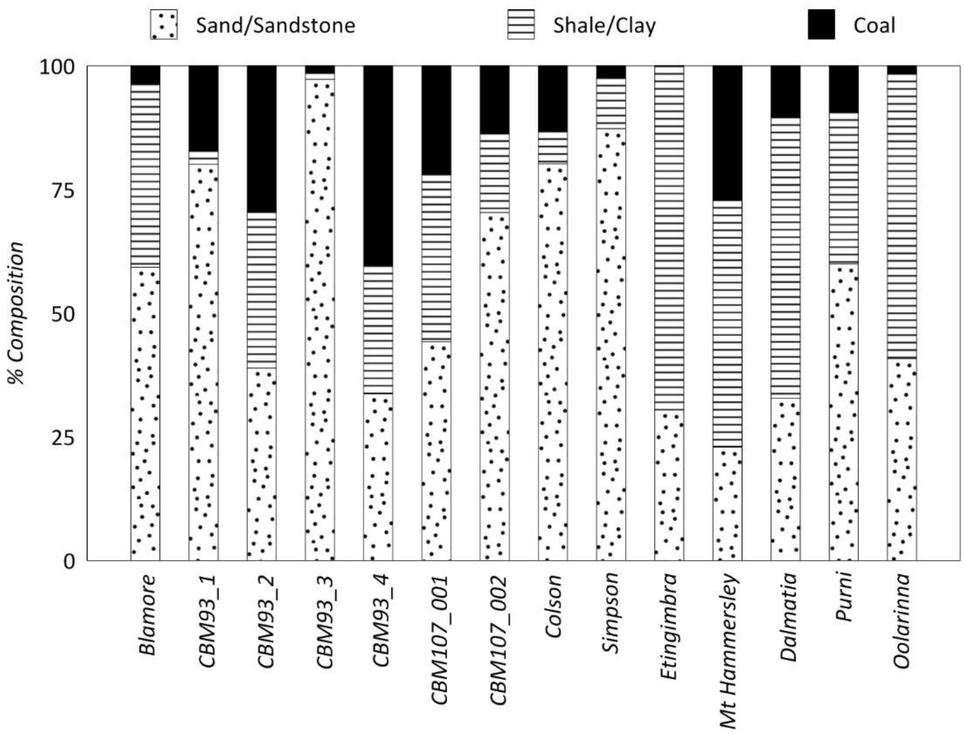


Figure 7-2 Relative sand/clay/coal composition of Upper Purni and Triassic Formations

7.2 Discussion

The stratigraphic profile between the Purni Formation coal measures and J Aquifer is dominated by coarse grained sediments with 12 of the 17 profiles assessed as connected. With the exception of Purni No. 1 and the connectivity site (RN18915) no significant low permeability layers were identified between the coal measures and J Aquifer. A comparison between the relative composition (Figure 7-2) and location (Figure 7-3) of each profile reveals a spatial trend in the relative sand/clay proportion in the upper Purni Formation, with wells located in the north of the Pedirka Basin displaying a sand dominated lithology. The Purni Formation in this region also contains the most significant and accessible coal resource in the Pedirka Basin. Wells located in the south of the basin have a higher relative proportion of fine grained sediments, a thinner sequence of Purni Formation and generally a less significant coal sequence.

With the exception of Purni 1, wells with “limited connection” between the Purni Formation coal measures and J Aquifer (Blamore 1, Oolarinna 1) contain a thick sequence of intervening Triassic sediments. However, the remaining three wells that intersect the Triassic sequence contain a greater proportion of sand and are classed as connected. Figure 7-3 suggests that the composition of Triassic Formations is structurally controlled. In basin depocentres, where the Simpson Basin sequence is thicker the stratigraphic profile contains a greater proportion of fine grained sediments (e.g. Blamore 1 in the Madigan Trough). Areas located on the edge of these depocentres (CBM107-002) and on structural highs (Simpson 1 on the Colson Shelf) have a thinner sequence of Triassic sediments or a profile containing a greater proportion of coarse grained material. The lithological analysis suggests that the Triassic sequence may limit connection between the Permian coal measures and GAB but only in select areas of the Pedirka Basin.

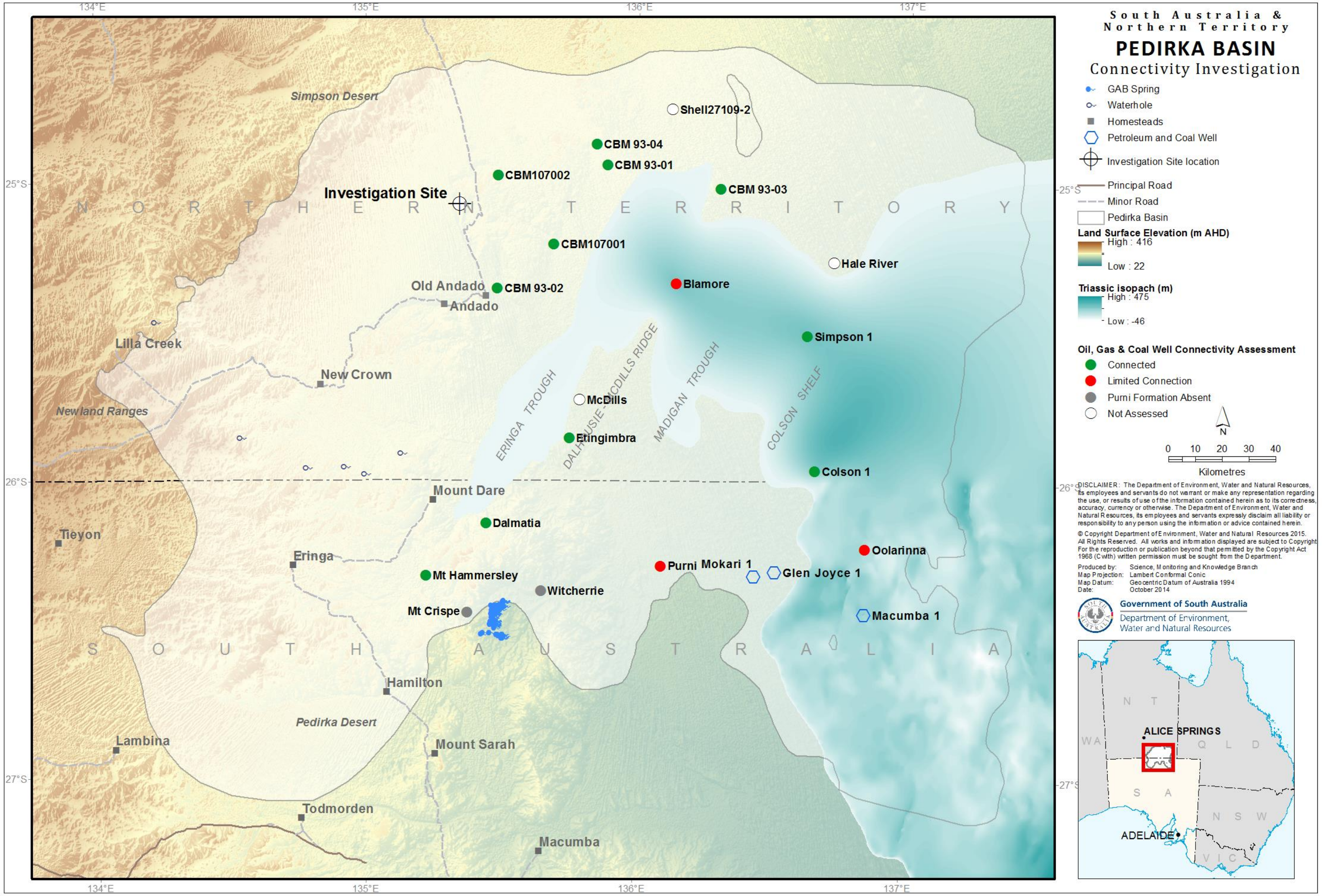


Figure 7-3 Pedirka Basin oil/gas/coal investigation well locations and connectivity assessment

8 Conclusions

The Pedirka Basin connectivity investigation involved the successful completion of five groundwater investigation wells constructed at increasing depths across the GAB and Pedirka Basin sequence. Evidence from multiple investigation techniques – down-hole geophysical surveys (Appendix A), aquifer testing (Section 5, Figure 5-2) and groundwater chemistry and environmental tracers (Section 6-1) – reveals the upper Purni Formation as a permeable sandstone aquifer that is highly connected to the overlying J Aquifer (GAB) at the investigation site. A comparison of the investigation site with lithology profiles from 21 oil, gas and coal wells across the Pedirka Basin suggests the Purni Formation and the J Aquifer are connected in the north-west of the basin where the major coal resource is located. Uncertainty remains regarding the level of interconnection between the J Aquifer/Purni Formation and the underlying Crown Point Formation, and intra-formational connection within the Purni Formation. Figure 8-1 summarises the geology and hydrostratigraphy encountered at the connectivity investigation site.

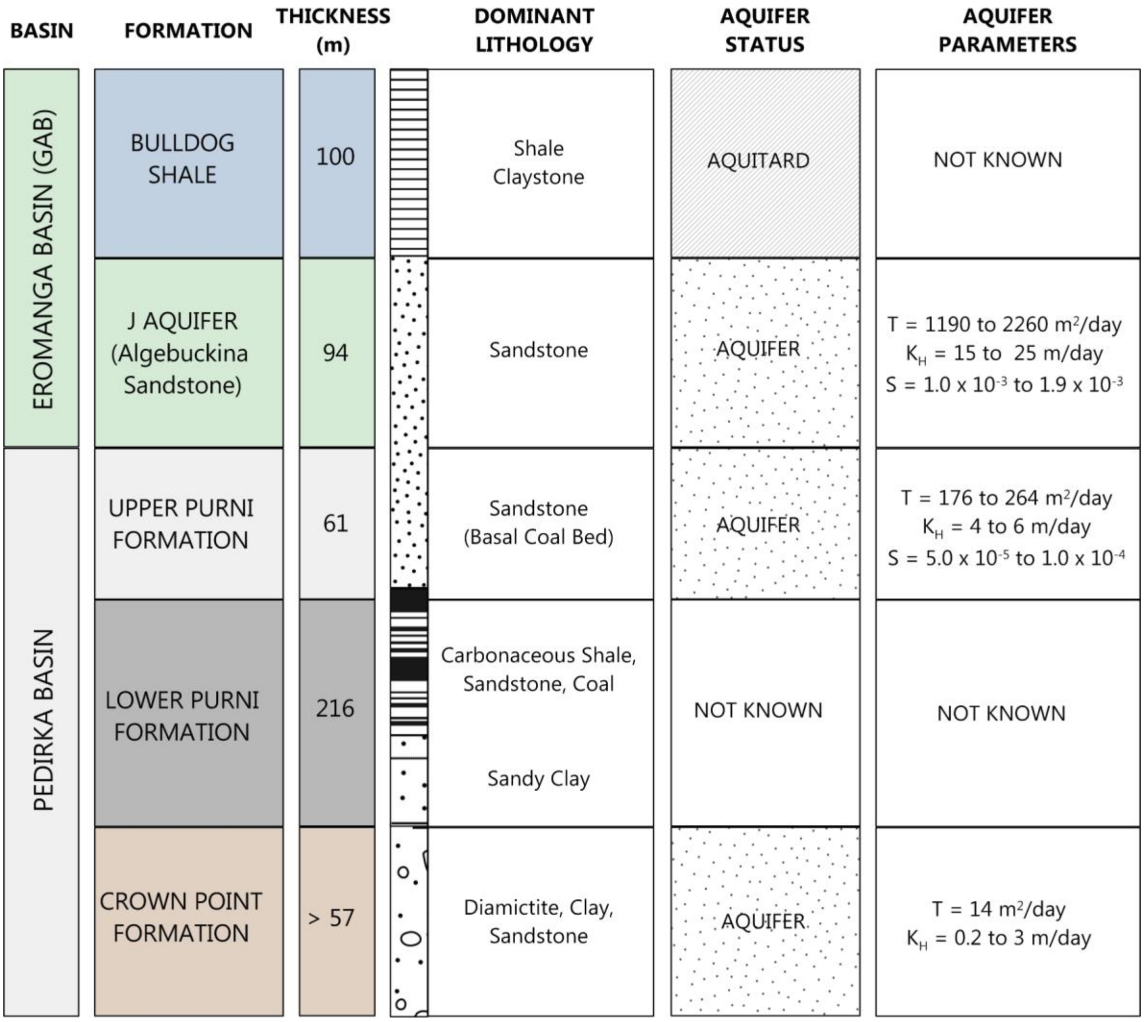


Figure 8-1 Hydrostratigraphy underlying the connectivity site

The key actions and/or findings in relation to the specific objectives of the project are:

Objective 1: *Drill a pilot hole through the GAB/Pedirka Basin and develop a hydrostratigraphic type section of the sequence.*

A pilot hole was drilled to a depth of 531 m in the basal Permian Crown Point Formation. The Purni Formation was significantly thicker than anticipated and as a result the pilot hole did not penetrate the entire Pedirka Basin sequence. Information derived from wireline logging, drill cuttings and the constructed piezometers provides a comprehensive and unprecedented picture of the hydrostratigraphy in this region of the Pedirka Basin.

Objective 2: *Establish a dedicated aquifer connectivity investigation site with piezometers constructed in the Crown Point Formation, Purni Formation, Algebuckina Sandstone and Rolling Downs Group.*

A nested piezometer site was completed with observation wells constructed in the Cadna-owie Formation, Algebuckina Sandstone and Crown Point Formation; in addition to a test production well in the Purni Formation. Due to the Rolling Downs Group not producing free water during drilling, the target formation for the uppermost piezometer was changed during drilling to the Cadna-owie Formation. A fifth well was constructed in the upper Purni Formation 70 m from the nested site.

Objective 3: *Assess the interconnectivity between the Permian coal bearing sequence and the overlying J Aquifer, and the intra-connectivity within the Pedirka Basin (i.e. between the Purni and Crown Point Formations).*

On the basis of findings from the stratigraphic drilling (Section 4, Appendix A and Appendix D) and aquifer test program (Section 5) it is concluded that the Permian coal bearing sequence is hydraulically connected to the J Aquifer at the investigation site. This conclusion is based on the absence of an effective intervening aquitard and the rapid pressure response (14 minutes after test commencement) observed in the J Aquifer during the 48-hour pumping test in the upper Purni Formation. Multi-well aquifer tests also reveal a high level of hydraulic connection within the J Aquifer. Uncertainty remains regarding the level of connection between the Purni and Crown Point Formations as the stress period in the 48-hour pumping test was most likely inadequate to produce a pressure response in the Crown Point Formation piezometer.

Objective 4: *Estimate aquifer parameters for the Purni Formation, and if possible the J Aquifer and Crown Point Formation.*

Aquifer parameter estimates were derived using analytical models and are presented as a range of probable values to best reflect the inherent uncertainty and non-unique nature of the solutions. The Purni Formation transmissivity is estimated at between 176 and 264 m^2/d, which corresponds to a K_H of 4 to 6 m/d, while the storage coefficient is estimated at between 5×10^{-5} and 1×10^{-4}. The cumulative transmissivity of the J Aquifer is estimated at between 1190 and 2260 m^2/d (K_H 15 to 25 m/d) and storage coefficient between 1×10^{-3} and 1.9×10^{-3}. The transmissivity of the Crown Point Formation is estimated at 14 m^2/d with K_H ranging between 0.2 and 2.3 m/d. No estimate of storage coefficient was made for the Crown Point Formation due to the single well test format.

