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Investigations of the potential for irrigated agriculture on the Bonaparte Plains: bore completion report, 2nd edition

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WESTERN AUSTRALIA

Investigations of the potential for irrigated agriculture on the Bonaparte Plains

Bore completion report

Second edition

Resource management technical report 414

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Cover: 2017 drilling operations on the Bonaparte Plains (photo: D Bennett)

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Preface

A study of the palynomorphs present within select drill cutting samples was completed in January 2019. Based on the results of this study, the second edition of this report contains revisions to the geological formation nomenclature and the palynology results. This edition replaces *Resource management technical report 409*.

Acknowledgements

This drilling program was made possible by Royalties for Regions. It was conducted by the Department of Primary Industries and Regional Development, Western Australia (DPIRD) through the *Implementing Bonaparte Plains project*.

Carlton Hill Station's manager Glen Brooker and his staff, and elders representing the Miriuwung Gajerrong Corporation (as the traditional owners), all provided valuable local knowledge and access to the area.

Drilling was undertaken in several stages:

- in 2013 by Direct Drilling Australia Wide Pty Ltd
- in 2016 by the former Department of Agriculture and Food Western Australia (now DPIRD)
- in 2017 by the Water Resources Section of the Northern Territory Department of Environment and Natural Resources.

Andrew 'Wilko' Wilkinson from Fysh Grader Hire provided experience, local knowledge and advice that was extremely valuable for planning access. Wilko also worked tirelessly and 'beyond the call of duty' on many occasions, to expertly refurbish tracks and support the access required for heavy drilling equipment.

Surveying was undertaken by Survey North in 2013. Tim Pope (DPIRD) worked tirelessly and cheerfully, often under very difficult conditions, to survey the locations of the 2016 and 2017 bores, plus other bores and groundwater discharge swamps in the wider investigation area.

Alastair Hoare and Scott Macaulay (Department of Water and Environmental Regulation) provided valuable input for the design of the 2017 drilling program.

Staff at Geoscience Australia provided the airborne electromagnetic (AEM) survey results and advice on AEM and geological interpretation.

Special thanks to Bob Paul for supervising the drilling of two holes at short notice.

DPIRD staff at the Frank Wise Institute of Tropical Agriculture provided guidance, logistical assistance and technical support, in particular Noel Wilson, Mark Warmington, Gerard Morgan, Shayne Cullimore and Lorraine Hartle.

Thank you to Arthur Mory (Geological Survey of Western Australia) for organising the palynology study and John Backhouse (Backhouse Biostrat Pty Ltd) for undertaking and reporting the palynology analysis.

Appreciation is gratefully extended to Penny Wallace-Bell for her technical review of the first edition, and to Angela Rogerson for the final edit of the second edition.

Summary

Drilling programs were undertaken in 2013 and 2016 by the former Department of Agriculture and Food, Western Australia and in 2017 by DPIRD, at 10 sites in the Bonaparte Plains area, north of Kununurra in the East Kimberley region of Western Australia (WA).

These drilling programs were a component of resource availability and risk investigations conducted to determine the potential for developing irrigated agriculture on 30 000 hectares (ha) of Cockatoo Sands — free-draining loamy soils that have the potential to support crops in the wet and dry seasons. There was limited hydrogeological information available at a suitable scale for the area. The drilling programs provided hydrogeological information for the underlying aquifer and included installing monitoring and test-pumping bores to help determine the potential for groundwater supply and development risks in the area.

Drilling occurred within the mid to late Carboniferous Point Spring Sandstone Formation at most sites, with depth ranging from 4 to 172 metres (m). Deep test-pumping bores were also installed at three sites.

Drill sites were mainly within the mapped area of Cockatoo Sands soils. Site selection and target depth was determined via:

- evaluation of available mineral and oil exploration reports
- field investigation of outcrop and groundwater discharge areas
- products derived from a preliminary inversion of an AEM survey
- the need for better spatial coverage for aquifer data collection and monitoring.

Site selection was somewhat constrained by access limitations and was guided by the location of conservation reserves, and heritage information provided by traditional owners and from the *Aboriginal Heritage Inquiry System*.

This edition provides bore completion details of the drilling programs undertaken in 2013, 2016 and 2017 on the Bonaparte Plains in the context of local and regional geology and hydrogeology. The results of subsequent water level monitoring, geochemical and isotopic sampling, test pumping and numerical water balance modelling undertaken within the Bonaparte Plains area are in separate reports.

This edition also contains the results of palynology analysis on select drill cutting samples undertaken by John Backhouse (Backhouse Biostrat Pty Ltd) for the Geological Survey of Western Australia in January 2019. Based on this study, the geological formation nomenclature in the first edition has been revised.

1 Introduction

Expanding irrigated agriculture within WA is a priority for the Western Australian Government, with the goal of doubling production of food supplies for local and export purposes by 2025. The *Implementing Bonaparte Plains project* is the second stage of the Cockatoo Sands investigations, following investigation of the Victoria Highway and Carlton Hill areas of Cockatoo Sands near Kununurra (stage one). It is a land and water assessment and a risk assessment aimed at investigating the potential for developing irrigated agriculture on the loamy sands (Cockatoo Sands) of the East Kimberley. Developing these areas with irrigated agriculture could potentially double the area of land suitable for production within 50 to 100 kilometres (km) of the Ord River Irrigation Area (Figure 1.1).

The need for scale is the biggest factor in providing investment opportunities to grow the north into a resilient and productive agricultural region (Department of Regional Development and Lands 2009). Importantly, Cockatoo Sands are free-draining loamy soils that have the potential to support crops in the wet and dry seasons. Baseline conditions, irrigation suitability, and prefeasibility engineering and power requirements were assessed for about 8000ha of suitable Cockatoo Sands soils (Bennett et al. 2015, Bennett et al. 2016, Smolinski et al. 2015). DPIRD is working with the local industry and the Miriuwung Gajerrong Corporation to enable development of the Victoria Highway and Carlton Hill areas of Cockatoo Sands near Kununurra (Figure 1.1).

An additional 30 000ha of Cockatoo Sands lie to the north of Kununurra on the Bonaparte Plains — the subject land for this third stage project. Smolinski et al. (2010) first assessed the potential of this land during a broad reconnaissance soil survey. A more-detailed soil survey has since been completed (Smolinski 2019) confirming the scale and suitability of the soils in the Bonaparte Plains area.

However, because of the Bonaparte Plains' landform and distance from the Ord River Dam, irrigation water for any development here would need to come from groundwater or other sources nearby. Therefore, an important component of the *Implementing Bonaparte Plains project* was to undertake investigative drilling and to install monitoring and test-pumping bores to help determine the potential for groundwater supply and development risks in the area.

To do this, we initially undertook a desktop review and field reconnaissance of existing bores, mineral exploration drilling, outcrop geology and groundwater outcrop within the area in early 2013. We discovered that the available information for Cockatoo Sands area was not at a suitable scale. Using the limited budget we had in 2013, we undertook exploratory drilling to determine if there were groundwater resources in the Kulshill Group and Weaber Group sandstones (Mory & Beere 1988) beneath the Cockatoo Sands, and if further investigation was warranted. We constructed nested deep monitoring bores and a test-pumping bore at site 13BP01, in the geographical centre of the Bonaparte Plains area of Cockatoo Sands. The results of combined step and constant low-rate (2.9 litres per second (L/s)) test pumping of the bore indicated that the apparent long-term (20 year) safe yield could be up to 25L/s.

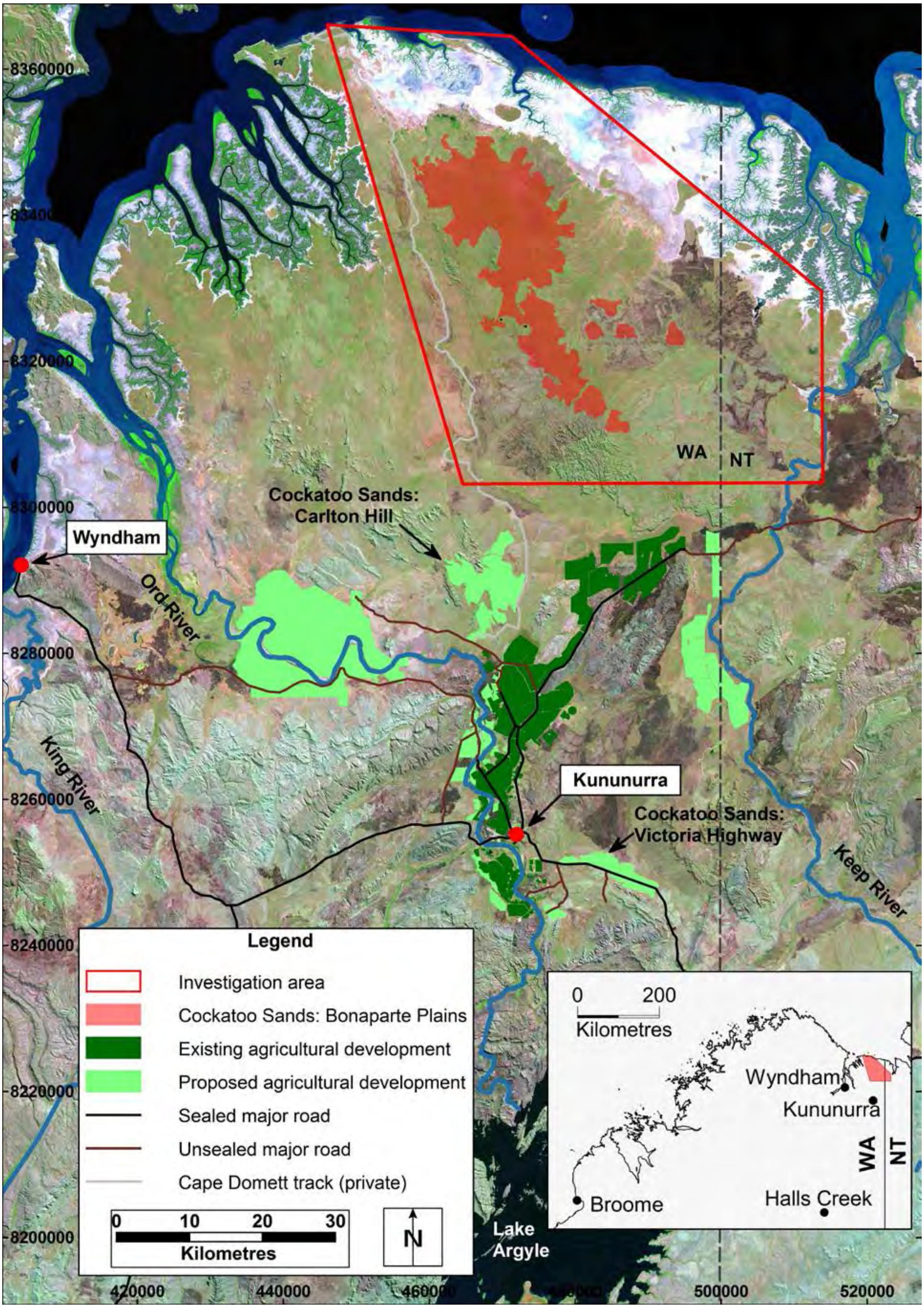


Figure 1.1 Major geographical features and existing and proposed agricultural developments near the Bonaparte Plains project area

During 2015 and 2016, a more intensive census was undertaken on operating and abandoned bores providing water to livestock, cased mineral exploration holes and groundwater outcrops in the area. An AEM survey (SkyTEM312 system) of the area was completed in December 2015, with some interpretation products of an initial AEM data inversion provided by Geoscience Australia in March 2016 (Symington et al. 2016).