Objective 5: *Characterise the water quality attributes and hydrochemistry of the Crown Point, Purni and J Aquifers.*

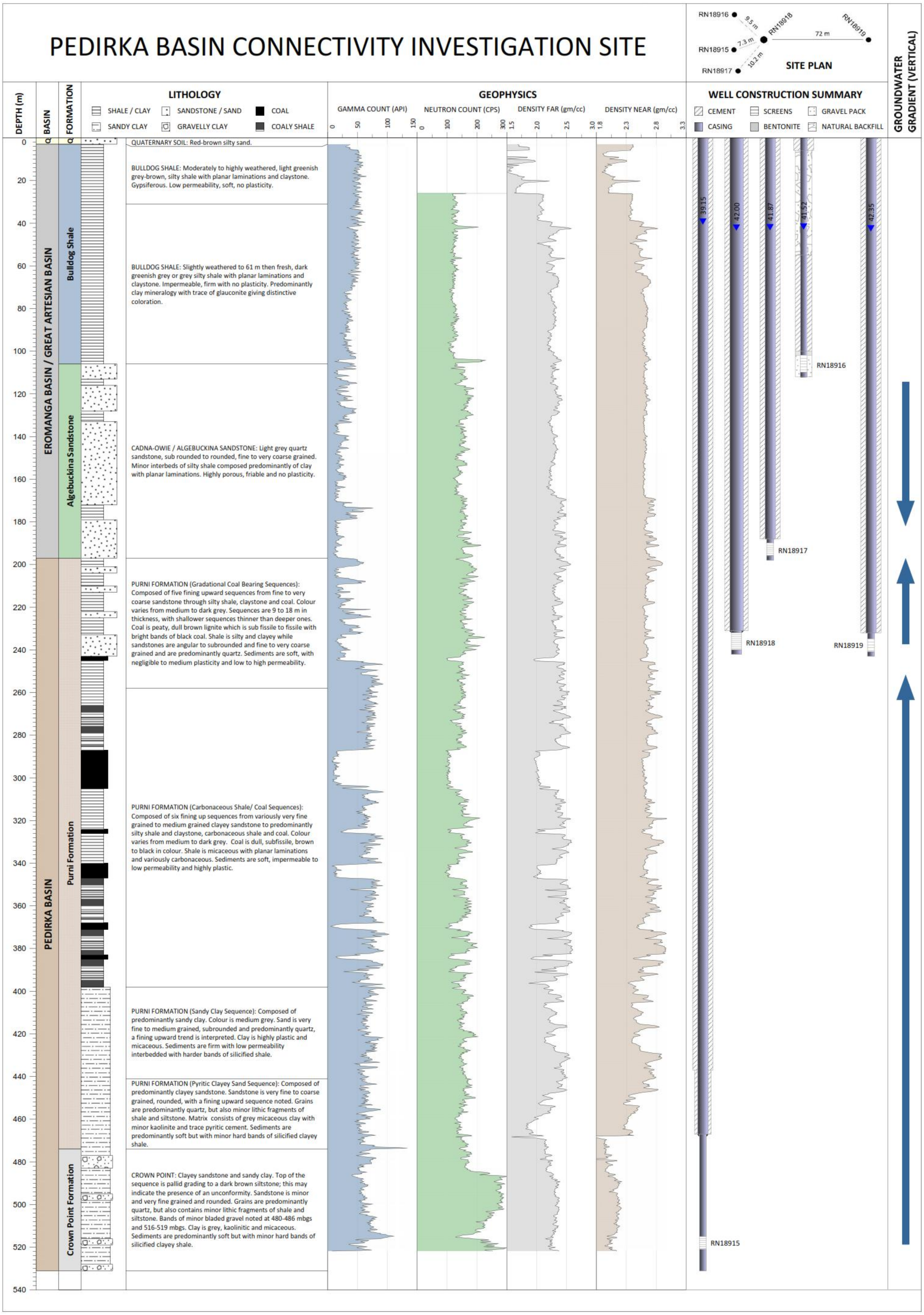
There is no evidence of a disconnected aquifer system in the major ion signature, stable isotope and strontium isotope composition of groundwater from the GAB and Permian aquifers. The apparent groundwater age, based on ^{14}C concentration, is consistently old across the three aquifers and indicates that modern recharge is not occurring at the site. This similarity in apparent groundwater age may indicate that palaeo-recharge to the Pedirka Basin and GAB Basin was contemporaneous in this area.

Objective 6: *Evaluate the site-specific connectivity findings in the context of the greater Pedirka Basin.*

An evaluation of the lithology between the Permian coal measures and the GAB in 21 oil/gas/coal exploration wells suggests the Purni Formation and J Aquifer are connected, particularly in the northwest of the basin where the major coal resource is located. The connection is assessed as limited where the Purni Formation and J Aquifer are separated by a thick sequence of fine grained Triassic sediments. Such sequences are spatially constrained to structural lows and basin depocentres such as the Madigan and Poolowanna Troughs.

9 Appendices

A. Composite log



B. Mud program report for pilot hole

AMC R&D LAB
an imdex limited company

MUD PROGRAM FOLLOW UP

SITE – PEDIRKA BASIN, Northern Territory

Drilling Company – Northern territory Government

30th July – 8th August 2013

Field trials conducted and report by

Angus Forbes 14th august 2013

1. INTRODUCTION

AMC was asked by the Department of Land Resources to design a mud program for a series of investigation/monitoring bores within the Pedirka Basin. The site is situated approximately 260km SE of Alice Springs in the Northern Territory (fig. 1). AMC was also asked that a fluid technician be available on the initial pilot hole due to the possibility of encountering some reactive shale within the Rumbulara Shale.

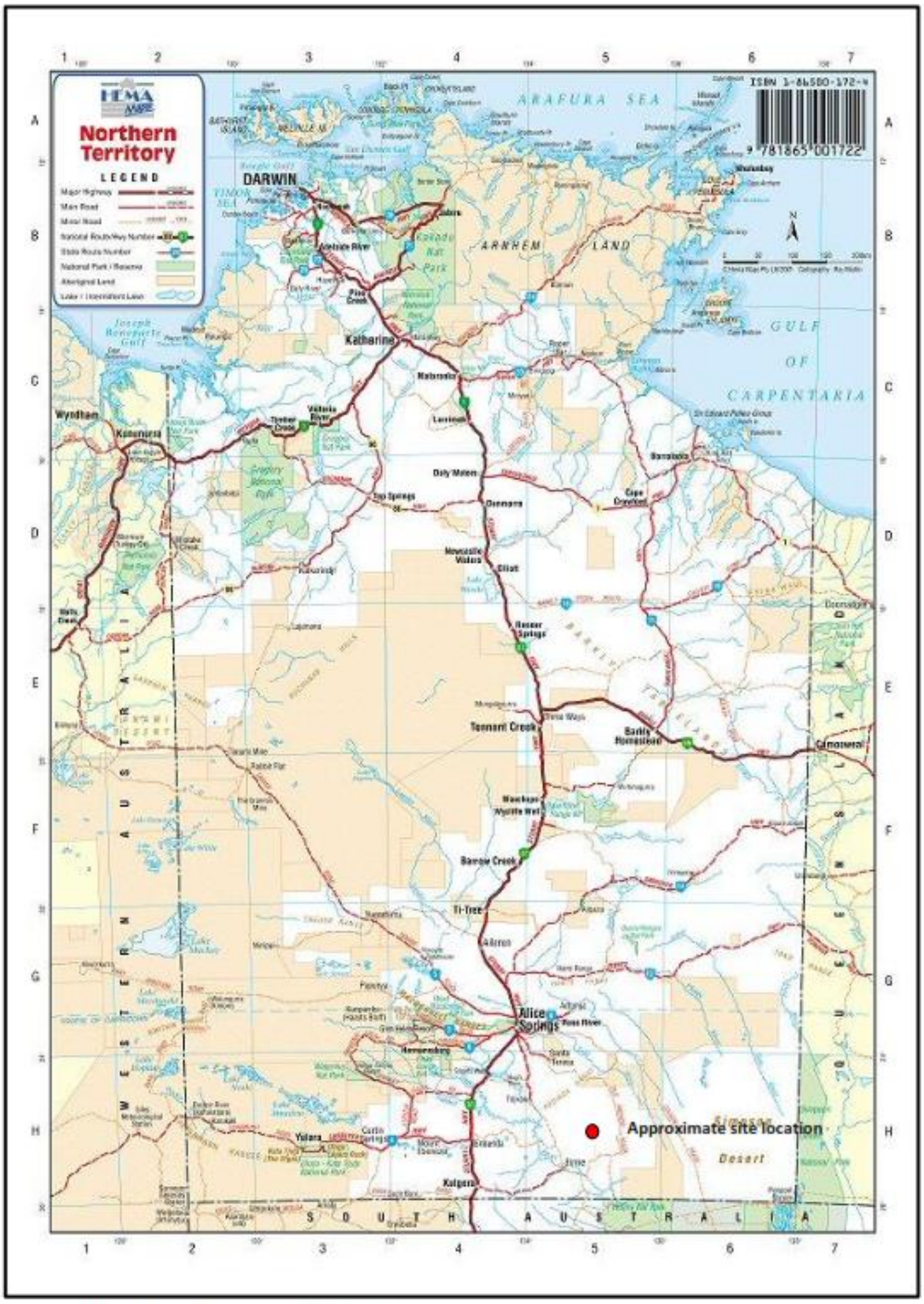


Figure 1 – Approximate site location

2. BACKGROUND INFORMATION

2.1. Drill Site Specifics

Drill rig –Ingersol Rand T75

Final depth – 473 metres

Casing depths during drilling – 12 metres 10" steel casing

Pump rates – 852 litres/minute

Running gear – 9" blade bit with 30m of drill collars & 4½" OD drill pipe

Onsite Water Quality – Total chlorides – 1100ppm

– Total Hardness – 320ppm

– Total calcium – 300ppm

– pH – 7 to 8

– supply rate 0.8 litres/sec

Circulation System – consisted of 3 interconnecting 10m^3 pits in the active system and 1 pre-mix tank of approximate usable volume of 12m^3 (fig. 2). The mixing system was through a 2" hopper.

Figure 2 – Mud System set up

2.2 Formation Description

Formation	Approximate thickness (m)	Description
Rumbulara Shale	100	Blue-grey to black swelling shale, competent in some horizons but weathered in some intervals to a light grey plastic clay. May contain minor intervals of fine to medium grained quartz sandstone, particularly towards the base of the formation.
Algebuckina Sandstone	100	Typically light grey, loose, medium to fine grained quartz sandstone. Formation is very friable and in some intervals is unconsolidated. Minor shale interbeds are expected particularly in the transition from the Rumbulara Shale.
Purni Formation	50	Coal seams, medium to coarse grained sandstones, grey siltstone and carbonaceous claystone.
Crown Point Formation	250	Interbedded sandstone, claystone and siltstone. Sandstones are light grey and range from hard silica/calcite cemented sandstone to loose, well sorted quartz sandstone. Claystone/siltstone is light to dark grey, sticky, soft and calcareous. Towards the base of the formation there are also conglomeratic sandstone, containing pebble size rock and mineral fragments.

3. MUD PROGRAM FLUID RECOMMNEDATIONS

To fresh water, add:

SODA ASH	0.25 kg/m^3	
AUS GEL	15 – 20 kg/m^3	
AMC PAC R	1.0 – 1.5 kg/m^3	(Viscosifier)
CLAY DOCTOR	2.0 – 3.0 kg/m^3	(Encapsulation)
AMC PAC L	2.0 – 3.0 kg/m^3	(Filtrate Control)
AUSDET XTRA	1.0 – 3.0 lt/m^3 (contingency)	
KCl	30 kg/m^3 (contingency)	

4. RESULTS

The initial mix into the pits were –

15kg Soda Ash (0.5 kg/m^3)

18 x 25kg AUS GEL (15 kg/m^3)

3 x 25kg AMC PAC L (2.5 kg/m^3)

3 x 20kg CLAY DOCTOR (2.0 kg/m^3)

2 x 25kg AMC PAC R (1.5 kg/m^3)

This produced consistent viscosity throughout the pits of between 40 – 43 seconds.

The bentonite was allowed to hydrate overnight before mixing in the polymers. This was mainly due to the low supply of water.

It was noticed that the bentonite dropped out by morning.

Initial Pre-mix tank –

6kg Soda Ash (0.5 kg/m^3)

2 x 25kg AMC PAC L (5.0 kg/m^3)

2 x 25kg CLAY DOCTOR (4.0 kg/m^3)

¾ x 25kg AMC PAC R (1.8 kg/m^3)

This produced consistent of between 40 – 42 seconds.

Fluid Properties

	2/8			3/8	
Time	**0930 hrs**	**1150 hrs**	**1610 hrs**	**1200 hrs**	**1520 hrs**
Pit	Suction	Suction	Suction	Middle	Suction
Depth (m)	67	84	115	156	193
Viscosity (sec)	43	40	43	40	40
600	43	40	41	42	42
300	26	24	36	25	26
PV	17	16	5	17	16
YP	9	8	31	8	10
Gels 10sec/10min	1/2	1/2	1/2	1/1	1/1
Filtrate (ml) (full)	12	14	8.4	7.8	8
Filter cake (mm)	1	1	1	1	1
Sand Content (%)	0.2	0.2	0.2	0.2	0.2
SG	1.02	1.02	1.02	1.02	1.02-1.03
Total Chlorides	1600	3000			
Total Hardness	400	520			
Total Calcium		320			
pH	7 – 8			8	

	4/8		5/8		6/8	7/8
Time	**1000 hrs**	**1500 hrs**	**1100 hrs**	**1545hrs**	**1215 hrs**	**1130 hrs**
Pit	Middle	Suction	Middle	Suction	Suction	Suction
Depth (m)	230	296	345	370	412	470
Viscosity (sec)	42	40	42	42	42	40
600	47	43	50	49	45	41
300	29	26	31	30	27	24
PV	18	17	19	19	18	17
YP	11	9	12	11	9	7
Gels 10sec/10min	1/1	1/1	1/1	1/1	1/1	1/1
Filtrate (ml) (full)	7.6	8.6	6.4	6	6	5.2
Filter cake (mm)	1	1	1	1	1	1
Sand Content (%)	0.2	0.3	0.5	0.6	0.2	0.2
SG	1.02-1.03	1.03	1.03-1.04	1.04-1.05	1.04	1.04-1.05
Total Chlorides		1580		1600	1800	
Total Hardness		250		400	260	
Total Calcium				220		
pH	7 – 8	8	8	8	8	8

5. CONLUSIONS

The fluid remained consistent throughout the pilot hole with CLAY DOCTOR and PAC L controlling the more reactive shales. From an examination from one section of the shales, they appeared to be more dispersive then swelling.

The fluctuation in the chlorides and hardness was possibly due to addition of formation fluids in the system as they were drilled through.

There were also the occasional coal/lignite seams encountered during the drilling process, up to approximately 10 metres in thickness. This had very little effect on the fluid system. These seams and along with the addition of mica to the formation caused a slight increase in the SG of the fluid, but they also assisted in reducing the filtrate loss.

Apon reaching depth (473m) the rods were pulled out and the bore was logged. The probes went to 470 metres, 3 metres off depth, without any sticking and catching up, indicating a very clean hole.

C. Driller's 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:	NT Government	**Registration No.:**	**18915**
Location/Address:	Andado Station	BC Permit No:	BCPGAB12
Intended Use:	Observation / Monitoring Bore		

GPS Location:	Zone:	GDA94	Other:	Specify:	Easting:	Northing:
	53 J	☐	☑	WGS 84	534789	7227116

From	To	Particulars of Strata
0	0.5	Red/Brown sandy clay
0.5	1.5	Lt/Brown sandy clay
1.5	28.3	Olive clay
28.3	110.1	Black clay/shale
110.1	111	Grey sandstone
111	116	Black clay/shale
116	199	Layered grey sandy clay, coarse sand, shale/clay
199	288	Grey/Black clay with sand and sandy clay layers
288	314	Charcoal
314	323	Grey clay and sandy clay
323	327	Black clay and charcoal
327	406	Clays (grey, dark grey, black) with some coal
406	487	Lt/Grey - Lt/Green sandy clay
487	488	Brown sandy/silt clay
488	525.4	Grey-Green-White clay with some shale/mudstone
525.4	526	Grey/White sandy clay
526	531	Grey/Green and brown clay

Name of Drilling Company: DLRM - Water Resources
Name of Driller: P Pardon / I McMasters
Name of supervising driller I McMasters

Date Commenced:	30/07/2013
Date Completed:	20/08/2013
Depth Drilled:	531.0 m
Completion Depth:	531.0 m

METHOD OF DRILLING

Other	Auger	Rev. Circ.	Rotary Air	Rotary Mud
☐	☐	☐	☐	☑

Specify:

HOLE DIAMETER From (m)	To (m)	Dia. (mm)	DRILLING FLUID Type
0	5.8	311 mm	Air/Mist
5.8	437	227 mm	Mud
437	467	216 mm	Mud

PARTICULARS OF CASING

From	To	Dia (ID)	Type
0	5.8	313 mm	Steel
0	467	158 mm	Steel
461	515.04	104 mm	Steel
521.04	531	104 mm	Steel

PARTICULARS OF PERFORATIONS OR SCREEN STRINGS

From	To	Dia (ID)	Aperture	Type
515.04	521.04	104 mm	0.5 mm	Stainless Steel Screens

Casing Suspended: Yes ☐ No ☑
Method:
Height of Casing above GL: 0.5 m x 325 mm OD Steel
0.6 m x 168 mm OD Steel

Top of Packer Set at: 460.91 m
Length of Packer: 0.13 m
Method of Packer Connection: Welded Joint

CEMENTING/GRAVEL PACKING

From	To	Type
0	5.8 m	Cement
0	467 m	Cement

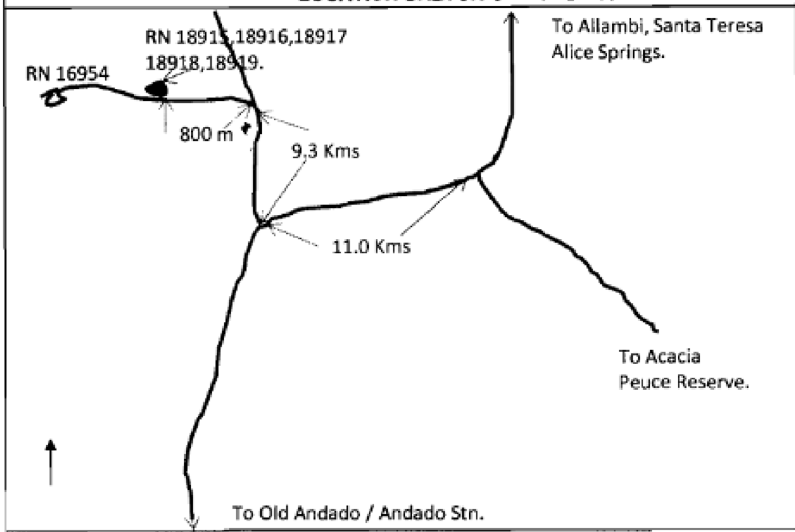
WATER BEARING BEDS

Depth (m) From	To	Yield (L/s)	SWL (m)	Duration (hr)	Quality	EC	pH	Bottle No.
	206.9	6			Poor	26100	7.45	No 1 & 2

STRATA / WATER SAMPLES
Have been ☑ Will be ☐
Left at:W/R Depot-A/Springs

Completion Yield: 6 (L/s) Method: Airlift Duration: 3.5 hrs
Completion SWL from GL: 39.16 m Depth of Lift: 206.9 m

NOTE: No company advertising is to be imprinted on this certificate apart from where requested.