Coinciding with the detailed field soil investigation undertaken in 2016, shallow bores were installed at two sites (16BP02 and 16BP03) using a small auger-drilling rig that was mounted to a four-wheel drive. Each site was near a perched lake with high-value cultural significance to the Garralyel of the Miriuwung Gajerrong traditional owners. The 2016 drilling focused on intersecting any shallow groundwater and perched layers associated with the lakes. The bores provided monitoring points to allow collection of data on the seasonal dynamics of shallow groundwater levels near the lakes.

We used information from the 2013 drilling, the bore census and the AEM to plan the 2017 drilling program. The eight sites were selected to provide better spatial characterisation and geometry of the aquifer within the Wadeye and Kulshill Group sandstones above a shale marker (identified at site 13BP01 and spatially from the AEM results) underlying the Cockatoo Sands. Site selection was guided by the location of conservation reserves, and heritage information provided by traditional owners and from the *Aboriginal Heritage Inquiry System*. We were also somewhat constrained by our ability to gain access.

Planning for the 2017 drill intersections and bore construction was based on:

- lithology and groundwater level data from site 13BP01
- information from existing bores mainly located around the margins of the study area
- preliminary inversions from the AEM survey.

Geoscience Australia completed a second AEM inversion in March 2018.

During the 2017 drilling program, we installed monitoring bores at seven sites in the lower layers of the aquifer. At five of these sites, where there was sufficient aquifer thickness, an adjacent shallow bore was installed so that piezometric pressure, isotopes and other geochemical attributes could be obtained from the top of the aquifer. These readings could then be compared to those obtained at depth to estimate recharge rates. To allow higher rate test pumping of the aquifer, test-pumping bores were installed at sites 17BP01 and 17BP05 in 2017 (in addition to the test-pumping bore installed site 13BP01 in 2013). We originally planned for an eighth site, located just inside the Northern Territory, but it was not drilled because of time and budget constraints.

This report summarises the results of the drilling programs undertaken in 2013, 2016 and 2017. Results of subsequent groundwater level monitoring, geochemical and isotopic sampling and analysis, test pumping and water balance modelling activities are reported separately, as is information about available groundwater resources and risks associated with agricultural development on the Bonaparte Plains.

This edition also contains the results of palynology analysis on select drill cutting samples undertaken by John Backhouse (Backhouse Biostrat Pty Ltd) for the Geological Survey of Western Australia in January 2019. Based on these palynology results, the geological formation nomenclature in the first edition has been revised.

2 Location

The Bonaparte Plains project area is located in the north-east Kimberley region of WA, about 2300km north of Perth. It covers the central part of a peninsula that extends northwards into the Joseph Bonaparte Gulf and is bordered by the Keep River Estuary to the east, the Cambridge Gulf to the west and the Weaber Range to the south.

The project area is about 2600 square kilometres (km^2) and its centre is about 80km north of Kununurra, the closest town. It is within the Carlton Hill Station pastoral lease. For groundwater allocation purposes, the area lies wholly within the extensive Canning–Kimberley groundwater area.

Extensive conservation reserves cover the Weaber Range to the south and the Ningbing Range to the west (Figure 2.1). Extensive Aboriginal heritage listed areas cover and surround the conservation reserves. North of the project area, there is also a large heritage area along the tidal mudflat margin. Some of the listed heritage areas — such as the areas surrounding the two perched lakes encompassing sites 16BP02 and 16BP03 — have the highest classification of heritage protection.

A formalised and extensive consultation process, managed through the Miriuwung Gajerrong Corporation, was conducted with the traditional owners to define areas where drilling or other ground-disturbing activities could occur and to specify special considerations for access. Strict conditions were applied to entering the heritage areas surrounding the perched lakes and for drilling at sites 16BP02 and 16BP03 (Figure 2.1). These sites should not be visited without prior permission from the traditional owners.

The 2013, 2016 and 2017 drilling sites are mainly located on the Cockatoo Sands soils, in the central part of the project area. This is because, during the bore census, we identified very few existing bores or exploration holes from which useful groundwater information could be obtained. Most of the existing sites were located around the edge of the Cockatoo Sands, or remote from it (see Figure 2.1 and Appendix A).

The general area can be accessed via the Cape Domett track, which starts from Carlton Hill Road and traverses north along the eastern edge of the Ningbing Range (and along the western edge of the project area) to Cape Domett. This track is often in poor condition, depending upon seasonal conditions and maintenance schedules. It is a privately owned track and prior permission needs to be obtained from Carlton Hill Station before travelling along it.

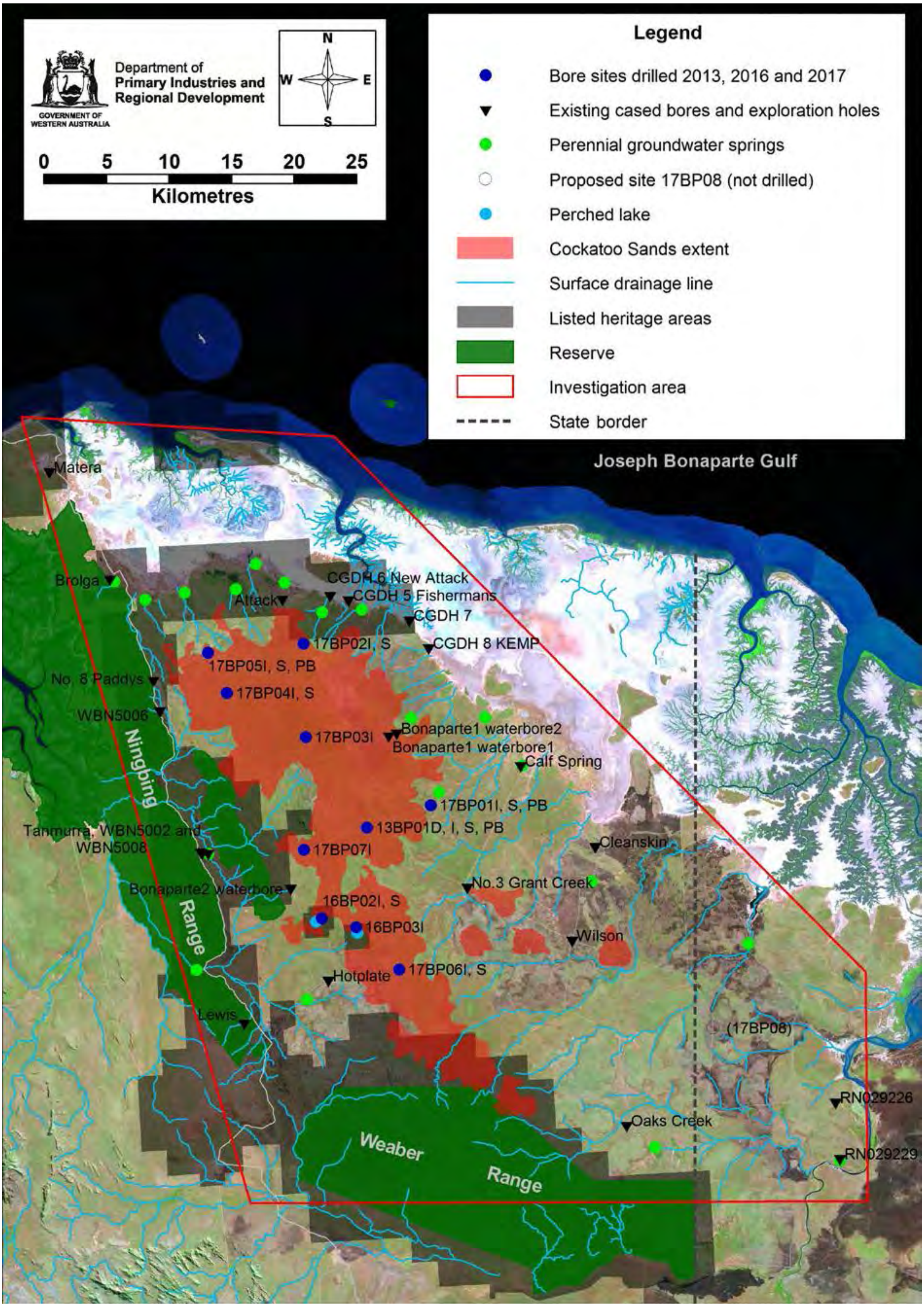


Figure 2.1 Location of bores drilled in 2013, 2016 and 2017 in relation to existing bores, the area of Cockatoo Sands and other natural features