LOCATION SKETCH OF BORE RN: 18915	LOCATION DESCRIPTION OF BORE
	2 kms NW ☐ North ☐ NE ☐ West ☐ East ☑ SW ☐ South ☐ SE ☐ OF: RN 16954

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)*

The bore cap is fitted with a Jackson Padlock.

A 2 7/8"IF left hand thread is welded to the inside of the sump at bottom.

Two water samples was taken and strata samples went to Mines and Energy - SA.

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.

P Pardon #55 & I McMasters #24
Name and licence number of driller:

No 24
Signature and licence number of licensed driller: Date: 14 / 10 / 2013

FOR OFFICIAL USE ONLY

How Located:	GPS	TST	Survey	Hand Plotted	Other
	☑	☐	☐	☐	☐

DESCRIPTION OF PROPERTY:

Rural	Mineral	Pastoral	Reserve	VCL	Other
☐	☐	☑	☐	☐	☐

Lease No: 1104 Lot No: Hundred of:
Portion No: 1361 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: 53 Scale: 1:250000.
Easting: 534789 Lattitude: Map Name: McDILLS.
Northing: 7227116 Longitude: Index Map Number: 71 5/SG53-07.
Date Registered: 16/10/13. Bore Plotted on the map? Yes ☑ No ☐
Dept Officer: N. GIBBONS. Signature: Ng
Remarks: RN018915

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

Name of Owner:	NT Government
Location/Address:	Andado Station
Intended Use:	Observation Bore
Registration No.:	**18916**
BC Permit No:	BCPGAB12

GPS Location:	Zone:	GDA94	Other:	Specify:	Easting:	Northing:
	53	☐	☑	WGS 84	534793	7227122

From	To	Particulars of Strata
0	1.3	Red/Brown sandy clay
1.3	2.8	White clay
2.8	24	Olive clay
24	27	Olive clay/siltcrete
27	37.8	Black sandy clay
37.8	38.2	Grey/Black sandstone
38.2	41.3	Black sandy clay
41.3	47	Grey/Black sandstone-sandy clay
47	48	Grey sand
48	66	Black sandy clay/shale/silt
66	104.9	Black shale/clay
104.9	105	Pyrites
105	111	Coarse quartz sand

Name of Drilling Company: DLRM - Water Resources
Name of Driller: I McMasters
Name of supervising driller I McMasters

Date Commenced: 3/09/2013
Date Completed: 6/09/2013
Depth Drilled: 111.0 m
Completion Depth: 110.28 m

METHOD OF DRILLING

Other	Auger	Rev. Circ.	Rotary Air	Rotary Mud
☐	☐	☐	☑	☐

Specify:

HOLE DIAMETER			**DRILLING FLUID**
From (m)	To (m)	Dia. (mm)	Type
0	5.9	254	Air/Mist
5.9	111	200	Air

PARTICULARS OF CASING

From	To	Dia (ID)	Type
0	5.9	203.2 mm	Steel
0	104.28	100 mm	PVC
109.78	110.28	100 mm	PVC

PARTICULARS OF PERFORATIONS OR SCREEN STRINGS

From	To	Dia (ID)	Aperture	Type
104.28	109.78	100 mm	1.0 mm Slotted	Class 12 PVC

Casing Suspended: Yes ☐ No ☑
Method:
Height of Casing above GL: 0.5 m x 219 mm OD Steel
0.42 m x 114 mm OD Class 12 PVC

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

CEMENTING/GRAVEL PACKING

From	To	Type
0	5.9	Cement
54.97	100.28	Cement
100.28	101.59	Bentonite Pellets
101.59	111	5-7 mm Gravel

WATER BEARING BEDS

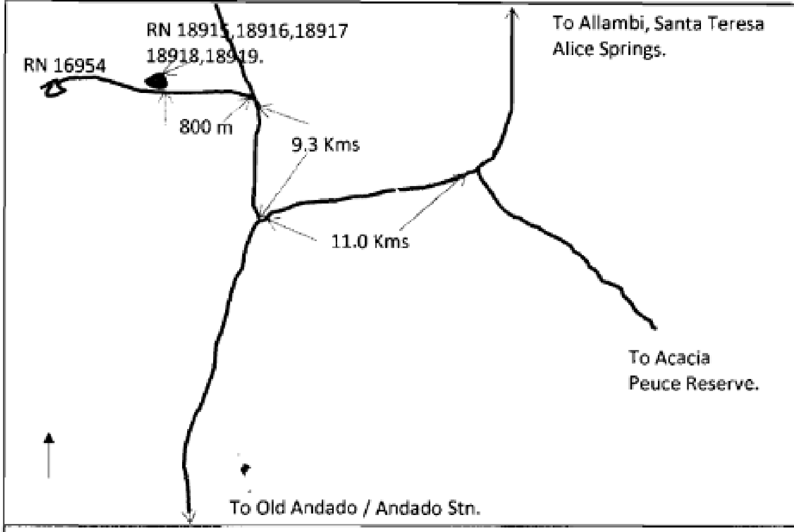
Depth (m) From	To	Yield (L/s)	SWL (m)	Duration (hr)	Quality	EC	pH	Bottle No.
105	108.8	8			Poor	6160	7.66	No 1
	111	2			Poor	5300	7.42	No 2
Final Airlift		5			Poor	5740	7.55	No 3

WATER SAMPLES
Have been ☑ Will be ☐
Left at:W/R Depot-A/Springs

Completion Yield: 5 (L/s) Method: Airlift through 1" GWP Duration: 3.5 hrs
Completion SWL from GL: 41.37 m Depth of Lift: 66.40 m

NOTE: No company advertising is to be imprinted on this certificate apart from where requested.

LOCATION SKETCH OF BORE RN: 18916 | **LOCATION DESCRIPTION OF BORE**



2 km

NW ☐	North ☐	NE ☐
West ☐		East ☑
SW ☐	South ☐	SE ☐

OF: RN 16954

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)*

The bore cap is fitted with a Jackson Padlock.

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.

I McMasters #24
Name and licence number of driller:

No. 24
Signature and licence number of licensed driller:

Date: 15 / 10 / 2013

FOR OFFICIAL USE ONLY

How Located:	GPS	TST	Survey	Hand Plotted	Other
	☑	☐	☐	☐	☐

DESCRIPTION OF PROPERTY:

Rural	Mineral	Pastoral	Reserve	VCL	Other
☐	☐	☑	☐	☐	☐

Lease No: 1104 Lot No: Hundred of:
Portion No: 1361 Section No: Town of:

	Town	Domestic	Investigation	Agriculture	Mineral	Pastoral	Other
Class of Bore:	☐	☐	☑	☐	☐	☐	☐

	Production	Investigation	Irrigation	Observation	Monitoring	Roads	None
Use of Bore:	☐	☐	☐	☑	☐	☐	☐

Grid Reference: AMG ☑ Clark ☐ Zone: 53 Scale: 1:250000

Easting: 534793 Lattitude: Map Name: MC DILLS

Northing: 7227122 Longitude: Index Map Number: 72 S/SG53-07.

Date Registered: 16/10/13 Bore Plotted on the map? Yes ☑ No ☐

Dept Officer: N. GIBBONS. Signature:

Remarks: RN018916.

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

Name of Owner:	NT Government	**Registration No.:**	**18917**
Location/Address:	Andado Station	BC Permit No:	BCPGAB12
Intended Use:	Observation Bore		

GPS Location:	Zone:	GDA94	Other:	Specify:	Easting:	Northing:
	53 J	☐	☑	WGS 84	534788	7227122

From	To	Particulars of Strata
0	0.7	Red/Brown sandy clay
0.7	2.9	Lt/Brown-White clay
2.9	5.9	Olive clay
5.9	25.3	Olive-Lt/Brown-Yellow-Grey clay
25.3	26.8	Olive and black clay
26.8	42	Black clay/shale
42	51	Black-Dark green sandy/silt clay
51	55.8	Black shale/clay
55.8	56	Hard grey clay
56	103.9	Black shale/clay
103.9	132	Grey sandy clay and quartz sand
132	176.4	Lt/Brown sandy clay, some sand bands
176.4	188.6	Brown-Grey sandy clay
188.6	196.8	Grey sandy clay and quartz sand
196.8	198.5	Grey clay

Name of Drilling Company: DLRM - Water Resources
Name of Driller: I McMasters
Name of supervising driller I McMasters

Date Commenced: 3/09/2013
Date Completed: 13/10/2013
Depth Drilled: 198.50 m
Completion Depth: 198.60 m

METHOD OF DRILLING

Other	Auger	Rev. Circ.	Rotary Air	Rotary Mud
☐	☐	☐	☐	☑

Specify:

HOLE DIAMETER			DRILLING FLUID
From (m)	To (m)	Dia. (mm)	Type
0	5.9	311	Air/Mist
5.9	187.6	219	Mud
187.6	198.5	143	Mud

PARTICULARS OF CASING

From	To	Dia (ID)	Type
0	5.9	260 mm	Steel
0	187.6	158 mm	Steel
186.54	190.54	104 mm	Steel
196.59	198.6	104 mm	Steel

PARTICULARS OF PERFORATIONS OR SCREEN STRINGS

From	To	Dia (ID)	Aperture	Type
190.54	196.59	104 mm	0.5 mm	Stainless Steel Screens

Casing Suspended: Yes ☐ No ☑
Method:
Height of Casing above GL: 0.5 m x 273 mm OD Steel
0.6 m x 168 mm OD Steel

Top of Packer Set at: 186.4 m
Length of Packer: 0.14 m
Method of Packer Connection: Welded Joint

CEMENTING/GRAVEL PACKING

From	To	Type
0	5.9	Cement
0	187.6	Cement

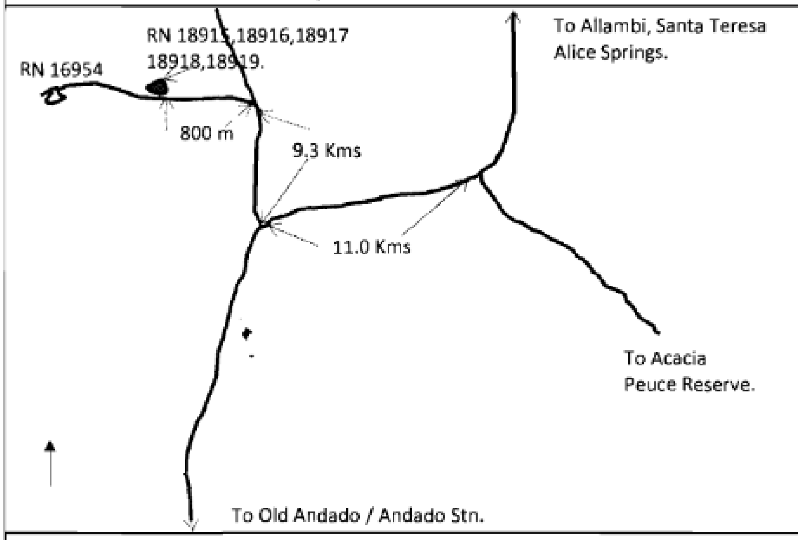
WATER BEARING BEDS

Depth (m) From	Depth (m) To	Yield (L/s)	SWL (m)	Duration (hr)	Quality	EC	pH	Bottle No.
	176.17	11			Poor	9130	7.21	No 1 & 2

WATER SAMPLES
Have been ☑ Will be ☐
Left at: W/R Depot-A/Springs

Completion Yield: 11 (L/s) Method: Airlift through drillstring Duration: 3 hrs
Completion SWL from GL: 41.75 m Depth of Lift: 176.17 m

NOTE: No company advertising is to be imprinted on this certificate apart from where requested.

LOCATION SKETCH OF BORE RN: 18917	LOCATION DESCRIPTION OF BORE
	2 km; NW ☐ North ☐ NE ☐; West ☐ East ☑; SW ☐ South ☐ SE ☐; OF: RN 16954

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)*
The bore cap is fitted with a Jackson Padlock.

A 2 7/8"IF left hand thread is welded to the inside of the sump at bottom.

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.

I McMasters #24	I McMasters № 24	Date: 15 / 10 / 2013
Name and licence number of driller:	Signature and licence number of licensed driller:	

FOR OFFICIAL USE ONLY

How Located: GPS ☑ TST ☐ Survey ☐ Hand Plotted ☐ Other ☐

DESCRIPTION OF PROPERTY:
Rural ☐ Mineral ☐ Pastoral ☑ Reserve ☐ VCL ☐ Other ☐

Lease No: 1104 Lot No: Hundred of:
Portion No: 1361 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: 53 Scale: 1:250000
Easting: 534788 Lattitude: Map Name: McDILLS.
Northing: 7227122 Longitude: Index Map Number: 73 5/SG53-07.
Date Registered: 16/10/13 Bore Plotted on the map? Yes ☑ No ☐
Dept Officer: N.GIBBONS. Signature: NG
Remarks: RN018917.

THE NORTHERN TERRITORY OF AUSTRALIA
APPROVED FORM 21 (25/01/2011)
STATEMENT OF BORE

As per Water Regulations (2009)

Name of Owner:	NT Government	**Registration No.:**	**18918**
Location/Address:	Andado Station	BC Permit No:	BCPGAB12
Intended Use:	Production Bore		

GPS Location:	Zone:	GDA94	Other:	Specify:	Easting:	Northing:
	53 J	☐	☑	WGS 84	534800	7227117

From	To	Particulars of Strata
0	0.5	Red/Brown sandy clay
0.5	1.5	Brown sandy clay
1.5	2.8	Lt/Brown-White clay
2.8	8	Olive clay
8	24.1	Lt/Brown-Yellow-Olive clay
24.1	25	Dark Grey sandstone (Hard)
25	104.8	Black shale/clay with bands of sandy clays
104.8	134	Lt/Grey sandy clay with layers of sand
134	240	Lt/Brown, Grey sandy clay with fine and coarse layers of sand
240	242	Grey clay

Name of Drilling Company: DLRM - Water Resources

Name of Driller: I McMasters

Name of supervising driller I McMasters

Date Commenced:	13/09/2013
Date Completed:	25/09/2013
Depth Drilled:	242.0 m
Completion Depth:	242.0 m

METHOD OF DRILLING

Other	Auger	Rev. Circ.	Rotary Air	Rotary Mud
☐	☐	☐	☑	☑

Specify:

HOLE DIAMETER			DRILLING FLUID
From (m)	To (m)	Dia. (mm)	Type
0	5.9	381	Air/Mist
5.9	231.7	270	Mud
231.7	242	200	Mud

PARTICULARS OF CASING

From	To	Dia (ID)	Type
0	5.9	313 mm	Steel
0	231.7	203.2 mm	Steel
229.98	231.98	158 mm	Steel
239.99	242	158 mm	Steel

PARTICULARS OF PERFORATIONS OR SCREEN STRINGS

From	To	Dia (ID)	Aperture	Type
231.98	239.99	158 mm	0.5 mm	Stainless Steel Screens

Casing Suspended: Yes ☐ No ☑

Method:

Height of Casing above GL: 0.5 m x 325 mm OD Steel; 0.6 m x 219 mm OD Steel

Top of Packer Set at: 229.83 m

Length of Packer: 0.15 m

Method of Packer Connection: Welded Joint

CEMENTING/GRAVEL PACKING

From	To	Type
0	5.9	Cement
0	231.7	Cement

WATER BEARING BEDS

Depth (m) From	To	Yield (L/s)	SWL (m)	Duration (hr)	Quality	EC	pH	Bottle No.
	180	32			Poor	12470	7.2	No 1 & 2

WATER SAMPLES

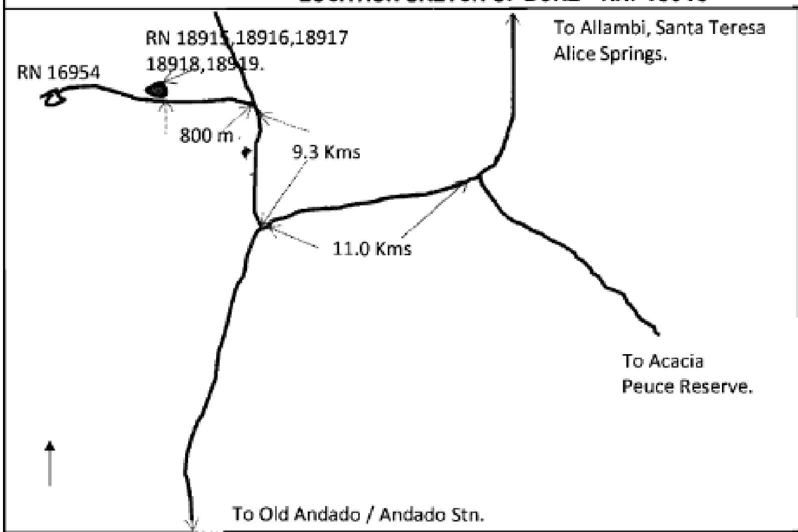
Have been ☑ Will be ☐

Left at:W/R Depot-A/Springs

Completion Yield: 32 (L/s) Method: Airlift through Drillstring Duration: 5 hrs

Completion SWL from GL: 41.88 m Depth of Lift: 180 m

NOTE: No company advertising is to be imprinted on this certificate apart from where requested.

LOCATION SKETCH OF BORE RN: 18918	LOCATION DESCRIPTION OF BORE
	2 km; NW ☐ North ☐ NE ☐; West ☐ East ☑ ; SW ☐ South ☐ SE ☐; OF: RN 16954

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)*

The bore cap is fitted with a Jackson Padlock.

A2 7/8"IF left hand thread is welded to the inside of the sump at bottom.

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.

I McMasters #24
Name and licence number of driller:

[signature] No 24
Signature and licence number of licensed driller:

Date: 16 / 10 / 2013

FOR OFFICIAL USE ONLY

How Located: GPS ☑ TST ☐ Survey ☐ Hand Plotted ☐ Other ☐

DESCRIPTION OF PROPERTY:

Rural ☐ Mineral ☐ Pastoral ☑ Reserve ☐ VCL ☐ Other ☐

Lease No: 1104 Lot No: Hundred of:

Portion No: 1361 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: 53 Scale: 1:250000

Easting: 534800 Lattitude: Map Name: M^c DILLS.

Northing: 7227117 Longitude: Index Map Number: 74 5/SG 53-07.

Date Registered: 16/10/13 Bore Plotted on the map? Yes ☑ No ☐

Dept Officer: N. GIBBONS. Signature: Ng

Remarks: RN018918

THE NORTHERN TERRITORY OF AUSTRALIA
APPROVED FORM 21 (25/01/2011)

STATEMENT OF BORE

As per Water Regulations (2009)

Name of Owner:	NT Government
Location/Address:	Andado Station
Intended Use:	Observation Bore
Registration No.:	**18919**
BC Permit No:	BCPGAB12

GPS Location:	Zone:	GDA94	Other:	Specify:	Easting:	Northing:
	53 J	☐	☑	WGS 84	534858	7227077

From	To	Particulars of Strata
0	0.5	Red/Brown sandy clay
0.5	1.5	Brown sandy clay
1.5	2.8	L/t Brown -White sandy clay
2.8	25.4	Olive and Grey clay
25.4	105.3	Black shale/clay with bands of sand
105.3	106	Grey/Black sandy clay
106	109.4	Black shale/clay with bands of sand
109.4	126	Grey sandy clay with layers of sand
126	166	Lt/Brown-White sandy clay with layers of sand
166	182.6	Grey sandy clay with layers of sand and coal bands
182.6	194	Lt/Brown-White sandy clay
194	201.3	Grey/Brown sandy clay with layers of sand
201.3	217	Dark Brown clay
217	217.1	Pyrites
217.1	232	Brown-Lt/Brown sandy clay with coarse sand
232	233.3	Brown clay and coal
233.3	241.2	Coarse sand
241.2	243	Brown clay

Name of Drilling Company:	DLRM - Water Resources
Name of Driller:	I McMasters
Name of supervising driller	I McMasters
Date Commenced:	25/09/2013
Date Completed:	3/10/2013
Depth Drilled:	243.0 m
Completion Depth:	242.3 m

METHOD OF DRILLING

Other	Auger	Rev. Circ.	Rotary Air	Rotary Mud
☐	☐	☐	☐	☑

Specify:

HOLE DIAMETER			DRILLING FLUID
From (m)	To (m)	Dia. (mm)	Type
0	5.9	311	Air/Mist
5.9	232	219	Mud
232	243	200	Mud

PARTICULARS OF CASING

From	To	Dia (ID)	Type
0	5.9	260mm	Steel
0	231.46	158mm	Steel
229.3	234.66	104mm	Steel
240.69	242.3	104mm	Steel

PARTICULARS OF PERFORATIONS OR SCREEN STRINGS

From	To	Dia (ID)	Aperture	Type
234.66	238.65	104mm	0.5mm	Stainless Steel Screens
238.65	240.69	114.3mm	0.5mm	Stainless Steel Screens

Casing Suspended:	Yes ☐ No ☑	Top of Packer Set at:	229.17 m
Method:		Length of Packer:	0.13 m
Height of Casing above GL:	0.5m x 273mm OD Steel 0.6m x 168mm OD Steel	Method of Packer Connection:	Welded Joint

CEMENTING/GRAVEL PACKING

From	To	Type
0	5.9	Cement
0	231.46	Cement

WATER BEARING BEDS

Depth (m) From	Depth (m) To	Yield (L/s)	SWL (m)	Duration (hr)	Quality	EC	pH	Bottle No.
	121	6			Poor	12650	7.43	No 1 & 2

WATER SAMPLES

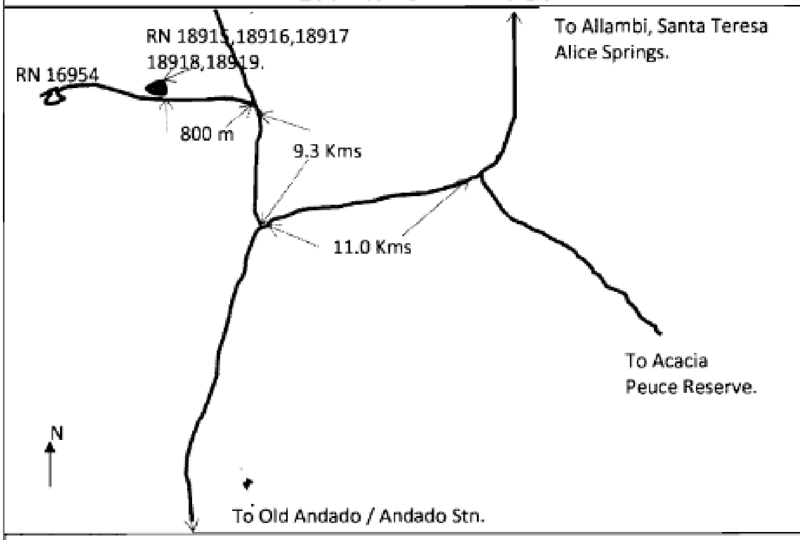
Have been ☑ Will be ☐

Left at:W/R Depot-A/Springs

Completion Yield:	6 (L/s)	Method: Airlift through drillstring	Duration: 2.5 Hrs
Completion SWL from GL:	42.27 m		Depth of Lift: 121.0 m

NOTE: No company advertising is to be imprinted on this certificate apart from where requested.

LOCATION SKETCH OF BORE RN: 18919	LOCATION DESCRIPTION OF BORE



2 km

NW ☐	North ☐	NE ☐
West ☐		East ☑
SW ☐	South ☐	SE ☐

OF: RN 16954

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)*

The bore cap is fitted with a Jackson Padlock.

A 2 7/8"IF left hand thread is welded to the inside of the sump at bottom.

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.

I McMasters #24 — Name and licence number of driller:

[signature] 24 — Signature and licence number of licensed driller:

Date: 16 / 10 / 2013

FOR OFFICIAL USE ONLY

How Located:

GPS	TST	Survey	Hand Plotted	Other
☑	☐	☐	☐	☐

DESCRIPTION OF PROPERTY:

Rural	Mineral	Pastoral	Reserve	VCL	Other
☐	☐	☑	☐	☐	☐

Lease No: 1104. Lot No: Hundred of:

Portion No: 1361 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: 53. Scale: 1:250000

Easting: 534868 Lattitude: Map Name: MCDILLS.

Northing: 7227077 Longitude: Index Map Number: 75 5/SG 53-07.

Date Registered: 16/10/13. Bore Plotted on the map? Yes ☑ No ☐

Dept Officer: N. GIBBONS. Signature: [signature]

Remarks: RN018919

D. Description of drill cuttings RN018915

Project: *Pedirka connectivity*	Logger: *MK*	Date: *4/08/2013*	Lithology Logging Sheet:	Drillhole Name/ No: *RN18915*	Page:

Depth_Fr	Depth_To	Samp_No.	Shade	Hue	Colour	Formation	Lith_1	Lith_1%	Desc11	Desc12	Desc13	Lith_2	Lith_2%	Desc11	Desc12	Desc13	Lith_3	Lith_3%	Desc11	Desc12	Desc13	Perm/Porosity	Consolidation	Weathering	Plasticity	Defects	MinFos1	MinFos1%	MinFos2	MinFos2%	MinFos3	MinFos3%	Comment
Drillhole Details			Colour			Stratigraphy/ Lithology																Geotechnical					Minerals/ Fossils						Comment
0	3		E	B	R	Q	SA		VF	OO		SI					GV	RG				PO	SI	R	NP		QZ		CL		IO		
3	6		L	W	F	Kmb	CS		SI	PL	GY	SH										LP	C2	H	HP		CL		GY				Mottled clay after shale
6	9		A	M	F	Kmb	CS		SI	PL	GY	SH										LP	C2	H	HP		CL		GY				Mottled clay after shale
9	12		A	M	F	Kmb	CS		SI	PL	GY	SH										LP	C2	H	HP		CL		GY				Mottled clay after shale
12	15		A	M	GB	Kmb	CS		SI	PL	GY	SH										LP	C3	H	NP		CL		GY				Mottled clay after shale
15	19		A	M	GB	Kmb	CS		SI	PL	GY	SH										LP	C3	H	NP		CL		GY				Mottled clay after shale
19	22		A	M	GB	Kmb	CS		SI	PL	GY	SH										LP	C3	H	NP		CL		GY				Mottled clay after shale
22	25		A	M	GB	Kmb	CS		SI	PL	GY	SH										LP	C3	H	NP		CL		GY				Mottled clay after shale
25	28		A	M	GB	Kmb	CS		SI	PL	GY	SH										LP	C3	H	NP		CL		GY				Mottled clay after shale
28	31		A	M	GB	Kmb	CS		SI	PL	GY	SH										LP	C3	H	NP		CL		GY				Mottled clay after shale
31	34		E		G	Kmb	SH		SI	PL		CS										IR	C3	S	LP		CL						
34	37		E		G	Kmb	SH		SI	PL		CS										IR	C3	S	LP		CL						
37	40		E		G	Kmb	SH		SI	PL		CS										IR	C3	S	LP		CL						
40	43		E		G	Kmb	SH		SI	PL		CS					SS		VF			IR	C3	S	LP		CL						
43	46		E		G	Kmb	SH		SI	PL		CS										IR	C3	S	LP		CL						
46	49		E		G	Kmb	SH		SI	PL		CS										IR	C3	S	LP		CL						
49	52		E		G	Kmb	SH		SI	PL		CS										IR	C3	S	LP		CL						
52	55		E		G	Kmb	SH		SI	PL		CS										IR	C3	S	LP		CL						
55	58		E		G	Kmb	SH		SI	PL		CS										IR	C3	S	LP		CL						
58	61		E		G	Kmb	SH		SI	PL		CS										IR	C3	S	LP		CL						
61	64		E	E	G	Kmb	SH		SI	PL		CS										IR	C3	F	LP		CL		GC	TR			
64	67		E	E	G	Kmb	SH		SI	PL		CS										IR	C3	F	LP		CL		GC	TR			
67	70		E	E	G	Kmb	SH		SI	PL		CS										IR	C3	F	LP		CL		GC	TR			
70	73		E	E	G	Kmb	SH		SI	PL		CS										IR	C3	F	LP		CL		GC	TR			
73	76		E	E	G	Kmb	SH		SI	PL		CS										IR	C3	F	LP		CL		GC	TR			
76	79		E	E	G	Kmb	SH		SI	PL		CS										IR	C3	F	LP		CL		GC	TR			
79	82		E	E	G	Kmb	SH		SI	PL		CS										IR	C3	F	LP		CL		GC	TR			
82	85		E	E	G	Kmb	SH		SI	PL		CS										IR	C3	F	LP		CL		GC	TR			
85	88		E	E	G	Kmb	SH		SI	PL		CS										IR	C3	F	LP		CL		GC	TR			
88	91		E	E	G	Kmb	SH		SI	PL		CS										IR	C3	F	LP		CL		GC	TR			
91	94		B	E	G	Kmb	SH		SI	PL		CS										IR	C4	F	LP		CL		GC	TR			
94	97		B	E	G	Kmb	SH		SI	PL		CS										IR	C4	F	LP		CL		GC	TR			
97	100		B	E	G	Kmb	SH		SI	PL		CS										IR	C4	F	LP		CL		GC	TR			
100	103		B	E	G	Kmb	SH		SI	PL		CS										IR	C4	F	LP		CL		GC	TR			
103	106		B	E	G	Kmb	SH		SI	PL		CS										IR	C4	F	LP		CL		GC	TR			
106	109		E		G	JK	SS		BG	BG		SH		PL	SI							PO	C4	F	NP		QZ		CL				
109	112		B	E	G	JK	SH		SI	PL		CS										IR	C4	F	LP		CL						
112	115		A		G	JK	SA		BG			SH		PL	SI							PO	S2	F	NP		QZ		CL				
115	118		A		G	JK	SS		BG	FX		SH		PL	SI							PO	S2	F	NP		QZ		CL				
118	121		A		G	JK	SS		BG	FX		SH		PL	SI							PO	S2	F	NP		QZ		CL				
121	124		A		G	JK	SS		BG	FX		SH		PL	SI							PO	S2	F	NP		QZ		CL				
124	127		A		G	JK	SS		BG	FX		SH		PL	SI							PO	S2	F	NP		QZ		CL				
127	130		A		G	JK	SS		BG	FX		SH		PL	SI							PO	S2	F	NP		QZ		CL				
130	133		A		G	JK	SS		BG	FX		SH		PL	SI							PO	S2	F	NP		QZ		CL				
133	136		A		G	JK	SS		BG	FX		SH		PL	SI							PO	S2	F	NP		QZ		CL				
136	139		A		G	JK	SS		BG	FX		SH		PL	SI							PO	S2	F	NP		QZ		CL				
139	142		A		G	JK	SS		BG	FX		SH		PL	SI							PO	S2	F	NP		QZ		CL				
142	145		A		G	JK	SS		BG	FX		SH		PL	SI							PO	S2	F	NP		QZ		CL				