3 Geology and hydrogeology

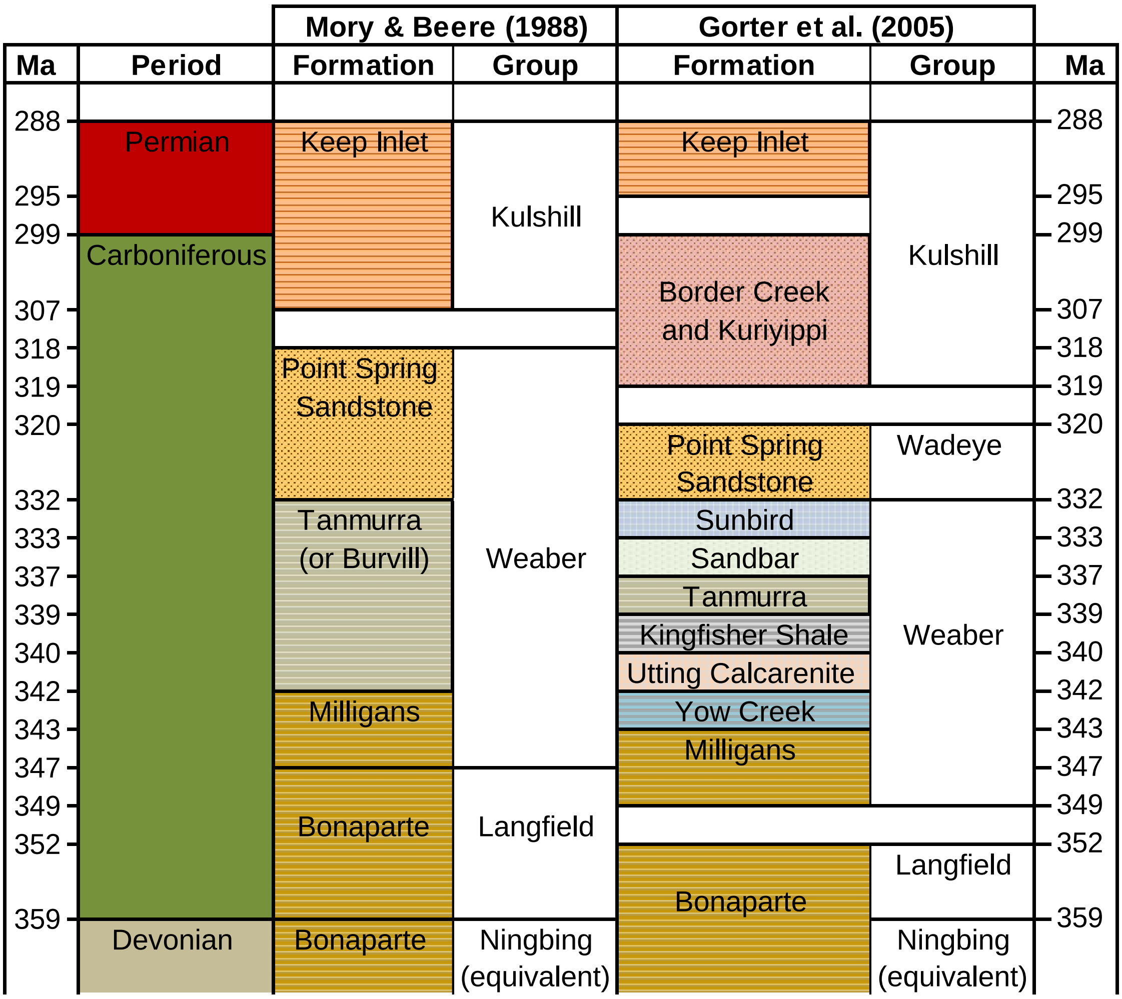
The geology within the investigation area is complex and has not been very well defined spatially at the relatively shallow depth of this drilling investigation. Mory and Beere (1988) provide the most comprehensive published mapping and description of the geology of the onshore portion of the Bonaparte Basin. The following overview mainly focuses on published information relevant to the hydrogeology of the Kulshill and Weaber Group sandstones (Mory & Beere 1988) and the major underlying and overlying lithostratigraphic units within the Bonaparte Plains investigation area.

Gorter et al. (2005) reappraised Mory and Beere’s (1988) stratigraphy of the Carboniferous formations of the south-eastern Bonaparte Basin using existing oil well logs, seismic profiles and palaeontological information. They describe several new formations within those described by Mory and Beere and assign different age ranges to some of Mory and Beere’s formation boundaries.

Figure 3.1 shows a generalised comparison (adapted from information also provided by D Cathro [Geoscience Australia] 2018, pers. comm. 20 May) between the Mory and Beere (1988) and the Gorter et al. (2005) lithostratigraphic interpretations of Carboniferous and Permian sediments within the investigation area.

Direct comparison of the depth relationships between the lithostratigraphy of Mory and Beere (1988) and Gorter et al. (2005) can only be made at one onshore oil well — Bonaparte1 — in the centre of the investigation area. Here, the depths at which both papers determined formation boundaries are consistent (Figure 3.2). However, within Mory and Beere’s (1988) boundaries, Gorter et al. (2005) did the following as shown in Figure 3.2:

- reassigned the interval 0–194m from the Keep Inlet Formation to the Kuriyippi Formation
- subdivided the Tanmurra Formation (194–497m) into the Sunbird (new) and Tanmurra formations
- subdivided the 1783m thick Milligans Formation into five new shale and calcareous formations.



Ma = million years before present

Figure 3.1 Generalised comparison of identified lithostratigraphic formations in the Petrel Sub-basin

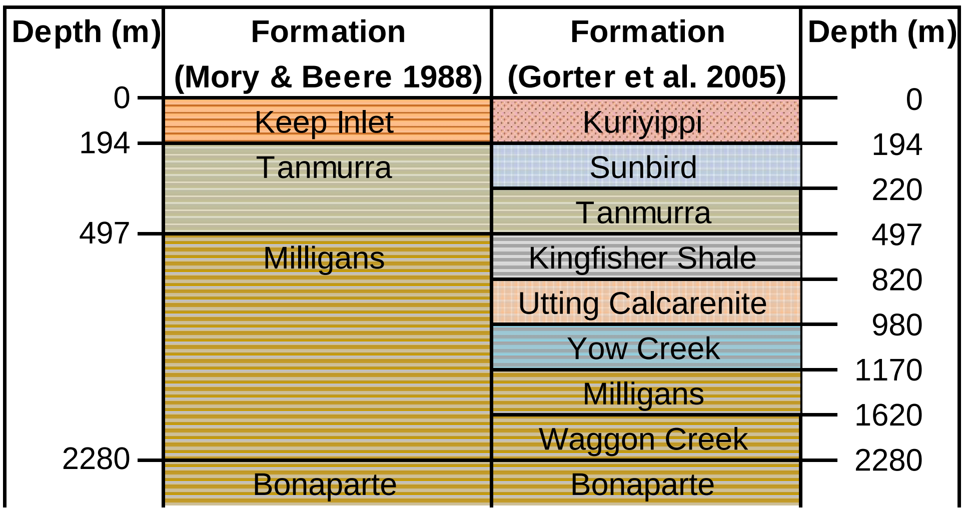


Figure 3.2 Depth-related comparison between formations assigned by Gorter et al. (2005) and Mory and Beere (1988) at Bonaparte1 oil well

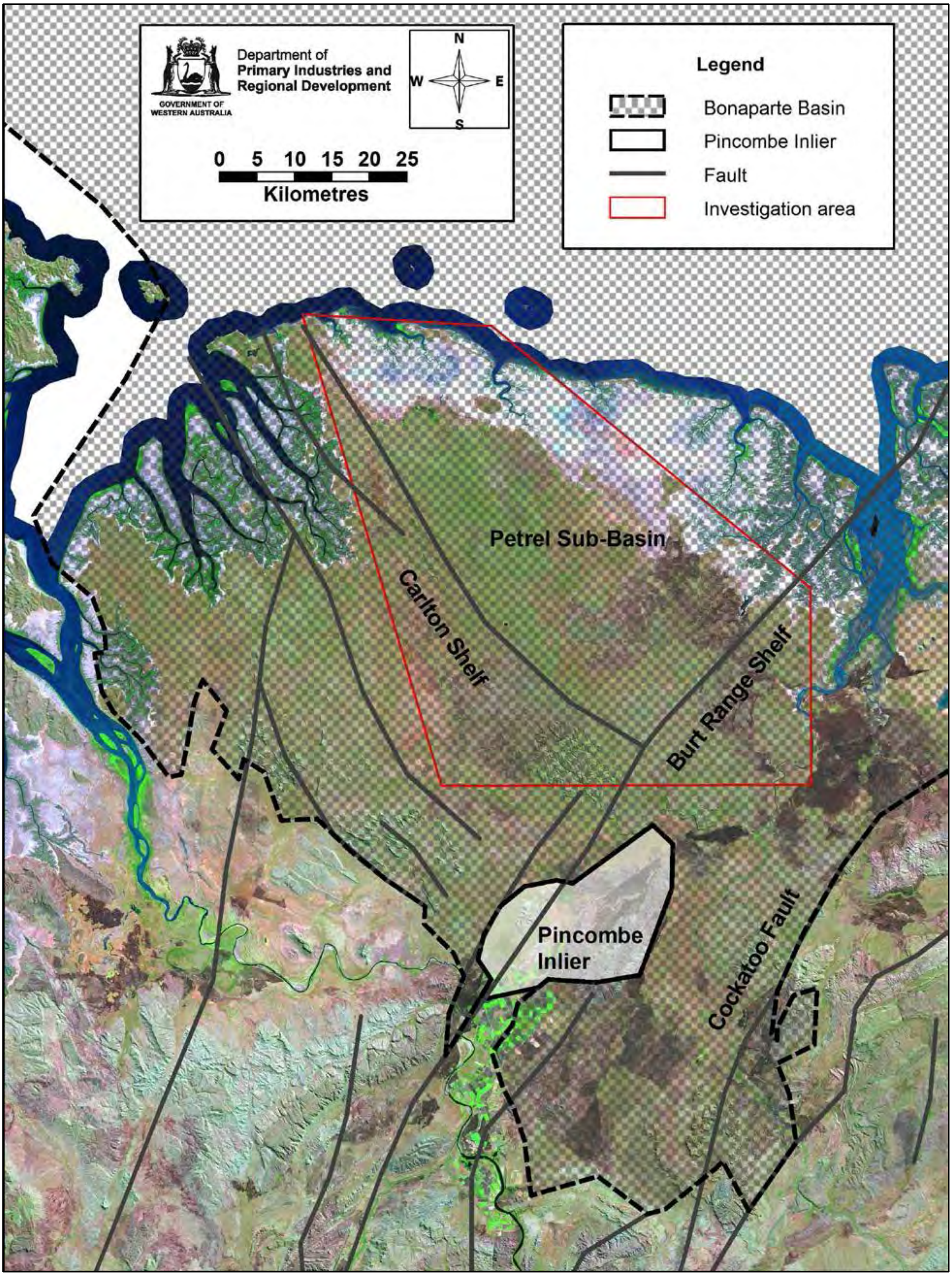
3.1 Regional setting

The Bonaparte Basin covers 270 000km^2, with the onshore WA portion covering 8000km^2. The Bonaparte Basin contains moderate economic hydrocarbon accumulations onshore, where two gas flows and numerous bitumen shows are recorded (Geological Survey of Western Australia 2011). There have also been some base metal deposits discovered, such as the carbonate-hosted silver–lead–zinc deposit at Sorby Hills. Diamonds derived from the Argyle kimberlite pipe, which intrudes Proterozoic sediments south of the Ragged Range Outlier, are found in Cainozoic gravels in adjacent parts of the Bonaparte Basin.