Project: *Pedirka connectivity*			Logger: *MK*					Date: *4/08/2013*			Lithology Logging Sheet:							Drillhole Name/ No: *RN18915*															Page:
Drillhole Details			Colour			Stratigraphy/ Lithology																Geotechnical					Minerals/ Fossils						Comment
Depth_Fr	Depth_To	Samp_No.	Shade	Hue	Colour	Formation	Lith_1	Lith_1%	Desc11	Desc12	Desc13	Lith_2	Lith_2%	Desc11	Desc12	Desc13	Lith_3	Lith_3%	Desc11	Desc12	Desc13	Perm/Porosity	Consolidation	Weathering	Plasticity	Defects	MinFos1	MinFos1%	MinFos2	MinFos2%	MinFos3	MinFos3%	
145	148		A		G	JK	SS		BG	FX		SH		PL	SI							PO	S2	F	NP		QZ		CL				
148	151		A		G	JK	SS		BG	FX		SH		PL	SI							PO	S2	F	NP		QZ		CL				
151	154		E		G	JK	SH		PL	SI		SS		BG	FX							PO	S2	F	NP		QZ		CL				
154	157		E		G	JK	SH		PL	SI		SS		BG	FX							PO	S2	F	NP		QZ		CL				
157	160		E		G	JK	SH		PL	SI		SS		BG	FX							PO	S2	F	NP		QZ		CL				
160	163		E		G	JK	SH		PL	SI		SS		BG	FX							PO	S2	F	NP		QZ		CL				
163	166		A		G	JK	SS		BG	FX		SH		PL	SI							PO	S2	F	NP		QZ		CL				
166	169		A		G	JK	SS		BG	FX		SH		PL	SI							PO	S2	F	NP		QZ		CL				
169	172		A		G	JK	SS		BG	FX		SH		PL	SI							PO	S2	F	NP		QZ		CL				
172	175		A		G	JK	SS		BG	FX		SH		PL	SI							PO	S2	F	NP		QZ		CL				
175	177		E		G	JK	SH		PL	SI												IR	C4	F	NP		CL						
177	180		E		G	JK	SH		PL	SI												IR	C4	F	NP		CL		CL				
180	183		E		G	JK	SH		PL	SI												IR	C4	F	NP		CL		CL				
183	186		A		G	JK	SS		BG	FX		SH		PL	SI							PO	C2	F	NP		QZ		CL				
186	189		A		G	JK	SS		BG	FX		SH		PL	SI							PO	C2	F	NP		QZ		CL				
189	192		A		G	JK	SS		BG	FX		SH		PL	SI							PO	C2	F	NP		QZ		CL				
192	195		A		G	JK	SS		BG	FX		SH		PL	SI							PO	C2	F	NP		QZ		CL				
195	198		B	B	G	P_p	SH		SI	LG		LG		FU	C2	DD		CS				LP	C2	F	MP		PE		CL		LG		FINING UPWARD SEQUENCE 1
198	201		B	B	G	P_p	SH		SI	LG		LG		FU	C2	DD		CS				LP	C2	F	MP		PE		CL				FINING UPWARD SEQUENCE 1
201	204		E		G	P_p	SA		FX	BG		CS		FU	SI							PO	C2	F	NP		QZ		CL				FINING UPWARD SEQUENCE 1
204	207		E	B	G	P_p	SH		SI	CL		SI		FU								LP	C2	F	MP		CL		MI				FINING UPWARD SEQUENCE 2
207	210		E	B	G	P_p	SH		SI	CL		SS		BG	AG	FR						MP	C2	F	NP		CL		QZ		MI		FINING UPWARD SEQUENCE 2
210	213		E		G	P_p	SS		BG	AG	FX	CS		FU	SI							PO	C2	F	NP		QZ		CL				FINING UPWARD SEQUENCE 2
213	216		E	B	G	P_p	SH		SI	CL		CS										HP	C2	F	MP		CL						FINING UPWARD SEQUENCE 3
216	219		E	B	G	P_p	SH		SI	CL		CS										HP	C2	F	MP		CL						FINING UPWARD SEQUENCE 3
219	222		E	B	G	P_p	SH		SI			SA		BG	AG			CS				MP	C2	F	NP		CL		QZ				FINING UPWARD SEQUENCE 3
222	225		E		G	P_p	SS		FX	BG	FX	CH		FU	SI			CS				NP	C2	F	NP		QZ		CL				FINING UPWARD SEQUENCE 3
225	228		E	B	G	P_p	SH		SI			SI		FU				CS				MP	C2	F	MP		CL						FINING UPWARD SEQUENCE 4
228	231		E	B	G	P_p	SH		SI			SA		BG	AG							MP	C2	F	MP		CL		QZ				FINING UPWARD SEQUENCE 4
231	234		E		G	P_p	SH		SI			SA		BG	AG							MP	C2	F	MP		CL		QZ				FINING UPWARD SEQUENCE 4
234	237		E		G	P_p	SH		SI			SA		BG	AG							MP	C2	F	MP		CL		QZ				FINING UPWARD SEQUENCE 4
237	240		E		G	P_p	SA		S6	BG	AG											PO	C2	F	NP		QZ						FINING UPWARD SEQUENCE 4
240	243		D		K	P_p	CO		SO	SF	DM	CS		XX	MI							MP	C2	F	FS		CO		CL		CO		FINING UPWARD SEQUENCE 5
243	246		E		G	P_p	SH		SI	MI	PL	SS		BG	FM	RG						LP	C2	F	MP		CL		MI				FINING UPWARD SEQUENCE 5
246	249		E		G	P_p	SH		SI	MI	PL	SS		BG	FM	RG						LP	C2	F	MP		CL		MI				FINING UPWARD SEQUENCE 5
249	252		E		G	P_p	SH		SI	MI	PL	SI		SA								LP	C2	F	MP		CL		MI				FINING UPWARD SEQUENCE 5
252	255		E		G	P_p	SH		SI	MI	PL	SI		SA								LP	C2	F	MP		CL		MI				FINING UPWARD SEQUENCE 5
255	258		E		G	P_p	SI		CL	MI		SA		SI	FF	RG						MP	C2	F	MP		CL		MI				FINING UPWARD SEQUENCE 5
258	261		D	K	G	P_p	ZH		MI	XX	PL	CO		DD	SF		ZC					IR	C2	F	HP		CL		MI		CO		CARBONACEOUS SHALE SEQUENCE 1
261	264		D	K	G	P_p	ZH		MI	XX	PL	CO		DD	SF		ZC					IR	C2	F	HP		CL		MI		CO		CARBONACEOUS SHALE SEQUENCE 1
264	267		D	K	G	P_p	ZH		MI	XX	PL	CO		DD	SF		ZC					IR	C2	F	HP		CL		MI		CO		CARBONACEOUS SHALE SEQUENCE 1
267	270		D	K	G	P_p	ZH		MI	XX	PL	CO		DD	SF		ZC					IR	C2	F	HP		CL		MI		CO		CARBONACEOUS SHALE SEQUENCE 1
270	273		D		G	P_p	SH		MI	PL	CL	CS										IR	C2	F	HP		CL		MI				CARBONACEOUS SHALE SEQUENCE 1
273	276		D		G	P_p	SH		MI	PL	CL	CS										IR	C2	F	HP		CL		MI				CARBONACEOUS SHALE SEQUENCE 1
276	279		D		G	P_p	SH		MI	PL	CL	CS										IR	C2	F	HP		CL		MI				CARBONACEOUS SHALE SEQUENCE 1
279	282		D		G	P_p	SH		MI	PL	CL	CS										IR	C2	F	HP		CL		MI				CARBONACEOUS SHALE SEQUENCE 1
282	285		D	K	G	P_p	ZH		MI	XX	PL	CO		DD	SF		ZC					IR	C2	F	HP		CL		MI		CO		CARBONACEOUS SHALE SEQUENCE 2
285	288		D	K	G	P_p	ZH		MI	XX	PL	CO		DD	SF		ZC					IR	C2	F	HP		CL		MI		CO		CARBONACEOUS SHALE SEQUENCE 2
288	291		D	K	G	P_p	ZH		MI	XX	PL	CO		DD	SF		ZC					IR	C2	F	HP		CL		MI		CO		CARBONACEOUS SHALE SEQUENCE 2
291	294		D	K	G	P_p	ZH		MI	XX	PL	CO		DD	SF		ZC					IR	C2	F	HP		CL		MI		CO		CARBONACEOUS SHALE SEQUENCE 2
294	297		D	K	G	P_p	ZH		MI	XX	PL	CO		DD	SF		ZC					IR	C2	F	HP		CL		MI		CO		CARBONACEOUS SHALE SEQUENCE 2

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Drillhole Details			Colour			Stratigraphy/ Lithology																Geotechnical					Minerals/ Fossils						Comment
Depth_Fr	Depth_To	Samp_No.	Shade	Hue	Colour	Formation	Lith_1	Lith_1%	Desc11	Desc12	Desc13	Lith_2	Lith_2%	Desc11	Desc12	Desc13	Lith_3	Lith_3%	Desc11	Desc12	Desc13	Perm/Porosity	Consolidation	Weathering	Plasticity	Defects	MinFos1	MinFos1%	MinFos2	MinFos2%	MinFos3	MinFos3%	
297	300		D	K	G	P_p	ZH		MI	XX	PL	CO		DD	SF		ZC					IR	C2	F	HP		CL		MI		CO		CARBONACEOUS SHALE SEQUENCE 2
300	303		E		G	P_p	SH		SI	FU	PL	SA		VF	CL		CS					LP	C2	F	HP		CL		MI		QZ		CARBONACEOUS SHALE SEQUENCE 2
303	306		E		G	P_p	SH		SI	FU	PL	SA		VF	CL		CS					LP	C2	F	HP		CL		MI		QZ		CARBONACEOUS SHALE SEQUENCE 2
306	309		E		G	P_p	SH		SI	FU	PL	SA		VF	CL		CS					LP	C2	F	HP		CL		MI		QZ		CARBONACEOUS SHALE SEQUENCE 2
309	312		E		G	P_p	SH		SI	FU	PL	SA		VF	CL		CS					LP	C2	F	HP		CL		MI		QZ		CARBONACEOUS SHALE SEQUENCE 2
312	315		E		G	P_p	SH		SI	FU	PL	SA		VF	CL		CS					LP	C2	F	HP		CL		MI		QZ		CARBONACEOUS SHALE SEQUENCE 2
315	318		E		G	P_p	SH		SI	FU	PL	SA		VF	CL		CS					LP	C2	F	HP		CL		MI		QZ		CARBONACEOUS SHALE SEQUENCE 2
318	321		E		G	P_p	SH		SI	FU	PL	SA		VF	CL		CS					LP	C2	F	HP		CL		MI		QZ		CARBONACEOUS SHALE SEQUENCE 2
321	324		D	K	G	P_p	CO		DD	SF		ZH		MI	XX	PL	ZC					IR	C2	F	HP		CL		MI		LG		CARBONACEOUS SHALE SEQUENCE 3
324	327		E		G	P_p	SH		SI	FU	PL	CS		MI								LP	C2	F	HP		CL		MI				CARBONACEOUS SHALE SEQUENCE 3
327	330		E		G	P_p	SH		SI	FU	PL	CS		MI								LP	C2	F	HP		CL		MI				CARBONACEOUS SHALE SEQUENCE 3
330	333		D	K	G	P_p	ZH		MI	XX	PL	ZC		MI	XX							IR	C2	F	HP		CL		MI		LG		CARBONACEOUS SHALE SEQUENCE 4
333	336		E		G	P_p	SH		SI	FU	PL	CS		MI								LP	C2	F	HP		CL		MI				CARBONACEOUS SHALE SEQUENCE 4
336	339		E		G	P_p	SH		SI	FU	PL	CS		MI								LP	C2	F	HP		CL		MI				CARBONACEOUS SHALE SEQUENCE 4
339	342		E		G	P_p	SH		SI	FU	PL	CS		MI								LP	C2	F	HP		CL		MI				CARBONACEOUS SHALE SEQUENCE 4
342	345		D	K	G	P_p	ZH		MI	XX	PL	CO		DD	SF		ZC					IR	C2	F	HP		CL		MI		CO		CARBONACEOUS SHALE SEQUENCE 5
345	348		D	K	G	P_p	ZH		MI	XX	PL	CO		DD	SF		ZC					IR	C2	F	HP		CL		MI		CO		CARBONACEOUS SHALE SEQUENCE 5
348	351		D	K	G	P_p	ZH		MI	XX	PL	ZC		MI	XX							IR	C2	F	HP		CL		MI		CO		CARBONACEOUS SHALE SEQUENCE 5
351	354		D	K	G	P_p	ZH		MI	XX	PL	ZC		MI	XX							IR	C2	F	HP		CL		MI		CO		CARBONACEOUS SHALE SEQUENCE 5
354	357		D	K	G	P_p	ZH		MI	XX	PL	ZC		MI	XX							IR	C2	F	HP		CL		MI		CO		CARBONACEOUS SHALE SEQUENCE 5
357	360		E		G	P_p	SH		SI	FU	PL	CS		MI								LP	C2	F	HP		CL		MI				CARBONACEOUS SHALE SEQUENCE 5
360	363		E		G	P_p	SH		SI	FU	PL	CS		MI								LP	C2	F	HP		CL		MI				CARBONACEOUS SHALE SEQUENCE 5
363	366		E		G	P_p	SH		SI	FU	PL	CS		MI			SS	TR	VF			LP	C2	F	HP		CL		MI		QZ		CARBONACEOUS SHALE SEQUENCE 5
366	369		E		G	P_p	SH		SI	FU	PL	CS		MI			SS	TR	VF	QZ		LP	C2	F	HP		CL		MI		PY		CARBONACEOUS SHALE SEQUENCE 5
369	372		E		G	P_p	CS	FU	SI	MI		SH		MI			SS	TR	VF			LP	C2	F	HP		CL		MI		QZ		CARBONACEOUS SHALE SEQUENCE 5
372	375		E		G	P_p	CS	FU	SI	MI		SH		MI			SS	TR	VF			LP	C2	F	HP		CL		MI		QZ		CARBONACEOUS SHALE SEQUENCE 5
375	378		E		G	P_p	CS	FU	SI	MI		SH		MI			SS	TR	VF			LP	C2	F	HP		CL		MI		QZ		CARBONACEOUS SHALE SEQUENCE 5
378	381		E		G	P_p	CS	FU	SI	MI		SH		MI			SS	TR	VF			LP	C2	F	HP		CL		MI		QZ		CARBONACEOUS SHALE SEQUENCE 5
381	384		D	K	G	P_p	ZH		MI	XX	PL	ZC		MI	XX							IR	C2	F	HP		CL		MI		CO		CARBONACEOUS SHALE SEQUENCE 6
384	387		D	K	G	P_p	ZH		MI	XX	PL	ZC		MI	XX							IR	C2	F	HP		CL		MI		CO		CARBONACEOUS SHALE SEQUENCE 6
387	390		D	K	G	P_p	ZH		MI	XX	PL	ZC		MI	XX							IR	C2	F	HP		CL		MI		CO		CARBONACEOUS SHALE SEQUENCE 6
390	393		D	K	G	P_p	ZH		MI	XX	PL	ZC		MI	XX							IR	C2	F	HP		CL		MI		CO		CARBONACEOUS SHALE SEQUENCE 6
393	396		D	K	G	P_p	ZH		MI	XX	PL	ZC		MI	XX		CO		C1	FS		IR	C2	F	HP		CL		MI		CO		CARBONACEOUS SHALE SEQUENCE 6
396	399		D	K	G	P_p	ZH		SI	XX	PL	ZC		MI	XX		CO		C1	FS		IR	C2	F	HP		CL		MI		CO	TR	CARBONACEOUS SHALE SEQUENCE 6
399	402		E		G	P_p	CS		FU	SI	MI	SH		MI	XX							IR	C2	F	HP		CL		MI				CARBONACEOUS SHALE SEQUENCE 6
402	405		E		G	P_p	CS		FU	SI	MI	SH		MI	XX							IR	C2	F	HP		CL		MI				CARBONACEOUS SHALE SEQUENCE 6
405	408		E		G	P_p	CS		FU	SA	MI	SS		VM	BG	LT	SH		SC	CL		LP	C6	F	HP		CL		MI		QZ		SANDY CLAY hard siliceous(?) shale
408	411		E		G	P_p	CS		FU	SA	MI	SS		VM	BG	LT						LP	C4	F	HP		CL		MI		QZ		SANDY CLAY
411	414		E		G	P_p	CS		FU	SA	MI	SS		VM	BG	LT						LP	C4	F	HP		CL		MI		QZ		SANDY CLAY
414	417		E		G	P_p	CS		FU	SA	MI	SS		VM	BG	LT						LP	C4	F	HP		CL		MI		QZ		SANDY CLAY
417	420		E		G	P_p	CS		FU	SA	MI	SS		VM	BG	LT	SH	TR	SC	CL		LP	C4	F	HP		CL		MI		QZ		SANDY CLAY
420	423		E		G	P_p	CS		FU	SA	MI	SS		VC	BG	LT						LP	C4	F	HP		CL		MI		QZ		SANDY CLAY
423	426		E		G	P_p	CS		FU	SA	MI	SS		VF	BG	LT						LP	C4	F	HP		CL		MI		QZ		SANDY CLAY
426	429		E		G	P_p	CS		FU	SA	MI	SS		VC	BG	LT						MP	C2	F	LP		QZ		CL		MI		CLAYEY SAND TO SANDY CLAY
429	432		E		G	P_p	CS		FU	SA	MI	SS		VC	BG	LT						MP	C2	F	HP		CL		MI		QZ		CLAYEY SAND TO SANDY CLAY
432	435		E		G	P_p	CS		FU	SA	MI	SS		VC	BG	LT						MP	C2	F	LP		QZ		CL		MI		CLAYEY SAND TO SANDY CLAY
435	438		E		G	P_p	CS		FU	SA	MI	SS		VC	BG	LT						MP	C2	F	LP		QZ		CL		MI		CLAYEY SAND TO SANDY CLAY
438	441		E		G	P_p	SS		VC	RD	LT	CS		MI	FU							MP	C2	F	HP		CL		MI		QZ		CLAYEY SAND TRACE PYRITE CEMENT
441	444		E		G	P_p	SS		VC	RD	LT	CS		MI	FU							MP	C2	F	HP		CL		MI		QZ		CLAYEY SAND TRACE PYRITE CEMENT
444	447		E		G	P_p	SS		VC	RD	LT	CS		MI	FU							MP	C2	F	LP		QZ		CL		MI		CLAYEY SAND TRACE PYRITE CEMENT
447	450		E		G	P_p	SS		VC	RD	LT	CS		MI	FU							MP	C2	F	LP		QZ		CL		MI		Clayey sand trace pyrite cement

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Drillhole Details			Colour			Stratigraphy/ Lithology																Geotechnical					Minerals/ Fossils						Comment
Depth_Fr	Depth_To	Samp_No.	Shade	Hue	Colour	Formation	Lith_1	Lith_1%	Desc11	Desc12	Desc13	Lith_2	Lith_2%	Desc11	Desc12	Desc13	Lith_3	Lith_3%	Desc11	Desc12	Desc13	Perm/Porosity	Consolidation	Weathering	Plasticity	Defects	MinFos1	MinFos1%	MinFos2	MinFos2%	MinFos3	MinFos3%	
450	453		E		G	P_p	SS		VC	RD	LT	CS		MI	FU							MP	C2	F	LP		QZ		PY		MI		Clayey sand trace pyrite cement
453	456		E		G	P_p	SS		VC	RD	LT	CS		MI	FU							MP	C2	F	LP		QZ		PY		MI		Clayey sand trace pyrite cement
456	459		E		G	P_p	SS		VC	RD	LT	CS		MI	FU		SH		SC	CL		MP	C3	F	LP		QZ		PY		MI		Clayey sand trace pyrite cement
459	462		E		G	P_p	SS		VC	RD	LT	CS		MI	FU							MP	C2	F	LP		QZ		PY		MI		Clayey sand trace pyrite cement
462	465		E		G	P_p	CS		VC	RD	LT	CS		MI	FU		SH		SC	CL		MP	C5	F	LP		QZ		CL		MI		Clayey sand trace pyrite cement
465	468		E		G	P_p	SS		VC	RD	LT	CS		MI	FU							MP	C2	F	LP		QZ		PY		MI		Clayey sand trace pyrite cement
468	471		E		G	P_p	SS		VC	RD	LT	CS		MI	FU							MP	C2	F	LP		QZ		BT		MI		Clayey sand trace biotite
471	474		E		G	P_p	SS		VC	RD	LT	CS		MI	FU	CO			C1	FS		MP	C2	F	LP		QZ		BT		CO		Clayey sand trace biotite and coal
474	477		L		G	CP-c	CS		SA	KA		SS		VF								MP	C2	W	HP		QZ		CL		KA		Sandy kaolinitic clay
477	480		L		G	CP-c	CS		KA			GV		BG	LT							MP	C5	W	HP		QZ		KA				Partly pallid kaolinitic clay with small bladed gravel grains of shale
480	483		L		G	CP-c	CS		KA	SA		GV		BG	LT							MP	C5	W	HP		QZ		KA				Partly pallid kaolinitic clay with small bladed gravel grains of shale
483	486		L		G	CP-c	CS		KA	SA												MP	C5	W	HP		KA						Partly pallid, kaolinitic clay
486	489		E		G	CP-c	CS		SA					SS	VC							MP	C2	F	HP		QZ		CL				Sandy clay
489	492		E		G	CP-c	CS		SA					SS	VC							MP	C2	F	HP		QZ		CL				Sandy clay
492	495		E		G	CP-c	CS		SA					SS	VC							MP	C2	F	HP		QZ		CL				Sandy clay
495	498		E		G	CP-c	CS		SA			GV		AF	LT	QT						MP	C5	F	HP		QZ		KA				Sandy clay with angular lithic fragments of quartzite and quartz grit
498	501		E		G	CP-c	CS		MI			SS		VF	RD							MP	C2	F	HP		QZ		CL				Sandy clay
501	504		E		G	CP-c	CS		MI			SS		VF	RD							MP	C2	F	HP		QZ		CL				Sandy clay
504	507		E		G	CP-c	CS		MI			SS		VF	RD							MP	C2	F	HP		QZ		CL				Sandy clay
507	510		E		G	CP-c	CS		MI			SS		VF	RD							MP	C2	F	HP		QZ		CL				Sandy clay
510	513		E		G	CP-c	CS		MI			SS		VF	RD							MP	C2	F	HP		QZ		CL				Sandy clay
513	516		E		G	CP-c	CS		MI			SS		VF	RD							MP	C2	F	HP		QZ		CL				Sandy clay
516	519		E	V	G	CP-c	CS		KA	SA	CA	GV		BG	LT		CL	BN				HP	C2	F	LP		QZ		KA				Sandy clay, small bladed gravel grains of shale, micritic calcite, bands of pallid clay
519	522		E		G	CP-c	CS		MI			SS		VF	RD							MP	C2	F	HP		QZ		CL				Sandy clay
522	525		E		G	CP-c	CS		MI			SS		VF	RD							MP	C2	F	HP		QZ		CL				Sandy clay
525	528		E		G	CP-c	CS		MI			SS		VF	RD							MP	C2	F	HP		QZ		CL				Sandy clay
528	531		E		G	CP-c	CS		SA			GV		AF	LT	QT						MP	C5	F	HP		QZ		KA				Sandy clay with small bladed gravel grains of shale and quartz grit

Table 9-1 Table of description codes for lithological log

HUES / COLOURS

- blackish / black K
- bluish / blue L
- brownish / brown B
- buff F
- creamy / cream C
- greenish / green E
- greyish / grey G
- orangey / orange O
- pinkish / pink P
- purplish / purple U
- reddish / red R
- whitish / white W
- yellowish / yellow Y

SHADES

- light L
- light to medium A
- light to dark C
- medium E
- medium to dark B
- dark D
- banded N
- mottled M
- speckled S
- variegated V

CRACKS

- desiccation cracks DC
- intraformational cracks IC
- mud casts/cracks MC
- shrinkage cracks SC
- syneresis cracks YC

Structures

- bioturbated BT
- boudinage BD
- bounce marks/prod casts PC
- burrowing BW
- climbing ripples CR
- colloidal iron deposit CI
- compaction feature CF
- flame structures FS
- imbricate clasts IM
- load cast LC
- pebble lag PG
- reworked RW
- ripple marks RM
- rip-up clasts RU
- rootlet beds RB
- scour and fill SF
- sedimentary dyke DY
- slumping SP
- soft sediment deformation DE
- stylolites ST
- varving VV
- water escape structures WE

FORMATIONS

CP-c	Crown Point Formation
E-O	Undifferentiated Warburton Basin
Jk-a	Algebuckina Sandstone
J-p	Poolowanna Formation
Kmb	Bulldog Shale
Kmc	Coorikiana Sandstone
Kmo	Oodnadatta Formation
Knc	Cadna-owie Formation
Knm	Mackunda Formation
Knw	Winton Formation
K-t	Toolebuc Formation
K-u	Murta Member
K-w	Wallumbilla Formation
P-p	Purni Formation
P-pl	Lower Purni Formation
P-pu	Upper Purni Formation
Q	Undifferentiated Quaternary
R-p	Peera Formation
R-w	Walkandi Formation
T	Undifferentiated Tertiary
Taee	Eyre Formation
Topn	Namba Formation

PLASTICITY

- non plastic NP
- low plasticity LP
- intermediate plasticity IP
- high plasticity HP

Other

- brecciated BR
- brittle BL
- cleated CE
- disintegrates on wetting DW
- expanding clay EX
- fissile FS
- fissured FI
- flaky FL
- fractured FR
- friable FB
- indurated IN
- micro faulted MF
- non-cleated NC
- powdery PO
- puggy PU
- sheared SH
- slickensided SK
- sticky ST
- subfissile SF

Unconsolidated Sediments

- Clay CL
- Silt SI
- Sand SA
- Gravel GV
- Boulders BO
- Alluvium AL
- Colluvium CV
- Diatomaceous Earth DE
- Fill/spoil FI
- Fireclay FC
- Loam LO
- Mud MD
- Soil SO

Clastic Sedimentary Rocks

- Conglomerate CG
- Sandstone SS
- Siltstone ST
- Claystone CS
- Breccia BR
- Fault Breccia FB
- Mudstone MS
- Sedimentary Rock, undifferentiated SU
- Shale SH
- Tillite TI

CONSOLIDATION

Unconsolidated Cohesive

- very soft C1
- soft C2
- firm C3
- stiff C4
- very stiff C5
- hard C6

Rock

- extremely low strength rock R1
- very low strength rock R2
- low strength rock R3
- medium strength rock R4
- high strength rock R5
- very high strength rock R6
- extremely high strength rock R7

WEATHERING

- residual soil R
- extremely weathered E
- highly weathered H
- distinctly weathered D
- moderately weathered M
- slightly weathered S
- weathered W
- fresh F

Metamorphic

- Basement Undifferentiated BU
- Gneiss GN
- Metamorphic Rock, undifferentiated MM
- Phyllite PH
- Quartzite QT
- Schist SZ
- Slate SL

Chemical Sedimentary Rocks

- Calcrete CC
- Carbonate CB
- Chalk CK
- Chert CH
- Cone in Cone Carbonate KK
- Dolomite DM
- Ferricrete FK
- Fossil Wood FW
- Ironstone IS
- Kaolinite KA
- Laterite LA
- Limestone LS
- Limonite LI
- Silcrete SC
- Tonstein TN

PERMEABILITY/ POROSITY

- impermeable (<0.1mD) IR
- low permeability (0.1-10mD) LP
- medium permeability (10-10000mD) MP
- high permeability (>10000mD) HP
- permeable PE
- porous PO

DEFECT TYPES

Natural

- bedding plane BP
- broken zone BZ
- clay band CL
- coal cleat CE
- contraction fracture CF
- cross bedding XB
- dyke DY
- fault FT
- foliation FO
- fracture (undifferentiated) FR
- joint JN
- shear zone SH
- sill SI
- softened zone (non-tectonic) SO
- vein VN

Carbonaceous Sediments

- Coal CO
- Lignite LG
- Brown Coal BC
- Peat PE
- Oil Shale OS
- Tar Sand TS
- Coaly Claystone ZC
- Coaly Mudstone ZM
- Coaly Sandstone ZS
- Coaly Shale ZH
- Coaly Siltstone ZT
- Carbonaceous Claystone XC
- Carbonaceous Mudstone XM
- Carbonaceous Sandstone XS
- Carbonaceous Shale XH
- Carbonaceous Siltstone XT

POSITION

- alternating AT
- near base of unit BU
- near middle of unit MU
- near top and base of unit XU
- near top of unit TU
- tends to TT
- throughout TO

FOSSILS

- bivalves BI
- brachiopods BR
- bryozoans BZ
- carbonaceous remains XR
- carbonaceous root traces RC
- charcoal FB
- coprolites CP
- faecal remains FR
- foraminifera FM
- fossil wood FW
- fossils FO
- gastropods GT
- marine fossils MF
- pelycepods PE
- plant fragments PF
- plant impressions PI
- resin RS
- resin aggregates RA
- root traces RT
- rootlets RO
- sediment filled root traces SR
- shells HY
- woody fragments WF

Unconsolidated Cohesionless

- very loose S1
- loose S2
- medium dense S3
- dense S4
- very dense S5

Other

- Core Loss KL
- Old Workings OW
- Non Coal NC
- No Recovery NR
- Not Logged NL
- Void VD

MINERALS

- ankerite AN
- apatite AP
- bauxite BA
- biotite BT
- calcite CA
- carbonate CB
- chalcedony CD
- chalcopyrite CC
- chert CH
- chlorite CR
- clay CL
- common opal OP
- dickite DI
- dolomite DM
- epidote EP
- feldspar FS
- galena GA
- garnet GR
- glauconite GC
- goethite GO
- graphite GP
- gypsum GY
- haematite HE
- heavy minerals HM
- illite IL
- ilmenite IM
- iron oxide IO
- ironstone IS
- kaolinite KA
- limonite LI
- magnetite MT
- manganese MG
- marcasite MC
- mica MI
- montmorillonite ML
- muscovite MV
- olivine OL
- opaque minerals OM
- orthoclase OR
- phosphates PP
- plagioclase PG
- pyrite PY
- quartz QZ
- siderite SD
- silica SC
- sulphides SU
- talc TA
- vivianite VV
- zeolite ZE

LITHOLOGICAL

acidic AC
arenitic AR
arkosic AK
basaltic BS
basic BC
bentonitic BE
calcareous CA
carbonaceous XX
carbonate CB
chloritic CR
clayey CL
coaly CO
conglomeritic CG
detrital DE
dolomitic DM
feldspathic FS
ferruginous FE
fossiliferous FO
glauconitic GC
graphitic GP
illitic IL
intermediate IM
intrusive IN
iron stained ID
kaolinitic KA
lateritic LA
limonitic LI
lithic LT
loamy LO
manganiferous MG
marly MR
metamorphosed MM
micaceous MI
muddy MD
oxidised OX
peaty PE
phosphatic PP
pyritic PY
quartzose QZ
sandy SA
shaly SH
shelly HY
sideritic SD
siliceous SC
silicified SF
silty SI
smectitic SM
sooty SX
stony SY
sub arenitic AM
tillitic TI
tonsteinous TN
tuffaceous TF
vitrainous VI
volcanic VO

LITHOLOGY QUALIFIERS

Coals

bright (>90%) BR
bright with dull bands (60-90%) BB
interbanded dull and bright (40-60%) BD
mainly dull with frequent bright
bands (10-40%) DB
dull with minor bright bands
(1-10%) DM
dull (<1%) DD
bright (>90% bright coal) C1
bright with dull bands
(60-90% bright coal) C2
Interbanded dull and bright
(40-60% bright coal) C3
mainly dull with frequent bright
bands (10-40% bright coal) C4
dull with minor bright bands
(1-10% bright coal) C5
dull (<1% bright coal) C6
mid-lustrous to bright M1
mid-lustrous M2
mid-lustrous to dull M3
anthracite AN
cindered CI
coked KC
cannel (torbanite, bog) CT
dull conchoidal DC
extremely weathered EW
fusainous FU
heat affected HA
inferior IF
sapropelic SP
stony SY
undifferentiated CU
weathered WE

UNCONSOLIDATED SEDIMENTS

clayey CL
silty SI
sandy SA
gravelly GV
Tuff / Tuffite
clay sized CS
mud sized MS
silt sized TS
sand sized SS

CONGLOMERATES

granular GG
granular to pebbly GP
granular to cobbly GO
granular to bouldery GU
pebbly PP
pebbly to cobbly PO
pebbly to bouldery PU
cobbly OO
cobbly to bouldery OU
bouldery UU

SANDSTONES / SAND / GRAVEL

very fine grained VV
very fine to fine grained VF
very fine to medium grained VM
very fine to coarse grained VC
very fine to very coarse grained VX
fine grained FF
fine to medium grained FM
fine to coarse grained FC
fine to very coarse grained FX
medium grained MM
medium to coarse grained MC
medium to very coarse grained MX
coarse grained CC
coarse to very coarse grained CX
very coarse grained XX

LITHOLOGY INTERRELATIONSHIPS

coarsening up to CU
disseminated with DS
fining up to FU
interbedded with IB
intercalated with IC
interlaminated with IL
intermixed with IM
irregularly interbedded with IR
with bands of BN
with boulders of BO
with cement of CM
with clasts of CT
with cobbles of OO
with fragments of FR
with granules of GR
with lenses of LN
with matrix of MX
with nodules of ND
with pebbles of PB
with pods of PO

APPEARANCE

altered AL
bright BR
clear LC
coarser (<10% of unit) XC
conchoidal CC
dull DD
fault gouge FT
finer (<10% of unit) FF
hard HR
heat affected HA
interbanded IB
irregular IR
lustrous LU
opaque OP
resinous RS
soft SO
translucent TL

SHAPE

very angular grains VG angular grains AG
subangular grains GG
subrounded grains BG
rounded grains RG
well rounded grains WG
bladed grains DG
prolate grains LG
tabular grains TG
very angular fragments VF
angular fragments AF
subangular fragments GF
subrounded fragments BF
rounded fragments RF
well rounded fragments WF
very angular pebbles VP
angular pebbles AP
subangular pebbles GP
subrounded pebbles BP
rounded pebbles RP
well rounded pebbles WP

BED SPACINGS

massive/absent bedding MA
very thickly bedded (> 2 m) VB
thickly bedded (600-2000 mm) CB
medium bedded (200-600 mm) MB
thinly bedded (60-200 mm) TB
very thinly bedded (20-60 mm) UB
thickly laminated (6-20 mm) LM
thinly laminated (< 6 mm) LL
irregular spaced bedding IR

SEDIMENTARY FEATURES

contorted bedding CT
convoluted bedding CV
current bedding CB
diffuse bedding DF
disturbed bedding DB
flasar bedding FL
graded bedding GB
lenticular bedding LB
penny bands PB
planar bedding PL
poorly developed bedding PD
ripple bedding RI
wavy bedding WB
well developed bedding WD
Cross Bedding
high angle cross bedding (>30°) HX
medium angle cross bedding (10°-30°) MX
low angle cross bedding (<10°) LX
cross bedding XB
fine cross bedding FX
tabular cross bedding TX
trough cross bedding RX
Laminations
large scale cross laminations (>2m) LL
medium scale cross laminations
(200–2000mm) ML
small scale cross laminations
(<200mm) SL
wavy laminations WL

QUANTITY

abundant AB
decreasing in abundance DA
highly HI
in part IP
increasing in abundance IA
large LR
minor MN
moderately MO
occasional OC
rare RA
slightly TY
sparse SE
sporadic SP
strongly TG
thick TK
thin TH
very VE

MINERAL

bands BN
blebs BL
clasts CT
cobbles OO
concretions CI
disseminated DS
fragments FR
grains GN
granules GR
laminae LM
layers LY
lenses LN
matrix MX
nodules ND
partings PA
pebbles PB
pellets PT
phases PH
pods PO
stringers SG
traces TR
wisps WP