The Bonaparte Basin contains a sedimentary succession that regionally dips to the north, with the oldest strata outcropping in the south. The Carlton and Burt Range Shelves and the Precambrian Pincombe Inlier occupy the southern margin. The Carlton and Burt Range Shelves deepen to the north into the Petrel Sub-basin, which extends offshore from the approximate intersection of the Ningbing Range to the west and the Weaber Range to the south (Figure 3.3). The Petrel Sub-basin makes up most of the onshore Bonaparte Basin and the majority of the area is overlain by Cockatoo Sands, as mapped by Smolinski (2019).

During the early to late Carboniferous period, the Weaber Group sediments were deposited in offshore to fluvial environments as a deltaic base-fill sequence on the Carlton and Burt Range Shelves and in the Petrel Sub-basin. They unconformably overlie older faulted and folded sediments that had been eroded as a result of uplift along the margins of the Bonaparte Basin. The Weaber Group sediments range in thickness from 600m on the onshore shelves to 2400m in the offshore Petrel Sub-basin.

Broad folding of the Weaber and basal Kulshill Group sediments occurred prior to the deposition of glacial, continental and shallow marine sediments of the Keep Inlet Formation (upper Kulshill Group) during the late Carboniferous and Permian periods. This occurred in response to movements along the regional Cockatoo Fault, which lies to the east of the Keep River and trends from the north-east to the south-west.



Source: Mory and Beere (1988)

Figure 3.3 Location of the Bonaparte Basin, its subdivisions and major faults in relation to the investigation area

3.2 Summary lithology of the major lithostratigraphical units

While Gorter et al. (2005) provide lithostratigraphic re-interpretations for most oil wells drilled within the Bonaparte Basin, they do not map outcrop. In contrast, Mory and Beere (1988) mapped, described and named much of the available outcrop relevant to the scale and depth of our investigation targets. The differences in lithostratigraphic interpretations and naming conventions between the two reports has remained a source of uncertainty, particularly at the shallow depths of our investigation, and is the subject of ongoing investigation (A Mory [Geological Survey of Western Australia] 2018, pers. comm., 25 October).

There are many similarities between Mory and Beere’s lithological descriptions of outcrop and our lithological descriptions of the profiles encountered during our drilling program (see Chapter 5). Also, the results of the analysis of palynology of our drilling samples (see Chapter 4.5) are consistent with Mory and Beere’s stratigraphy for the upper geological formations. Therefore, in this report we have adopted Mory and Beere’s (1988) stratigraphic nomenclature for the formations that were drilled.

The spatial relationships of upper solid geology were also adapted from the Mory and Beere (1988) mapping, the only available map source (Figure 3.4). In this figure, only the major sedimentary units proximal to the aquifer within the Point Spring Sandstone Formation are labelled, with their likely corresponding classifications from Gorter et al. (2005) shown in parentheses.

3.2.1 Weaber Group formations

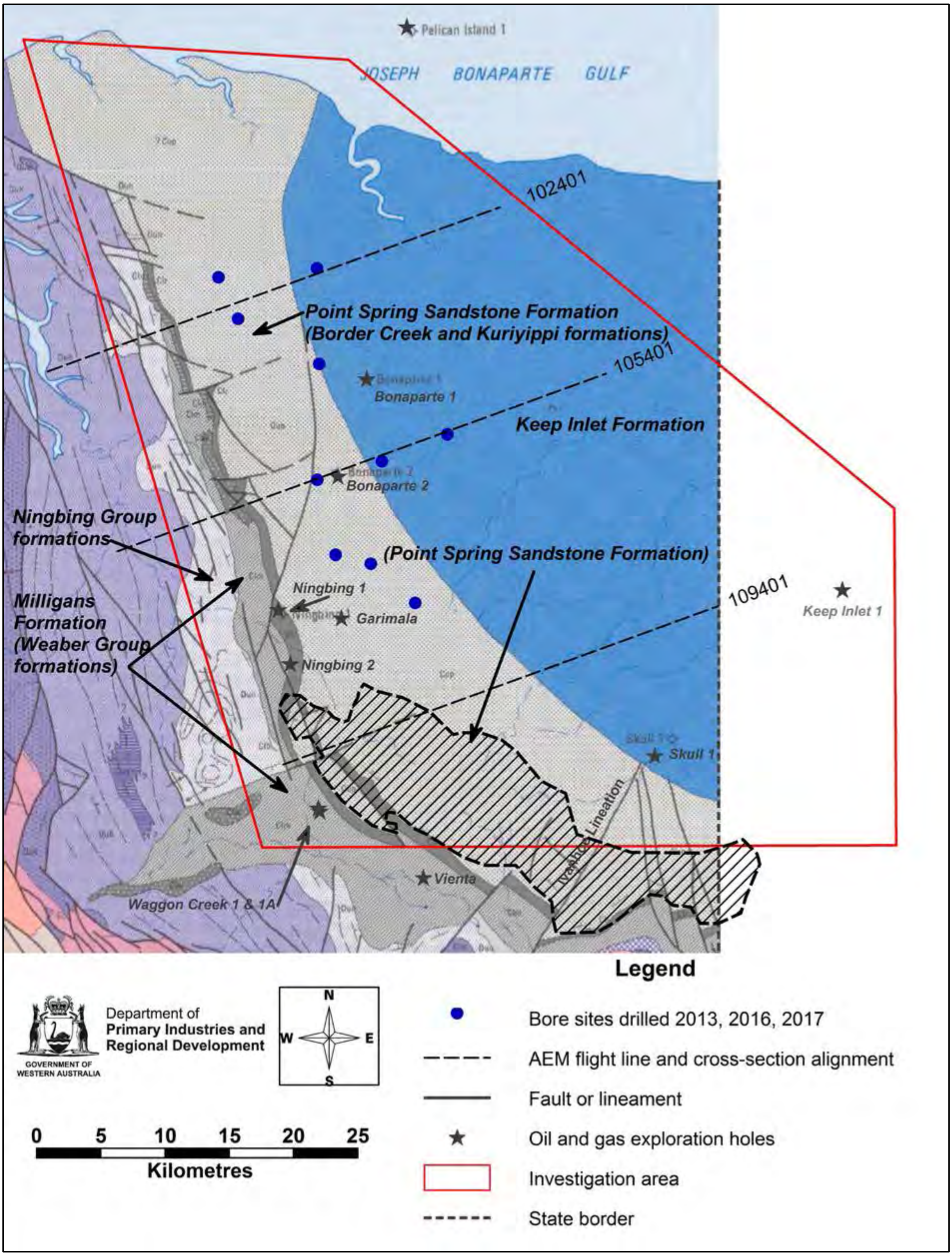
The shale-dominated Milligans, Yow Creek and Kingfisher formations within the Weaber Group form an impermeable boundary along the Ningbing Range to the west where they subcrop (Figure 3.4). Elsewhere onshore, the carbonaceous and sandy siltstones of the Sunbird and Tanmurra formations lie above the older shale units of the Weaber Group as it dips towards the north and the east.

Limestones and other carbonates of the Ningbing Group underlie the Milligans Formation and outcrop to form the Ningbing Range to the west of the Weaber Group subcrop.

3.2.2 Sunbird and Tanmurra formations

The Sunbird Formation consists of a massive, recrystallised, oolitic limestone that grades to grainstone and packstone. Locally, the matrix can also consist of white clay. The Sunbird Formation is thought to have been deposited in a relatively agitated shallow, probably shelfal, environment.

The Tanmurra Formation consists of calcareous and dolomitic sandstone with significant calcareous re-cementation plus siltstone, shale, minor limestone. The Tanmurra Formation is thought to have been deposited as shelf carbonates, although the large clastic component observed in current onshore locations may indicate a deltaic depositional environment.



Note: Only the major sedimentary units proximal to the aquifer within the Point Spring Sandstone Formation are labelled. Labels in parentheses show the likely corresponding classification of Gorter et al. (2005).

Source of geology information: Mory and Beere (1988)

Figure 3.4 Solid geology map for the Bonaparte Plains project area

At the time of publication it was not possible to distinguish between the Tanmurra and Sunbird formations by palynology or lithology. Therefore, they have been named the Sunbird/Tanmurra Formation throughout this report. A subsequent drilling program being undertaken at sites 13BP01, 17BP01 and 17BP07 by Geoscience Australia during 2018 — which includes the collection of intact cores from selected intervals — may provide additional information to enable these formations to be distinguished within the profile at these sites.

3.2.3 Point Spring Sandstone Formation

The Point Spring Sandstone Formation consists of fine to coarse sandstone and pebbly sandstone with minor and siltstone and shale. Its occurrence appears to be largely restricted to outcrops throughout the Weaber Range where it is generally very well consolidated. Mory and Beere (1988) indicate that the Point Spring Sandstone Formation extends northwards from the Weaber Range, almost to the mudflats (Figure 3.4).

Mory and Beere (1988) identify the Border Creek Member within the Point Spring Sandstone Formation and map its outcrop in several locations within the investigation area, including a relatively large area of hard rock located between bore sites 17BP03I and 17BP07I, near the centre of the investigation area.

The sandstones within the Border Creek Member are texturally similar to those of the Point Spring Sandstone Formation. However, the Border Creek Formation also contains thick sequences of conglomerate, siltstone, silty sandstone and pebbly quartz sandstone. Mory and Beere describe the conglomerate as consisting of pebbles, cobbles and boulders of well-rounded quartzite.

Most of the sites we drilled contained beds of pebble and cobble-sized rounded quartzite. At several surface locations within or adjacent to the areas Cockatoo Sands we observed remnant beds consisting of unconsolidated cobbles and boulders of quartzite. We speculate that Border Creek Member sandstones are present in most of the profiles that were drilled and underlay much of the Cockatoo Sands area.

3.2.4 Keep Inlet Formation

From the late Carboniferous to Permian period, the Keep Inlet Formation consists of sandstone, mudstone and shale-dominated units, plus minor conglomerate, which were deposited in continental, shallow marine and glaciomarine environments.

Onshore, the Keep Inlet Formation unconformably laps onto the Point Spring Sandstone Formation, thickening to the east where it is up to 480m thick. However, based on our drilling and the upper lithology described at Bonaparte1 oil well, the actual location of the margin is likely to be parallel to though further east of the position indicated by Mory and Beere (1988) in Figure 3.4.