TEXTURES

amorphous AM
amygdaloidal AG
aphanitic AP
chalky CK
cherty CH
concretionary CI
crystalline XL
earthy EA
equigranular EQ
fibrous FB
flaggy FG
flow banded FL
glassy GS
granular GG
gritty GT
nodular ND
oolitic OO
pelletal PT
pisolitic PS
platey PL
porphyritic PR
schistose SZ
soapy SO
vesicular VS
vitreous VT
vuggy VU
waxy WX

MINERAL ASSOCIATION

amorphous AM
bands BN
cement CM
clasts CT
coarse grains CC
coating OU
concentrated at base CB
concentrated at top CN
concretions CI
cone in cone structure KK
crystals XL
detrital DE
disseminated DS
fibrous FB
fine grains FF
fragments FR
grains GN
in blebs BL
in cavities CV
in cleat CE
in pods PO
in veins VN
in vesicles VS
in vughs VU
infilling fault discontinuities FD
infilling of burrows IB
infilling vesicles IV
intercalations IC
laminae LM
lenses LN
matrix MX
microflakes MF
nodules ND
on bedding planes BP
on fracture planes FP
on joints JN
oolites OO
pebbles PB
pellets PT
phenocrysts PH
radial filaments FL
replacement RE
replacing fossils RF
resinous RS
rhombs RH
staining SN
traces TR
wisps WP

E. Aquifer test water level data

Table 9-2 Water level data for RN18918 Purni Formation 48-hour constant rate test

RN018918 (PRODUCTION)		RN18919		RN18917		RN18916	
Time	Drawdown (m)	Time	Drawdown (m)	Time	Drawdown (m)	Time	Drawdown (m)
0	0.00	0	0.00	0	0.00	0	0.00
1	18.07	1	0.16	15	0.02	200	0.01
2	20.92	2	0.62	20	0.03	300	0.02
3	21.72	3	0.99	25	0.05	400	0.03
4	21.96	4	1.25	30	0.07	500	0.04
5	22.19	5	1.43	40	0.09	600	0.04
6	22.43	6	1.57	50	0.11	800	0.05
7	22.38	7	1.68	60	0.12	1000	0.06
8	22.61	8	1.77	70	0.13	1100	0.07
9	22.70	9	1.85	80	0.15	1200	0.08
10	22.86	10	1.91	90	0.16	1300	0.08
12	22.98	12	2.02	100	0.17	1400	0.09
15	23.12	15	2.14	120	0.19	1500	0.09
20	23.29	20	2.27	150	0.22	1600	0.10
25	23.34	25	2.36	200	0.25	1700	0.11
30	23.35	30	2.42	300	0.29	1800	0.12
40	23.44	40	2.49	400	0.32	1900	0.12
50	23.55	50	2.55	500	0.34	2000	0.12
60	23.56	60	2.58	600	0.35	2200	0.12
70	23.58	70	2.61	800	0.37	2400	0.13
80	23.55	80	2.63	1000	0.40	2600	0.14
90	23.62	90	2.65	1100	0.41	2800	0.14
100	23.72	100	2.67	1200	0.42	2880	0.14
120	23.73	120	2.69	1300	0.42	2881	0.15
150	23.72	150	2.73	1400	0.43	2882	0.15
200	23.81	200	2.76	1500	0.43	2883	0.15
300	23.76	300	2.81	1600	0.44	2884	0.15
400	23.73	400	2.84	1700	0.45	2885	0.15
500	23.74	500	2.87	1800	0.46	2886	0.15
600	23.78	600	2.88	1900	0.47	2887	0.15
800	23.80	800	2.91	2000	0.47	2888	0.15
1000	23.88	1000	2.94	2200	0.47	2889	0.15
1100	23.83	1100	2.95	2400	0.48	2890	0.15
1200	23.90	1200	2.96	2600	0.49	2892	0.15
1300	23.88	1300	2.97	2800	0.49	2895	0.15
1400	23.87	1400	2.97	2880	0.50	2900	0.15
1500	23.85	1500	2.97	2881	0.50	2905	0.15
1600	23.89	1600	2.99	2882	0.50	2910	0.15
1700	23.87	1700	3.00	2883	0.51	2920	0.15
1800	23.92	1800	3.00	2884	0.51	2930	0.15
1900	23.88	1900	3.01	2885	0.51	2940	0.15
2000	23.87	2000	3.01	2886	0.50	2950	0.15
2200	23.86	2200	3.01	2887	0.50	2960	0.15
2400	23.79	2400	3.02	2888	0.50	2970	0.15
2600	23.96	2600	3.03	2889	0.50	2980	0.15
2800	23.90	2800	3.04	2890	0.50	3030	0.15
2880	21.97	2880	3.04	2892	0.49	3080	0.15
2881	4.34	2881	2.82	2895	0.48	3180	0.15
2882	2.77	2882	2.36	2900	0.47	3280	0.14
2883	2.22	2883	2.00	2905	0.45	3380	0.14
2884	1.89	2884	1.75	2910	0.44	3480	0.13

RN018918 (PRODUCTION)		RN18919		RN18917		RN18916	
Time	**Drawdown (m)**	**Time**	**Drawdown (m)**	**Time**	**Drawdown (m)**	**Time**	**Drawdown (m)**
2885	1.65	2885	1.58	2920	0.41	3680	0.12
2886	1.48	2886	1.44	2930	0.39	3880	0.11
2887	1.35	2887	1.33	2940	0.38	3980	0.10
2888	1.25	2888	1.24	2950	0.36	4080	0.10
2889	1.16	2889	1.17	2960	0.35	4180	0.10
2890	1.08	2890	1.11	2970	0.34	4280	0.09
2892	0.95	2892	1.00	2980	0.33	4380	0.09
2895	0.82	2895	0.89	3030	0.29	4480	0.08
2900	0.66	2900	0.76	3080	0.26	4580	0.08
2905	0.57	2905	0.67	3180	0.22	4680	0.08
2910	0.50	2910	0.61	3280	0.20		
2920	0.42	2920	0.53	3380	0.18		
2930	0.36	2930	0.48	3480	0.16		
2940	0.33	2940	0.44	3680	0.13		
2950	0.29	2950	0.42	3880	0.11		
2960	0.28	2960	0.40	3980	0.11		
2970	0.26	2970	0.38	4080	0.10		
2980	0.26	2980	0.37	4180	0.10		
3030	0.21	3030	0.32	4280	0.10		
3080	0.18	3080	0.28	4380	0.09		
3180	0.15	3180	0.24	4480	0.08		
3280	0.11	3280	0.21	4580	0.08		
3380	0.09	3380	0.19	4680	0.07		
3480	0.08	3480	0.17	4780	0.07		
3680	0.05	3680	0.14	4880	0.07		
3880	0.03	3880	0.12	5080	0.06		
3980	0.02	3980	0.11	5280	0.05		
4080	0.03	4080	0.11	5480	0.04		
4180	0.02	4180	0.10	5680	0.05		
4280	0.02	4280	0.10				
		4380	0.09				
		4480	0.08				
		4580	0.08				
		4680	0.07				
		4780	0.07				
		4880	0.07				
		5080	0.06				
		5280	0.05				
		5480	0.05				
		5680	0.05				
		5760	0.05				

Table 9-3 Water level data for RN18917 Lower J Aquifer 8-hour constant rate test

RN018917 (PRODUCTION)		RN18918		RN18919	
Time	Drawdown (m)	Time	Drawdown (m)	Time	Drawdown (m)
0	0.00	0	0.00	0	0.00
1	1.84	50	0.01	50	0.01
2	1.77	60	0.02	60	0.02
3	1.72	70	0.03	70	0.03
4	2.85	80	0.03	80	0.03
5	2.92	90	0.04	90	0.03
6	2.91	100	0.04	100	0.04
7	2.90	120	0.05	120	0.05
8	2.91	150	0.06	150	0.05
9	2.92	200	0.07	200	0.07
10	2.91	250	0.08	250	0.07
12	2.92	300	0.09	300	0.08
14	2.92	350	0.10	350	0.09
16	2.93	400	0.10	400	0.10
18	2.93	450	0.11	450	0.11
20	2.93	470	0.11	470	0.11
22	2.94	480	0.11	480	0.11
24	2.94	481	0.12	481	0.11
26	2.94	482	0.12	482	0.11
28	2.94	483	0.12	483	0.11
30	2.95	484	0.12	484	0.11
35	2.95	485	0.12	485	0.11
40	2.95	486	0.12	486	0.11
45	2.95	487	0.12	487	0.11
50	2.95	488	0.12	488	0.11
55	2.96	489	0.12	489	0.11
60	2.95	490	0.12	490	0.11
70	2.97	492	0.12	492	0.11
80	2.95	495	0.12	495	0.11
90	2.97	500	0.12	500	0.11
120	3.00	505	0.12	505	0.11
140	2.99	510	0.12	510	0.11
160	2.99	520	0.12	520	0.11
180	3.00	530	0.11	530	0.11
200	3.00	540	0.10	540	0.10
250	3.01	550	0.10	550	0.09
300	3.00	560	0.09	560	0.09
350	3.02	570	0.08	570	0.08
400	3.02	580	0.08	580	0.07
450	3.00	590	0.08	590	0.07
480	3.00	600	0.07		
481	0.09	610	0.07		
482	0.07	620	0.06		
483	0.04	640	0.06		
484	0.03	650	0.05		
485	0.02	660	0.05		
486	0.01				
487	0.00				

Table 9-4 Water level data for RN18915 Crown Point Formation 8-hour constant rate test

RN018915 (PRODUCTION)		*Continued . . . .*	
Time	**Drawdown (m)**	**Time**	**Drawdown (m)**
0	0.00	560	1.94
1	12.47	570	1.80
2	14.19	580	1.68
3	15.76	590	1.57
4	16.80	600	1.48
5	17.52	620	1.32
6	18.09	640	1.20
7	18.41	660	1.10
8	18.70	680	1.01
9	18.84	700	0.93
10	19.07	750	0.78
12	19.47	800	0.67
15	19.85	850	0.60
20	20.27	900	0.53
25	20.42	1000	0.42
30	20.70	1100	0.35
37	20.97	1200	0.31
40	21.16	1300	0.28
50	21.13	1334	0.27
60	21.70		
70	21.73		
80	22.09		
90	22.11		
100	22.56		
120	22.94		
150	23.34		
200	23.61		
250	23.90		
300	24.24		
350	24.09		
400	24.26		
450	24.49		
470	24.64		
480	24.73		
481	9.76		
482	8.65		
483	7.68		
484	6.93		
485	6.36		
486	5.61		
487	4.94		
488	4.84		
489	4.86		
490	4.78		
492	4.55		
495	3.84		
500	3.87		
505	3.12		
510	3.24		
520	2.87		
530	2.56		
540	2.30		
550	2.11		

F. Supplementary pump test analysis graphs

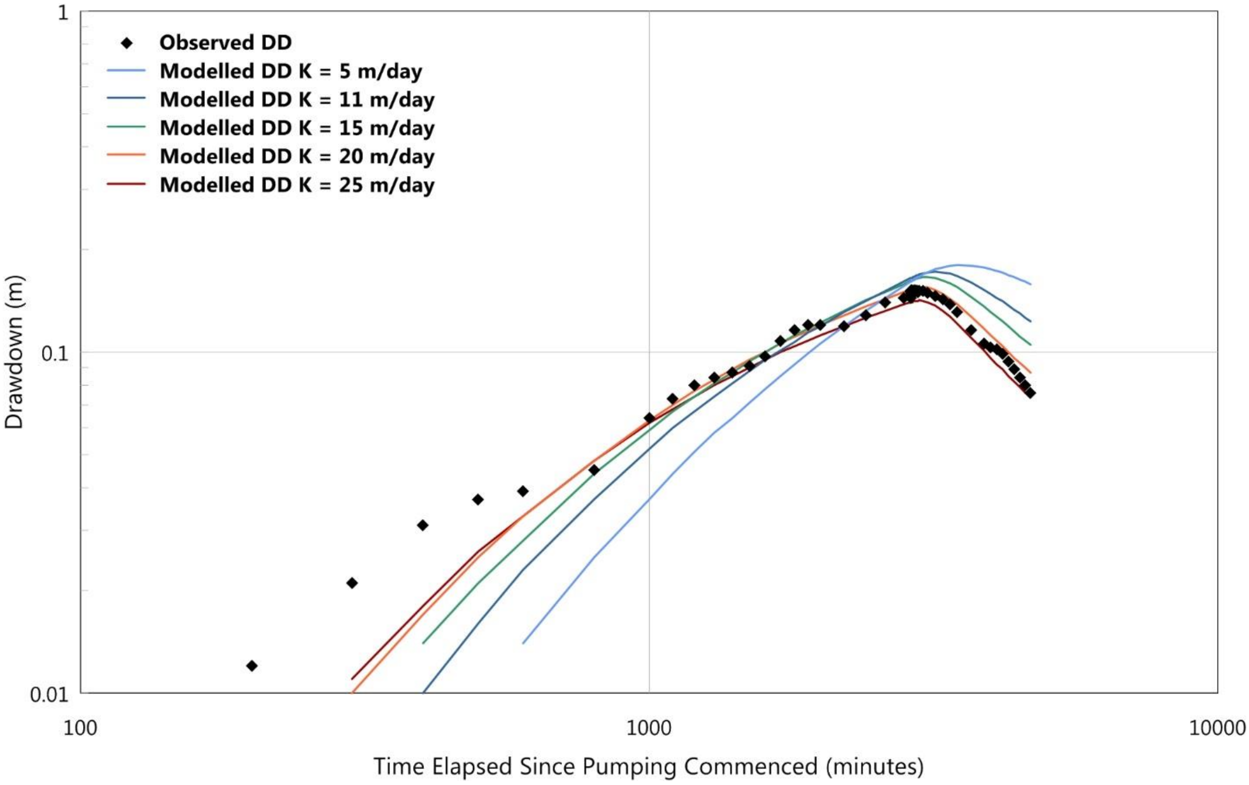

Figure 9-1 J Aquifer K_H sensitivity testing, RN18916 (Upper J Aquifer) modelled and observed drawdown

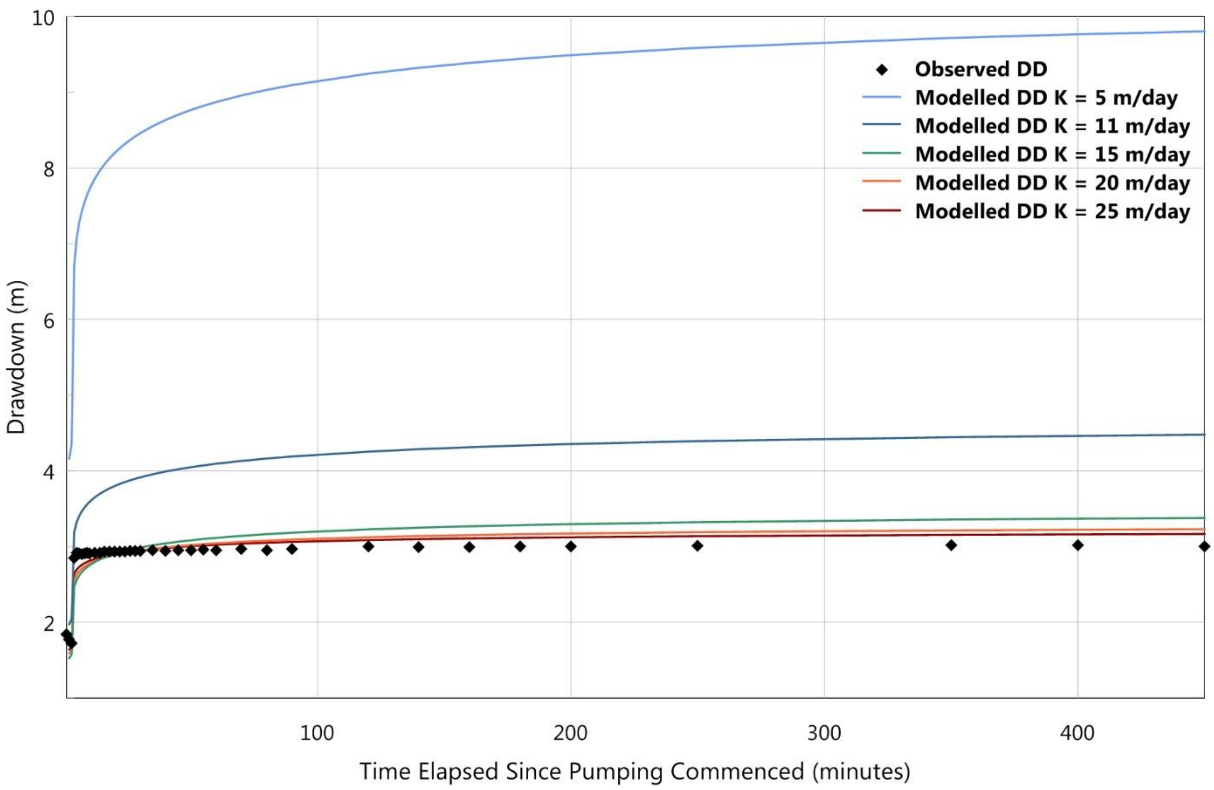

Figure 9-2 J Aquifer K_H sensitivity testing, RN18917 8-hour constant rate test modelled and observed drawdown

G. Groundwater sampling and analysis methods

Groundwater samples were taken after three casing-volumes had been purged and field parameters (pH, EC and temperature) had stabilised. EC, temperature, pH and dissolved oxygen were measured using either a YSI Professional Plus or Hydrolab Quanta multi-parameter instrument. EC and pH was calibrated against standard solutions for a precision of ±0.5 % and ±0.1 units respectively. Dissolved oxygen was laboratory calibrated prior to each field trip to an accuracy of ±0.2 mg/L (<20mg/L) and ±0.6mg/L (>20mg/L). Alkalinity (CaCO3) was determined in the field using a Hach digital titrator and reagents with a relative precision of ±5 %. Cations were filtered through 0.45 µm cellulose nitrate filters and acidified with nitric acid to pH <2 then analysed at CSIRO Land & Water, Adelaide using a Varian Vista ICP-AES to a precision of ±2%. Anions were analysed on filtered un-acidified samples at CSIRO Land & Water, Adelaide using a Metrohm Ion Chromatograph to a precision of ±2%.

Stable isotope ratios ($\delta^{2}H$, $\delta^{18}O$) were measured at UC Davis Stable Isotope Facility (SIF) in California. The SIF provides simultaneous analysis of $^{18}O/^{16}O$ 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 ^{18}O and ≤0.8 permil for D/H. Final $^{18}O/^{16}O$ and D/H values are reported relative to VSMOW.

$\delta^{13}C$ and $\delta^{14}C$ were measured by Accelerator Mass Spectrometry (AMS) at the Rafter Radiocarbon Laboratory, GNS Science National Isotope Centre, Gracefield, New Zealand. Samples were submitted in white opaque plastic bottles tightly capped. CO2 was generated by phosphoric acid evolution and was converted to graphite by reduction with hydrogen over iron catalyst before analysis by AMS

$^{87}Sr/^{86}Sr$ ratios were measured at the University of Adelaide on a Finnigan MAT 262 thermal ionisation mass spectrometer in static mode. Sufficient water to yield 1–2 µg Sr was evaporated to dryness. The residue was dissolved in 2 ml of 6 M HCl, evaporated to dryness, and redissolved in 2 M HCl. Sr was extracted from centrifuged supernatant using cation exchange columns and Biorad AG50W X8 200–400 mesh resin. $^{88}Sr/^{86}Sr$ was normalized to 8.375209. $^{87}Sr/^{86}Sr$ ratios of silicate and carbonate minerals were measured using similar techniques. Analyses of SRM987 gave 87Sr/86Sr ratios of 0.710260 ±0.000009 (1σ).

H. Major ion composition 48-hour test data

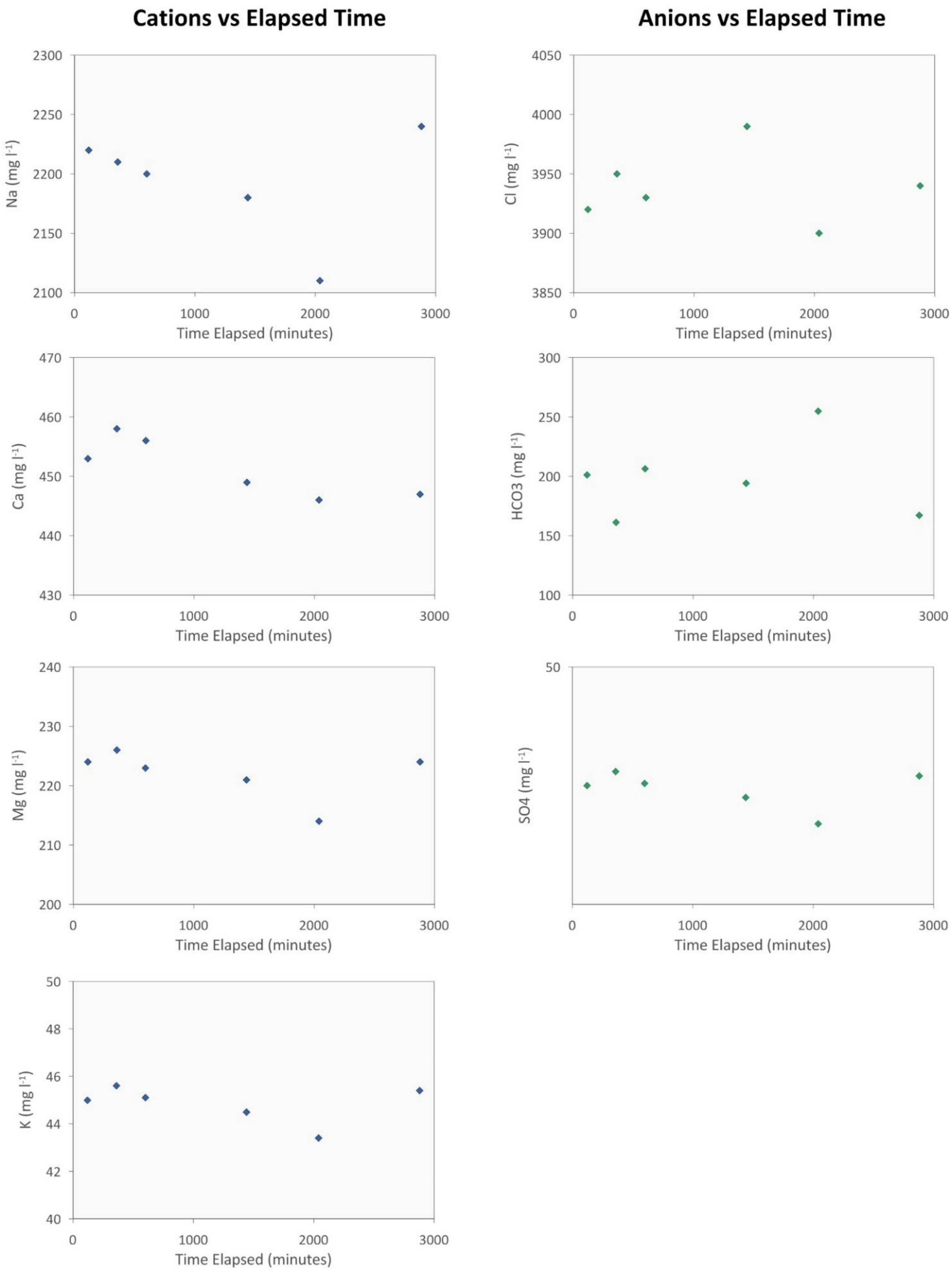

Figure 9-3 Major ion concentration over 48-hour Purni Formation pumping test

10 Units of measurement

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

Name of unit	Symbol	Definition in terms of other metric units	Quantity
day	d	24 h	time interval
gigalitre	GL	10^6 m^3	volume
gram	g	10^{-3} kg	mass
hectare	ha	10^4 m^2	area
hour	h	60 min	time interval
inch	In	base unit	length
kilogram	kg	base unit	mass
kilolitre	kL	1 m^3	volume
kilometre	km	10^3 m	length
litre	L	10^{-3} m^3	volume
megalitre	ML	10^3 m^3	volume
metre	m	base unit	length
microgram	µg	10^{-6} g	mass
microliter	µL	10^{-9} m^3	volume
milligram	mg	10^{-3} g	mass
millilitre	mL	10^{-6} m^3	volume
millimetre	mm	10^{-3} m	length
millivolt	mV	base unit	potential difference
minute	min	60 s	time interval
second	s	base unit	time interval
tonne	t	1000 kg	mass
year	y	365 or 366 days	time interval

1.1 Shortened forms

bgs	below ground surface
EC	electrical conductivity (mS/cm)
K	hydraulic conductivity (m/d)
K_H	horizontal hydraulic conductivity (m/d)
K_V	vertical hydraulic conductivity (m/d)
T	transmissivity (m^2/d)
S	storage coefficient (dimensionless)
pH	acidity
pmC	percent of modern carbon
^{14}C	Cabon-14
ORP	Oxidation Reduction Potential (mV)
DO	Dissolved Oxygen (mg/L)
mD	millidarcy (unit of permeability)

11 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 (**‰**)

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

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

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

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'

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 m^2/d or millidarcies

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

12 References

Audibert, M. 1973, Hydrogeological Study of the Great Artesian Basin. Bureau of Mineral Resources, Australia Record 1973/174, p. 32-35.

Ambrose, G.J. and Heugh, J. 2012, The Geology of the Pedirka Basin Coal Measures in The Purni Formation, Simpson Desert Area. Central Australian Basin Symposium III, Special Publication 2. Alice Springs, 16-17 July, 2012. Petroleum Exploration Society of Australia.

Berry, K.A. and Armstrong, D., 1995, Olympic Dam Operations hydrogeological investigation and numerical modelling Lake Eyre region, Great Artesian Basin. Report HYD T044, Western Mining Corporation Limited.

Carman, P.C. 1956, Flow of gases through porous media. Butterworths, London.

Carman, P.C. 1937, Fluid flow through granular beds. Transactions, Institution of Chemical Engineers, London, 15: 150-166.

Central Petroleum. 2010, CBM 107-002 Well Completion Report Basic Data EP 107, Pedirka Basin Northern Territory. Central petroleum Ltd, Northern Territory Geological Survey, Open File Petroleum Report PR2009-0226.

Clark, I & Fritz, P 1997, Environmental Isotopes in Hydrogeology, Lewis Publishers, Boca Raton, Florida.

Commonwealth of Australia. 2014. Aquifer connectivity within the Great Artesian Basin, and the Surat, Bowen and Galilee Basins, Background review, Commonwealth of Australia 2014, Canberra.

Davis, S. N., Whittemore, D. O. and Fabryka-Martin, J. 1998, Use of Chloride/Bromide Ratios in Studies of Potable Water. Groundwater, 36 (2), Pages 338–350.

Fetter, C. W. 1986, Applied Hydrogeology (3rd Ed). Prentice Hall, New Jersey.

Fontes, J.-Ch. and Garnier, J-M. 1979, Determination of the initial ^{14}C activity of total dissolved carbon: A review of existing models and a new approach. *Water Resources Research,* 15: 399-413

Fulton S. A. 2012, Technical Report Great Artesian Basin Resource Assessment, Department of Land Resource Management, Report 14/2012A, Darwin, October 2012

Fulton, S. A. 2013, Northern Territory Great Artesian Basin Investigations Fieldwork Completion Report. Department of Land Resource Management Unpublished Report.

Hemker, C. J. 1999a, Transient well flow in layered aquifer systems: the uniform well-face drawdown solution, Journal of Hydrology, Volume 225, Issues 1–2, 22 November 1999, Pages 19-44, ISSN 0022-1694,

Hemker, C. J. 1999b, Transient well flow in vertically heterogeneous aquifers, Journal of Hydrology, Volume 225, Issues 1–2, 22 November 1999, Pages 1-18, ISSN 0022-1694

Hemker, C. J., Maas C. 1987, Unsteady flow to wells in layered and fissured aquifer systems, Journal of Hydrology, Volume 90, Issues 3–4, 15 April 1987, Pages 231-249, ISSN 0022-1694.

Herczeg, A. L., Torgersen, T., Chivas, A.R. and Habermehl, M.A. 1991, Geochemistry of ground waters from the Great Artesian Basin, Australia, Journal of Hydrology, 126, 225-245.

Hounslow, A. W. 1995, Water Quality Data; analysis and interpretation, CRC Press, Florida, USA

Hydrosolve 2006, AQTESOLV® for Windows Version 4.01 – Professional, Hydrosolve Inc.

IESC, 2014, Aquifer connectivity within the Great Artesian Basin, and the Surat, Bowen and Galilee Basins, Background review. Commonwealth of Australia 2014. www.iesc.environment.gov.au

Ingerson, E. and Pearson, F. J. 1964. Estimate of Age and rate of motion of groundwater by the ^{14}C-method. In Recent Researches in the Field of Hydrosphere, Atmosphere and Nuclear Geochemistry, ed. Y Miyake T. Koyama, 263-268. Tokyo.

Kalin, R. M. 1999, 'Radiocarbon dating of groundwater systems', in: Cook, P, Herczeg & AL (eds), Environmental tracers in subsurface hydrology, Kluwer Academic Publishers, Emeryville, California, pp. 111–144.

Kellett, J., Veitch, S., McNaught, I. and van der Voort, A. 1999, Hydrogeological Assessment of a Region in Central Northern South Australia, BRS Australia, Canberra.

Keppel et al. (eds) 2013, Allocating Water and Maintaining Springs in the Great Artesian Basin, Volume I: Hydrogeological Framework of the Western Great Artesian Basin, National Water Commission, Canberra.

Kozeny, J. 1927, Ueber kapillare Leitung des Wassers im Boden. Sitzungsber Akad. Wiss., Wien, 136(2a): 271-306.

Kruseman, G. G., de Ridder, N. A. 1994, Analysis and Evaluation of Pumping Test Data (2nd Edition). International Institute of Land Reclamation and Improvement. ILRI Publication 47, Amsterdam.

Lau, J.E., Jacobson, G. 1991, Aquifer characteristics and groundwater resources of the Amadeus Basin. In Korsch, R. J. and Kennard J. M. (eds) Geological and geophysical studies in the Amadeus Basin, central Australia. Bureau of Mineral Resources, Australia. Bulletin 236 P 563–576

Love, A., Shand, P., Crossey, L., Harrington, G.A., Rousseau-Gueutin, P. 2013 a, Allocating Water and Maintaining Springs in the Great Artesian Basin, Volume III: Groundwater Discharge of the Western Great Artesian Basin, National Water Commission, Canberra.

Love, A., Wohling, D., Fulton, S., Rousseau-Gueutin, P. and De Ritter, S. 2013 b, Allocating Water and Maintaining Springs in the Great Artesian Basin, Volume II: Groundwater Recharge, Hydrodynamics and Hydrochemistry of the Western Great Artesian Basin, National Water Commission, Canberra.

McCormac, FG, Hogg, AG, Blackwell, PG, Buck, CE, Higham, TFG & Reimer, PJ 2004, 'SHCal04 Southern Hemisphere calibration, 0-11.0 cal kyr BP', Radiocarbon, vol. 46(3), pp. 1087–1092.

Munson, T.J. and Ahmad, M., 2012, Chapter 38: Pedirka Basin. In: Ahmad, M. and Munson, T.J. (in prep.) Geology and mineral resources of the Northern Territory. NTGS. Spec. Pub. 5.

National Uniform Drillers Licensing Committee, 2012, Minimum Construction Requirements for Water Bores in Australia 3rd edition, National Water Commission's Raising National Water Standards Program.

Peat, V. and Yan, W., 2015, Pedirka Basin Numerical Groundwater Model 2014, DEWNR Technical Report 2014/04, Government of South Australia, through Department of Environment, Water and Natural Resources, Adelaide.

Post, V., H. Kooi, and C.T. Simmons, 2007, 'Using Hydraulic Head Measurements in Variable-Density Ground Water Flow Analyses.' Ground Water 45(6): 664-671.

Radke, B. M., Ferguson, J., Cresswell, R. G., Ransley, T. R., and Habermehl, M. A. 2000, Hydrochemistry and Implied Hydrodynamics of the Cadna-owie - Hooray Aquifer, Great Artesian Basin, Australia. Bureau of Rural Sciences, Canberra.

Sampson, L., Wohling, D., Jensen-Schmidt, B and Fulton, S. 2012, South Australian and Northern Territory Great Artesian Basin (Eromanga Basin) Hydrogeological Map. Department of Environment, Water and Natural Resources, South Australian Government.

Sampson, L., Wohling, D., Fulton, S., Jensen-Schmidt, B., Keppel, M. and Costar, A. 2013. South Australia and Northern Territory Pedirka Basin Hydrogeological Map – Part 1 & Part 2. Department of Environment, Water and Natural Resources, South Australian Government.

Smerdon, B.D., Welsh, W.D. and Ransley, T.R. (eds) 2012. Water resource assessment for the Western Eromanga Region. A report to the Australian Government from the CSIRO Great Artesian Basin Water Resource Assessment. CSIRO Water for a Healthy Country Flagship, Australia.

Stuiver, M & Polach, HA 1977, 'Discussion: Reporting of C data', Radiocarbon, vol. 19, pp.355–363.

Tamers, M. A. 1975. The validity of radiocarbon dates on groundwater. Geophysical Survey, 2, 217-239.

Theis, C.V. (1935). The relation between the lowering of the piezometric surface and the rate and duration of discharge of a well using groundwater storage, Am. Geophys. Union Trans., vol. 16, pp. 519-524.

Todd, D. K. 1959. Ground Water Hydrology. Wiley and Sons International, New York.

Wohling, D., Keppel, M., Fulton, S. and Costar, A. 2013, Australian Government Initiative on Coal Seam Gas and Large Coal Mining – Arckaringa Basin and Pedirka Basin Groundwater Assessment Projects, DEWNR Technical Report 2013/11, Government of South Australia, through Department of Environment, Water and Natural Resources, Adelaide

Youngs B. C. 1975. The Early Permian Purni Formation of the Pedirka Basin. Geological Survey of South Australia, Quarterly Geological Notes 54, 5–12.

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