The Keep Inlet Formation extends under the tidal mudflats to the north and east of Bonaparte Plains. Coal exploration drilling, undertaken around the inland margin of the mudflats (Williams 1982), shows that mudstone, shale, sandstone and minor coal beds comprise the lithology of the upper Keep Inlet Formation. The finer textured beds — described by Williams (1982) — likely form aquitards causing the large artesian heads (Appendix A) in several of the partially cased, abandoned coal exploration holes along the northern mudflat margin. Isolated zones of weakness in the aquitards are likely to be responsible for the locations of isolated groundwater discharge springs that occur on the edge of the mudflats (Figure 2.1).

Variable but relatively thin Cainozoic alluvium, sandplains and coastal deposits, in turn, overlie the Keep Inlet Formation.

3.3 AEM results

An AEM survey (SkyTEM312 system) across much of the investigation area was completed in December 2015. Some interpretation products of the initial AEM data inversion were provided by Geoscience Australia in March 2016, with a subsequent inversion completed in March 2018. The results of the latter inversion and interpretation products will be reported by Geoscience Australia.

Figure 3.5 shows three one-dimensional AEM inversions, presented as cross-sections, located along the three AEM flight lines shown in Figure 3.4 (102401, 105401 and 109401). These cross-sections show the resistive Ningbing Group limestones of the Ningbing Range towards the west, and the Milligans Formation as a strong conductor to the east of the Ningbing Group. They also show a reduction in the contact angle between the Milligans Formation and the resistive Point Spring Sandstone Formation from north to south.

The strong, near-surface conductor in the east of flight lines 102401 and 105401 (and to the west of line 102401) corresponds to the position of the tidal mudflats. Features beneath the mudflats are largely masked by the high, near-surface conductivity.

West of the mudflats, all three AEM cross-sections have a weak, near-surface conductor that is continuous with the mudflats. This feature is likely to indicate mudstone and shale confining layers in the upper part of the Keep Inlet Formation. The other weak conductor, at about 100m deep between the mudflats and the conductive Milligans Formation, is the shale unit used as the drilling target. Discontinuities in the shale layer caused by faulting are most pronounced in flight line 105401.

Below the shale, the slightly conductive layer is likely to mark the Sunbird/Tanmurra Formation, but it is poorly defined even in the logarithmically stretched inversions in Figure 3.5.

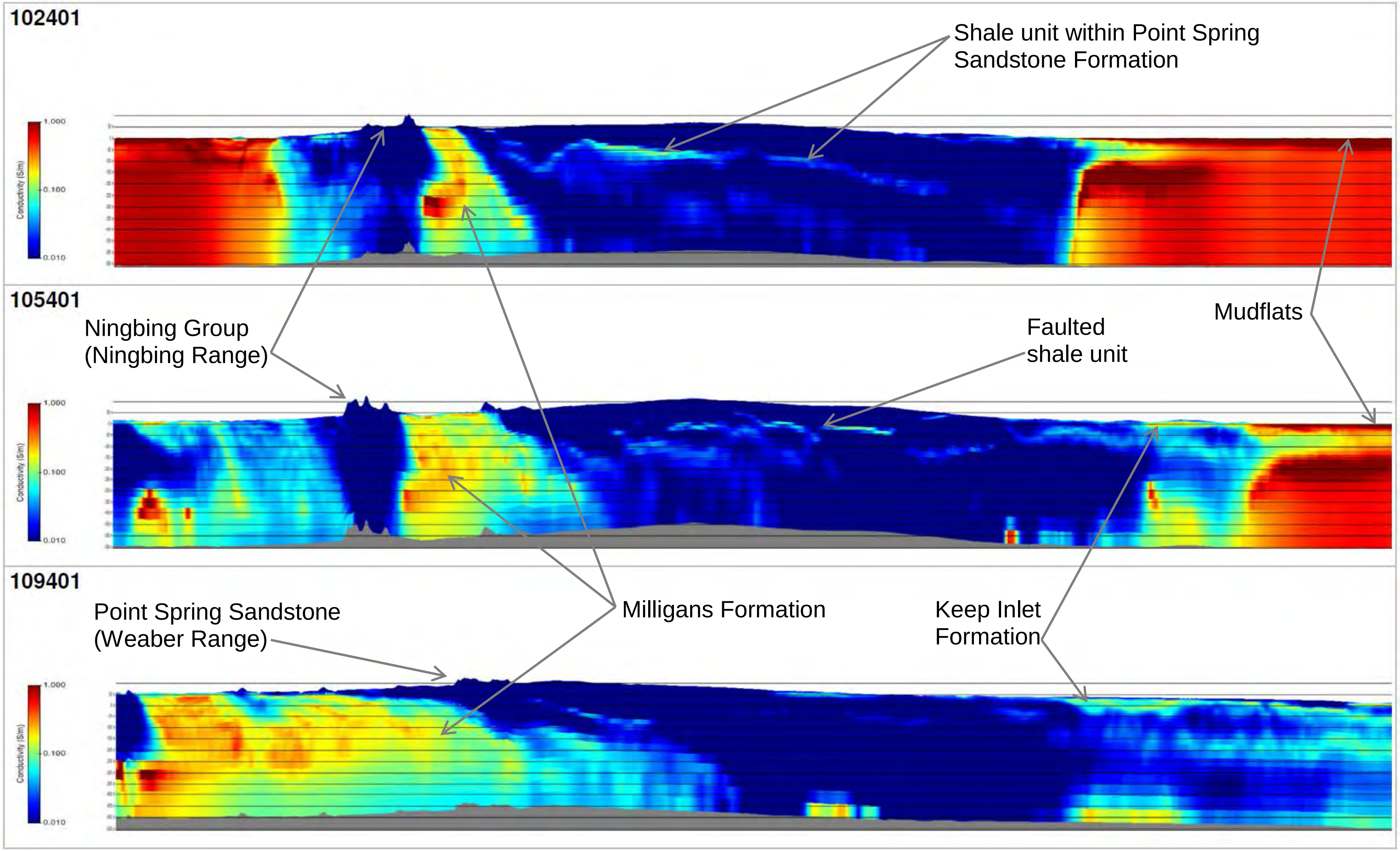


Figure 3.5 Airborne electromagnetic inversions as cross-sections for AEM flight lines 102401, 105401 and 109401

4 Drilling and bore construction

4.1 Access

Gaining access to the sites for drilling rigs was difficult. Station tracks and fencelines in the area mostly align with various geophysical survey lines constructed through the area for oil, gas and mineral exploration programs since the early 1960s. These tracks are sporadically maintained by Carlton Hill Station for light four-wheel drive vehicle access. The tracks we chose required a considerable amount of re-grading to fill washouts and clearing to remove regrowth and fallen trees. Even after grading, the tandem-drive drilling and support trucks used in 2013 required towing with two coupled road graders to be able to traverse the loose, sandy tracks to reach site 13BP01. In 2017, the eight-wheel drive drilling and support trucks had less difficulty in the sandy conditions, although still required towing through the more sandy sections with a large front-end loader.

Figure 4.1 shows the location of the drill sites and the tracks used for access. Any future access for monitoring purposes should follow the tracks shown in this map. However, the track conditions are likely to deteriorate rapidly without maintenance.

The coordinates of the major intersections are provided in Figure 4.1 to assist with navigation because the internal tracks are unnamed, do not have any signs and cannot be meaningfully described. Individual bores are best located using GPS navigation. Sites 16BP02 and 16BP03 can only be reached by traversing through the bush.

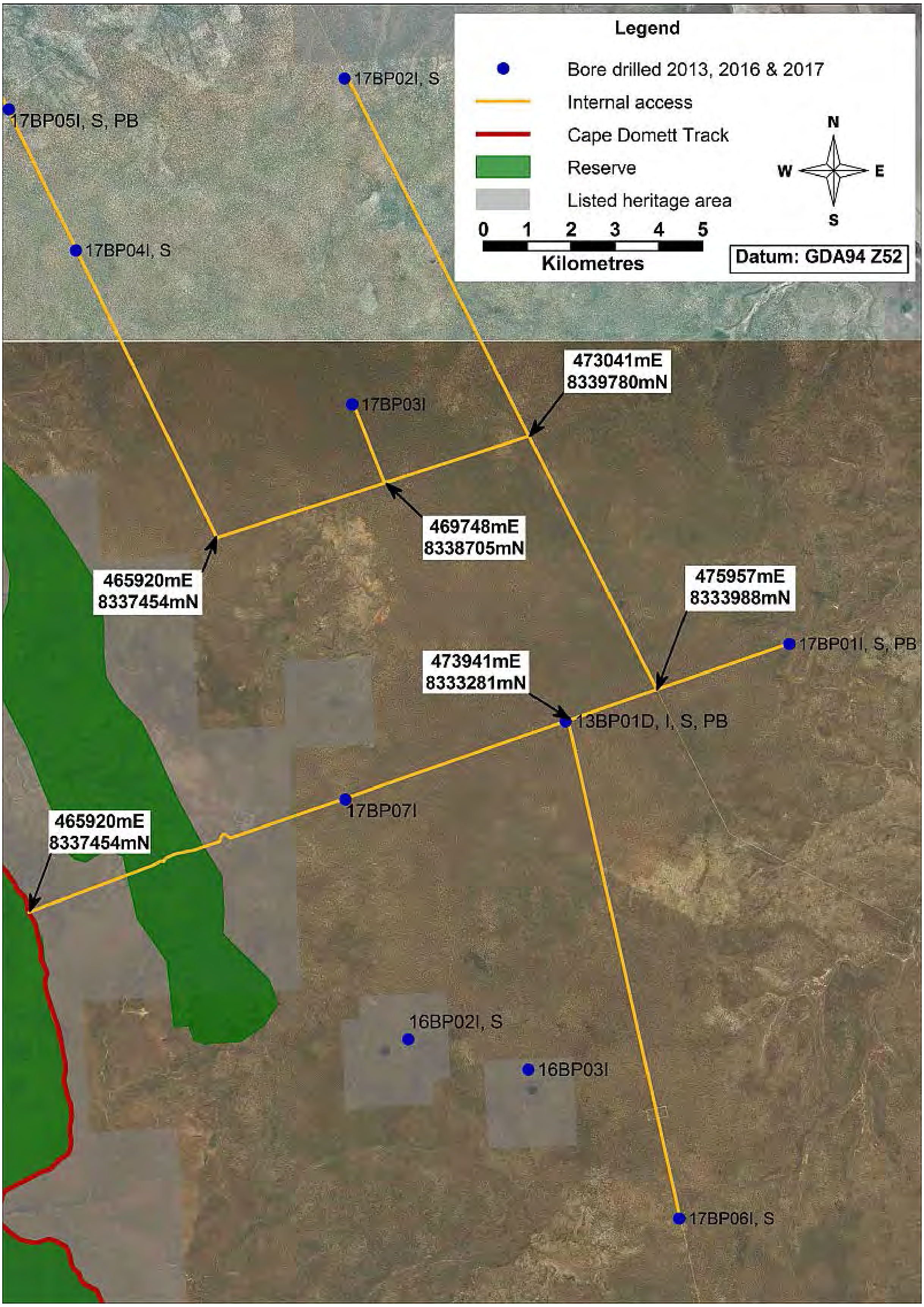
4.2 Drilling methods and bore casing

Three different drilling methods were used to construct 21 bores at 10 sites:

- mud rotary
- rotary air blast (with hammer engaged through occasional well-consolidated layers)
- solid stem auger.

Table 4.1 summarises the locations, drilling techniques, drill depths and screen intervals for bores installed during the 2013, 2016 and 2017 programs. Figures 5.1–5.19 in Section 5 provide more detailed information about bore construction.

Bores were constructed in a manner consistent with *Minimum construction requirements for water bores in Australia* (National Uniform Drillers Licensing Committee 2012).



Note: Datum is Geocentric Datum of Australia 1994 Zone 52.

Figure 4.1 Location and starting coordinates of suggested access routes to bore sites

Table 4.1 Summary drilling data for the 2013, 2016 and 2017 drilling programs

Site	Bore name	AWRC reference	Easting (GDA94 Z52)	Northing (GDA94 Z52)	Casing elevation (mAHD)	Ground elevation (mAHD)	Drilling technique[a]	Date completed	Depth drilled (mBGL)	Screen interval (mBGL)	Geological formation screened	Water level (mBGL)	SC[b] (mS/m)
13BP01	13BP01D	81070023	473887	8333261	84.640	84.040	MR	25/06/2013	172	156–168	Point Spring Sandstone	46.27	31.6
	13BP01I	81070024	473887	8333261	84.640	84.040	MR	25/06/2013	172	100–118	Point Spring Sandstone	46.71	40
	13BP01S	81070026	473887	8333261	84.640	84.040	MR	25/06/2013	172	52–82	Point Spring Sandstone	46.53	38.1
	13BP01PB	81070025	473925	8333272	84.560	83.960	MR	20/06/2013	83.3	35–83	Point Spring Sandstone	46.42	22.9
16BP02	16BP02I	80970156	470297	8325993	88.507	87.707	SSA	16/08/2016	7	5.2–6.2	Possibly Point Spring Sandstone	Dry	Dry
	16BP02S	80970157	470298	8325994	88.547	87.747	SSA	16/08/2016	4	2.45–3.45	Quaternary colluvium	Dry	Dry
16BP03	16BP03I	80970158	473038	8325290	98.393	97.793	SSA	17/08/2016	11.5	9.43–11.43	Quaternary colluvium	Dry	Dry
17BP01	17BP01I	81070027	478993	8335027	42.550	41.750	MR	25/07/2017	126.5	112.75–124.75	Point Spring Sandstone	5.9	8.91
	17BP01S	81070029	478984	8335023	42.763	41.963	RAB	21/07/2017	15	12–15	Point Spring Sandstone	6.06	14.62
	17BP01PB	81070028	479013	8335027	41.897	41.097	RAB/MR	26/10/2017	126.25	112.75–124.75	Point Spring Sandstone	5.29	8.7
17BP02	17BP02I	81070030	468839	8347946	44.989	44.489	MR	27/07/2017	131.68	102–114	Point Spring Sandstone	24.35	14.5
	17BP02S	81070031	468830	8347942	45.080	44.580	RAB	29/07/2017	34	30–33	Point Spring Sandstone	24.54	17.1
17BP03	17BP03I	80970159	469012	8340499	110.125	109.525	RAB	22/08/2017	52	44.7–47.7	Point Spring Sandstone	38.5	35.4
17BP04	17BP04I	80970160	462706	8344019	67.074	66.474	RAB	25/08/2017	62	45–57	Point Spring Sandstone	38.24	21.1
	17BP04S	80970161	462707	8344008	66.995	66.395	RAB	28/08/2017	49	45–48	Point Spring Sandstone	38.11	20.8
17BP05	17BP05I	81070032	461179	8347242	41.933	41.333	RAB	31/08/2017	95.8	77.13–89.13	Point Spring Sandstone	19.03	17.8
	17BP05S	81070034	461182	8347233	42.056	41.456	RAB	2/09/2017	29.5	26–29	Point Spring Sandstone	19.34	23.7
	17BP05PB	81070033	461173	8347265	41.474	40.874	RAB/MR	20/11/2017	93	76.97–88.97	Point Spring Sandstone	18.64	15.5
17BP06	17BP06I	81070035	476482	8321900	95.217	94.617	RAB/MR	28/09/2017	107.65	85–91	Point Spring Sandstone	38.75	7.34
	17BP06S	81070036	476484	8321891	95.202	94.602	RAB	30/09/2017	34.5	31–34	Point Spring Sandstone	23.59	4.7
17BP07	17BP07I	80970162	468860	8331473	93.747	93.147	RAB/MR	6/10/2017	83.77	50–56	Point Spring Sandstone	44.49	15.8

AWRC = Australian Water Resources Council; GDA94 Z52 = Geographical Datum of Australia 1994 Zone 52

a MR = mud rotary; SSA = solid stem auger; RAB = rotary air blast (with and without hammer)

b SC = specific conductivity (25°C)

4.2.1 Site 13BP01

Drilling at site 13BP01 was carried out by Direct Drilling Australia Wide Pty Ltd between 17 and 25 June 2013 with a Hydco70 drilling rig using the mud rotary drilling technique. During drilling operations, a drilling-mud consultant was on-site to continuously test drilling-mud viscosity and other parameters, and to advise the drillers on the most effective drilling-mud mixtures. Appendix B provides a report that summarised the results of drilling-mud tests and the recommendations made for mud mixtures used during drilling (Clifton 2013).

The test-pumping bore (13BP01PB) was installed first so that it could be used to supply water to drill the monitoring bore. It was drilled using a 165mm diameter Chevron tri-blade bit and then reamed with a 244mm diameter Chevron tri-blade bit. It was drilled to a depth of 83.3m, and cased with plain, 155mm *Diametre Nominel* (DN) PN12 PVC (polyvinyl chloride) bore casing. The screen was placed at 35–83m below ground level (mBGL) and constructed from 1mm aperture, machine-slotted, 155mm DN PN12 PVC bore casing. A PVC cap was glued on the bottom. It was very difficult to estimate the watertable depth at this site using the mud rotary drilling technique. It was erroneously estimated to be at about 33mBGL (observed to be 47.02mBGL after bore completion) so the top of the screen section was set at 35mBGL during bore construction. The annulus was backfilled with 2–4mm graded sand to 6.5mBGL, with a cement grout plug installed to the surface. Following construction, the bore screen section was jetted with air plus water and then airlifted until the water was free of coarse sediment and the physical parameters stabilised. Finally, it was fitted with a lockable steel headwork and concrete pad.

Three nested monitoring bores — 13BP01D, 13BP01I and 13BP01S — were installed into one drill hole 174m deep, 40.25m east (and up the hydraulic and topographic gradients) of the test-pumping bore (13BP01PB). The borehole was drilled with a 200mm diameter tri-cone roller bit, and the screens were constructed from 0.5mm aperture, machine–slotted, 50mm DN PN18 PVC pipe. PVC caps were glued onto the bottom of each screen. Unscreened (blank) casing was 50mm DN PN18 or PN12 PVC pipe, depending on the depth.

The casing of each monitoring bore was suspended to ensure that the screens remained at their target depths during backfilling. The annulus around each screen was backfilled with 2–4mm graded sand. A calcium bentonite (PelPlug®) plug was carefully installed, through a tremmie pipe, above each screen section to prevent annulus flow between each casing. A 0.5m thick bentonite plug was also installed immediately below the cement grout plug that encases all three bore casings, from the surface to 11mBGL. A single, lockable steel headwork and a concrete pad protect the three bore casings.

Following construction, each monitoring bore was airlifted until the water was free of coarse sediment and the physical parameters stabilised. InSitu® groundwater level loggers were installed in late 2013.

4.2.2 Sites 16BP02 and 16BP03

On 16 and 17 June 2016, the former Department of Agriculture and Food, Western Australia constructed bores 16BP02I, 16BP02S and 16BP03I using an EVH EziProbe® drilling rig mounted on a light four-wheel drive vehicle. The rig was equipped with 85mm diameter solid stem augers and a 100mm tungsten-prong bit. The bore screens were composed of 50mm DN PN12 PVC pipe slotted with a hacksaw to about 1mm aperture. The blank casing sections were also 50mm DN PN12 PVC pipe. In each bore, the annulus surrounding and extending 0.5m above the screen was filled with 2–4mm graded sand. The remainder of the annulus was filled with bentonite powder to the surface. Both ends of each bore were fitted with a PVC cap.

To protect against damage from cattle and fires, a 100mm nominal bore (NB) steel pipe that extends from the top of the exposed casing to about 0.5mBGL was pushed into each annulus. The three bores were dry following drilling. InSitu® groundwater level loggers were installed in bores 16BP02S and 16BP03I soon after drilling.

4.2.3 Sites 17BP01 to 17BP07

Between 24 July and 20 November 2017, the Water Resources section of the Northern Territory Department of Environment and Natural Resources conducted their drilling program. They used an Atlas Copco T3WDH drilling rig to drill 14 holes at seven sites to depths of 16 to 132m, using a combination of rotary air blast (where aquifer conditions permitted) and mud rotary techniques.

A 200mm diameter, tungsten carbide insert, fixed-cutter drilling bit was used to drill the monitoring boreholes and the pilot holes for the test-pumping bores. The pilot holes were then reamed to 381mm in diameter, using a tungsten carbide insert reaming tool.

Each monitoring and test-pumping bore had a 200mm NB and 375mm NB steel surface casing, respectively, cemented into unconsolidated soil layers near the surface.

At each site, the deeper monitoring bores were drilled first and their water levels measured. At sites where there was a sufficient thickness of aquifer above the screen interval, a shallow monitoring bore was installed about 10m away and hydraulically up-gradient of the deeper bore.

For the shallower bores, a 3m-long section of screen was positioned so that the top of the screen was 6m (as measured in the adjacent deep bore at the time) below the watertable.

The test-pumping bores were installed last. Test-pumping bore 17BP01PB was installed 21.4m east (hydraulically down-gradient) of bore 17BP01I. Test-pumping bore 17BP05PB was installed 23.8m north (down-gradient) of bore 17BP05I.

All monitoring bore casings and sumps (where installed) were constructed with 100mm DN PN12 PVC pipe. Monitoring bore screens were 1mm aperture, machine-slotted, 100mm DN PN12 PVC pipe. Test-pumping bore casings were 200mm NB mild steel pipe. Test-pumping bore screens were wire-wound 200mm NB stainless steel, with 2mm aperture. PVC caps were glued to the bottom of the monitoring bores and steel plates were welded to the bottom of the test-pumping bores.

The annulus around the screen sections and sumps (where installed) below the screen sections was filled with 2–4mm graded sand. Prior to casing the test-pumping bores, particle size analyses were undertaken on samples from the interval to be screened to ensure that the screen aperture and the size of the graded sand used to fill the annulus was appropriate (National Uniform Drillers Licensing Committee 2012).

A layer of bentonite about 0.5m thick was placed in the annulus above the graded sand-pack in most bores. A cement grout plug about 5m thick was placed around the casing above the bentonite. The remainder of the annulus was filled with washed and graded sandstone pebbles of 10–20mm diameter, to about 1m below the bottom of the surface casing. The remaining annulus was filled with cement.

Threaded 100mm DN PVC faucet socket fittings and threaded plugs were installed on the top of the monitoring bore PVC casings. Steel extensions with lockable steel cover plates were welded onto the monitoring bore surface casings to protect them. For test-pumping bores, lockable steel cover plates were welded directly onto the top of the casings. Concrete pads were placed around all of the bores.

InSitu® groundwater level loggers were installed in the deepest monitoring bore at each site, and in shallow bores 17BP01S, 17BP05S and 17BP06S.

4.3 Lithology samples

We collected samples of the drill cuttings at 1m intervals of the deepest drill hole at each site, and from the test-pumping drillholes. As at 2018, the samples are stored in plastic chip trays at the DPIRD office in Bunbury.

4.4 Downhole geophysical profiling

We undertook downhole total count gamma profiling from within the casing of the bores drilled in 2013. The natural gamma tool used was a Geonics Gamma39 Natural Gamma Probe®, with data recorded on a Geonics EM39® wireline logger at 0.05m depth intervals.

The sites drilled in 2017 were profiled using a Matrix 2PGA-1000 natural gamma probe (Mount Sopris Instrument Co., Inc.) recording at 0.05m intervals, recorded by a Matrix logger and 4MXA-1000 wireline encoder (Mount Sopris Instrument Co., Inc.). The gamma measurements were obtained from within the open drill holes at sites 17BP01 and 17BP02. At other bore sites drilled during 2017, similar gamma measurements were obtained from within the casing, immediately following bore completion.

In late 2017 Geoscience Australia undertook downhole electrical resistivity and nuclear magnetic resonance profiling of the holes drilled in 2013 and 2017. The results from these surveys will be contained in separate Geoscience Australia reports.

4.5 Palynology

As most of the profiles drilled are dominated by sandstone materials that have little or no organic material and are highly oxidised, they are unlikely to contain sufficient palynomorphs for analysis. Therefore we sampled cuttings from the major shale layer (where present) at each drill site, and from the carbonaceous interval from the bottom of drill hole 13BP01I (171–172mBGL) for palynology analysis by the Geological Survey of

Western Australia. Since there was no shale encountered at site 17BP07I, the clayey interval 71–83mBGL was sampled, though this was subsequently found to be entirely oxidised and was therefore not assessed for palynomorphs.

The results from the palynology analysis are reported by Backhouse (2019), which is included as Appendix D.

Table 4.2 summarises the results of the palynology analysis. At each site the shale contains palynomorphs consistent with the *Spelaeotriletes ybertii* spore-pollen zone, of Serpukovian–Bashkirian age (316–327 million years before present [Ma BP]) and placing it within the mid to late Carboniferous period. The age of this material is consistent with the age of the Point Spring Sandstone Formation as described by Mory and Beere (1988). Gorter et al.'s (2005) narrower age range of 320 to 332Ma BP for the Point Spring Sandstone Formation lies within the age range of the palynology results. However, Gorter et al.'s proposed ages for their new Border Creek and Kuriyippi formations were younger than the ages from the palynology of our drilling samples.

Table 4.2 Summary of palynology results from the drill cutting samples

GSWA sample number	Borehole	Depth (m)	Spore-pollen zone	Approximate age
229658	13BP01I	143–152	*Spelaeotriletes ybertii*?	Serpukhovian–Bashkirian
229659	13BP01I	171–172	*S. ybertii–Grandispora maculosa*?	Serpukhovian–Bashkirian
229660	17BP01I	125–126.5	*S. ybertii*?	Serpukhovian–Bashkirian
229661	17BP03I	51–52	*S. ybertii*	Serpukhovian–Bashkirian
229662	17BP04I	60.55–62	*S. ybertii*?	Serpukhovian–Bashkirian
229663	17BP05I	90.5–95.8	*S. ybertii*	Serpukhovian–Bashkirian
229664	17BP06I	40.5–41	*S. ybertii*	Serpukhovian–Bashkirian

Source: Backhouse (2019)

The carbonaceous sample from 171–172mBGL at 13BP01I had a polynomorph assemblage assigned to the combined *S. ybertii–Grandispora maculosa* spore-pollen zones indicating that it is likely to be older, within the range of 316 to 332Ma BP. It was not possible to assign a more definitive age to this sample.

Taking account of the lithology at this depth (see Chapter 5.1) and the above age range, it appears likely that this material is from either the upper Tanmurra Formation as described by Mory and Beere (1988), or the upper Sunbird Formation as described by Gorter et al. (2005).

4.6 Water sampling

Groundwater samples were collected during September and October 2017 from the bores installed during the three drilling programs, plus a selection of 19 of the existing bores (Figure 2.1). Immediately prior to sampling, water in the bore casings was pumped until field water quality parameters stabilised and at least a volume of water equivalent to at least four times the bore casing volume was removed. Samples were sent for analysis of general chemistry, heavy metals, isotopes, radiocarbon, tritium chlorofluorocarbons and sulfur hexafluoride. The laboratory results will be contained in separate reports.

4.7 Surveying

In 2013, local licensed surveyors Survey North determined the position and elevation of the tops of the bore casings at site 13BP01 and several other existing bores. Additionally, Survey North established several survey control points in the area using real-time kinematic GPS survey methodology.

In late 2017, DPIRD staff surveyed the bores installed during 2016 and 2017 (and other existing bores) to determine the position and elevation of the tops of the bore casings. They used similar real-time kinematic GPS survey methods and cross-checked their results against Survey North’s 2013 data. Appendix C contains this survey accuracy information.

5 Description of the bore sites

This section describes the following for each site:

- a site description
- the reasons the site was selected for bore installation
- the drilling finishing depths and the intervals screened
- the stratigraphy and lithology of each bore
- bore completion diagrams for each bore.

5.1 Site 13BP01

5.1.1 Site description

In 2013, site 13BP01 was chosen for exploratory drilling to determine if there were groundwater resources beneath the Cockatoo Sands and if further groundwater resource investigation was warranted. This site was chosen because:

- it was relatively central within the Cockatoo Sands area
- it was relatively easy to access
- it was located between the Bonaparte1 and Bonaparte2 oil wells, from which the lithology could be anticipated and compared.

5.1.2 Drilling depths and screen placement

Bore 13BP01PB (test-pumping bore) was drilled to 83.3m, finishing in moderately consolidated, silty and (minor) clayey sandstone. It was screened at 35–83mBGL, mainly within poorly consolidated, slightly silty sandstone.

The hole for 13BP01D reached 174mBGL, penetrating 2m into the calcareous siltstone of the Sunbird/Tanmurra Formation. It was screened at 156–158mBGL, above the Sunbird/Tanmurra Formation and below the well-consolidated shale layer at 143–152mBGL.

The casings for bores 13BP01D, 13BP01I and 13BP01S are in one drill hole. Bore 13BP01I was screened above the shale layer at 110–118mBGL and bore 13BP01S was screened at 52–82mBGL.

5.1.3 Bore stratigraphy and lithology

Table 5.1 and Table 5.2 show the formation stratigraphy and the lithology, respectively, for monitoring bores 13BP01D, 13BP01I and 13BP01S. Figure 5.1 shows the bore completion diagram.

Table 5.3 and Table 5.4 show the formation stratigraphy and the lithology, respectively, for test-pumping bore 13BP01PB. Figure 5.2 shows the bore completion diagram.

Table 5.1 Summary formation log for monitoring bores 13BP01D, 13BP01I and 13BP01S

Depth (mBGL)	Stratigraphy
0–28	Cainozoic sandplain (Cockatoo Sands)
28–171	Point Spring Sandstone Formation
171–174	Sunbird/Tanmurra Formation

Table 5.2 Lithology log for monitoring bores 13BP01D, 13BP01I and 13BP01S

Depth (mBGL)	Lithology	Description
0–0.3	Sand, loamy	Red (2.5YR 5/8) loamy sand. Sand mainly quartz, fine-grained, subrounded and poorly sorted.
0.3–6	Sand, loamy	Red (10R 5/8) loamy sand. Sand quartz, fine-grained, subrounded and well sorted. Some (minor) rounded quartz grains to 0.5mm.
6–8	Clay-loam, sandy	Red (2.5YR 4/8) sandy clay-loam. Sand quartz, fine- to medium-grained and moderately sorted.
8–12	Clay-loam, sandy	Dark red (2.5YR 3/6) sandy clay-loam. Sand quartz, fine-grained and well sorted. Some (minor) ironstone nodules.
12–14	Loam, sandy	Yellowish-red (5YR 5/8) sandy loam. Sand quartz, fine- to medium-grained, subrounded to rounded and well sorted. Minor flecks of soft, grey feldspar.
14–24	Sand	Reddish-yellow (5YR 7/6) sand. Sand quartz, medium- to coarse-grained, subrounded and well sorted. Numerous angular quartz shards to 10mm. Some (minor) flecks of soft, grey clay.
24–28	Sand	Pink (5YR 7/4) sand. Sand quartz, medium- to coarse-grained, subrounded to rounded and well sorted. Some (minor) flecks of soft, grey clay.
28–34	Sandstone, conglomerate	Cobbles of hard, fine-grained quartz sandstone in a yellowish-red (5YR 5/8), poorly consolidated sandstone matrix.
34–38	Sandstone	Yellowish-red (5YR 5/8), poorly consolidated sandstone. Sand quartz, fine- to medium-grained, subrounded and moderately sorted.
38–46	Sandstone, iron induration	Reddish-yellow (5YR 6/6), variably poorly and well-consolidated (iron induration layers) sandstone. Sand quartz, fine- to very fine-grained, subrounded and moderately sorted.
46–53	Sandstone	Very pale-brown (10YR 7/4), very poorly consolidated sandstone. Sand quartz, fine- to very fine-grained, subrounded and moderately sorted.
53–62	Sandstone	Red (2.5YR 5/8), moderately consolidated (iron-indurated) sandstone. Sand quartz, fine- to medium-grained, subrounded and moderately sorted.
62–82	Sandstone	Reddish-yellow (7.5YR 6/6), poorly consolidated sandstone. Sand quartz, fine- to medium-grained, subrounded and well sorted. Minor yellowish clay particles.

(continued)

Table 5.2 continued

Depth (mBGL)	Lithology	Description
80–82	Sandstone	Reddish-brown (5YR 5/4) moderately consolidated sandstone. Sand quartz, fine- to medium-grained, subrounded and well sorted.
82–86	Sandstone, silty	Mottled or banded red/grey/yellow moderately consolidated silty sandstone. Sand quartz, very fine- to fine-grained, subrounded and moderately well sorted. Minor white clay particles.
86–94	Sandstone, silty	Pink (5YR 7/4), poorly consolidated silty sandstone. Sand quartz, fine to medium grained, subrounded and well sorted.
94–96	Sandstone, silty, iron induration	Dusky red (10R 3/4), well-consolidated (iron-indurated) silty sandstone. Sand quartz, very fine- to medium-grained, subrounded and poorly sorted. Minor granules of grey well-consolidated siltstone.
96–118	Sandstone	Pink (7.5YR 7/3) to pinkish-grey (7.5YR 7/2), poorly consolidated sandstone. Sand quartz, medium- to coarse-grained, subrounded and well sorted. Minor subrounded quartz pebbles to 5mm at 99–113m.
118–127	Sandstone, silty	Light reddish-brown (5YR 6/3), variably consolidated and variably silty sandstone. Sand quartz, fine- to very coarse-grained, subrounded and very poorly sorted. Angular, very fine-grained, hard sandstone shards to 20mm plus subrounded quartz pebbles to 15mm.
127–129	Siltstone	Reddish-brown (5YR 5/3), moderately consolidated sandy siltstone. Sand quartz, very fine-grained, subrounded and well sorted.
129–131	Siltstone	As above but well consolidated (iron induration).
131–137	Clay, silty	Pinkish-white (5YR 8/2), moderately consolidated, silty clay.
137–140	Sandstone, silty	Pink (5YR 7/3), poorly consolidated, slightly silty sandstone. Sand quartz, fine- to coarse-grained, subrounded and poorly sorted. Minor opaque, subrounded, quartz pebbles to 5mm.
140–143	Siltstone	Light reddish-brown (5YR 6/4) to very pale-brown (10YR 7/6), well-consolidated sandy siltstone.
143–152	Shale	Grey (Gley1 6/N) well-consolidated shale.
152–162	Sandstone, silty	Light-brown (7.5YR 6/3), poorly consolidated, slightly silty sandstone. Sand quartz, medium-grained, subrounded and moderately sorted. Minor flecks of soft, white clay.
162–171	Sandstone	Pink (7.5YR 7/3), very poorly consolidated sandstone. Sand quartz, medium- to coarse-grained, subrounded and moderately sorted. Minor angular clear quartz clasts to 10mm.
171–172	Siltstone	Very dark greyish-brown (10YR 3/2), well-consolidated sandy and clayey siltstone.
172–174	Siltstone, calcareous	Dark olive-brown (2.5Y 3/3), well-consolidated sandy (minor) and clayey siltstone. Contains numerous white, medium-hard oolitic carbonate (strong fizz with sulfuric acid) nodules to 5mm.

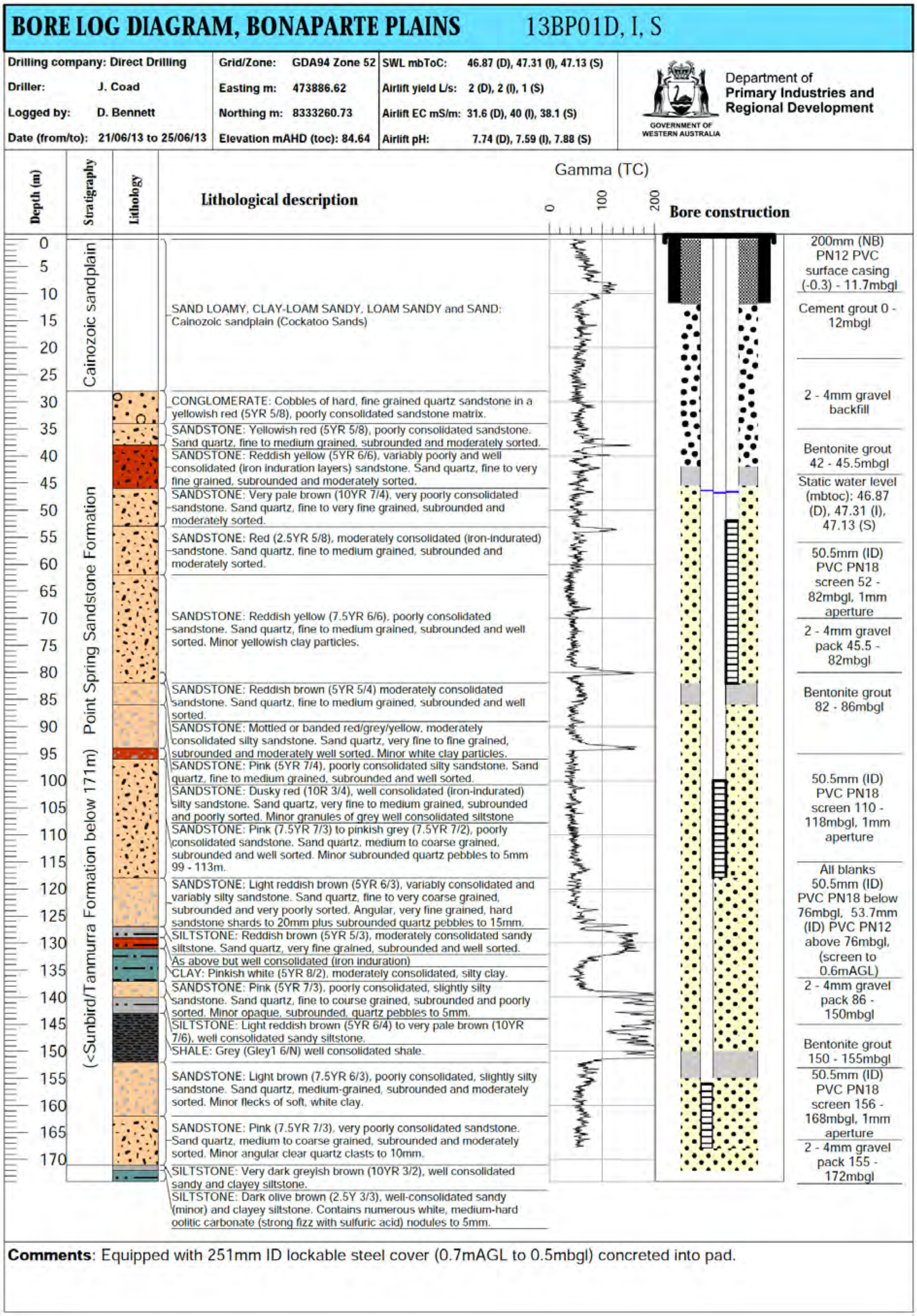


Figure 5.1 Bore diagram for monitoring bores 13BP01D, 13BP01I and 13BP01S

Table 5.3 Summary formation log for test-pumping bore 13BP01PB

Depth (mBGL)	Stratigraphy
0–19	Cainozoic sandplain (Cockatoo Sands)
19–83.3	Point Spring Sandstone Formation

Table 5.4 Lithology log for test-pumping bore 13BP01PB

Depth (mBGL)	Lithology	Description
0–0.3	Sand, loamy	Red (2.5YR 5/8), loamy sand. Sand mainly quartz, fine-grained, subrounded and poorly sorted.
0.3–6	Sand, loamy	Red (10R 5/8), loamy sand. Sand quartz, fine-grained, subrounded and moderately sorted. Some (minor) rounded quartz grains to 0.5mm.
6–9	Sand, loamy	Red (2.5YR 4/8), sandy clay-loam. Sand quartz, fine- to medium-grained and moderately sorted.
9–14	Loam, clayey	Dark red (2.5YR 3/6), very fine sandy clay-loam. Sand quartz, fine- to medium-grained and moderately sorted. Minor ironstone nodules and soft black (possibly ash) flecks.
14–17	Loam, sandy	Reddish-brown (2.5YR 5/4), very fine sandy loam. Sand quartz, fine-grained, subrounded and moderately sorted.
17–19	Loam, sandy	As above, with minor yellow/brown, soft, clayey granules.
19–21	Sandstone	Yellowish-brown (5YR 5/8), poorly consolidated sandstone. Sand quartz, fine- to coarse-grained, subrounded and poorly sorted. Minor angular to subrounded quartz pebbles to 5mm. Minor soft, yellow/grey clay casts. Minor iron-indurated hard sandstone granules.
21–38	Sandstone	Yellowish-brown (5YR 5/8), poorly consolidated sandstone. Sand quartz, fine- to medium-grained, subrounded and poorly sorted. Minor subrounded to rounded quartz pebbles to 5mm.
38–49	Sandstone, silty	Reddish-yellow (5YR 7/8), poorly consolidated, silty sandstone. Sand quartz, fine- to medium-grained, subrounded and poorly sorted. Some soft, white clay clasts. Minor subrounded quartz pebbles to 5mm.
49–59	Sandstone, iron induration	Yellowish-red (5YR 5/6), moderately consolidated sandstone. Sand quartz, medium-grained, subrounded and moderately sorted. Variable layers of iron induration.
59–66	Sandstone	Pink (5YR 7/4), poorly consolidated sandstone. Sand quartz, medium-grained, subrounded and moderately sorted.
66–73	Sandstone, silty	Pink (5YR 7/4), poorly consolidated slightly silty sandstone. Sand quartz, fine- to medium-grained subrounded and poorly sorted. Minor flecks of soft, grey clay.
73–76	Sandstone	Yellowish-red (5YR 5/6), poorly consolidated sandstone. Sand quartz, medium- to coarse-grained, subrounded and poorly sorted.
76–82	Sandstone, iron induration	Reddish-brown (5YR 4/4), moderately consolidated (iron-indurated) sandstone. Sand quartz, medium- to coarse-grained, subrounded and poorly sorted.
82–83.3	Sandstone, silty	Light-brown (7.5YR 6/4) moderately consolidated silty sandstone. Sand quartz, fine- to medium-grained, subrounded and moderately well sorted. Minor soft, white clay particles.

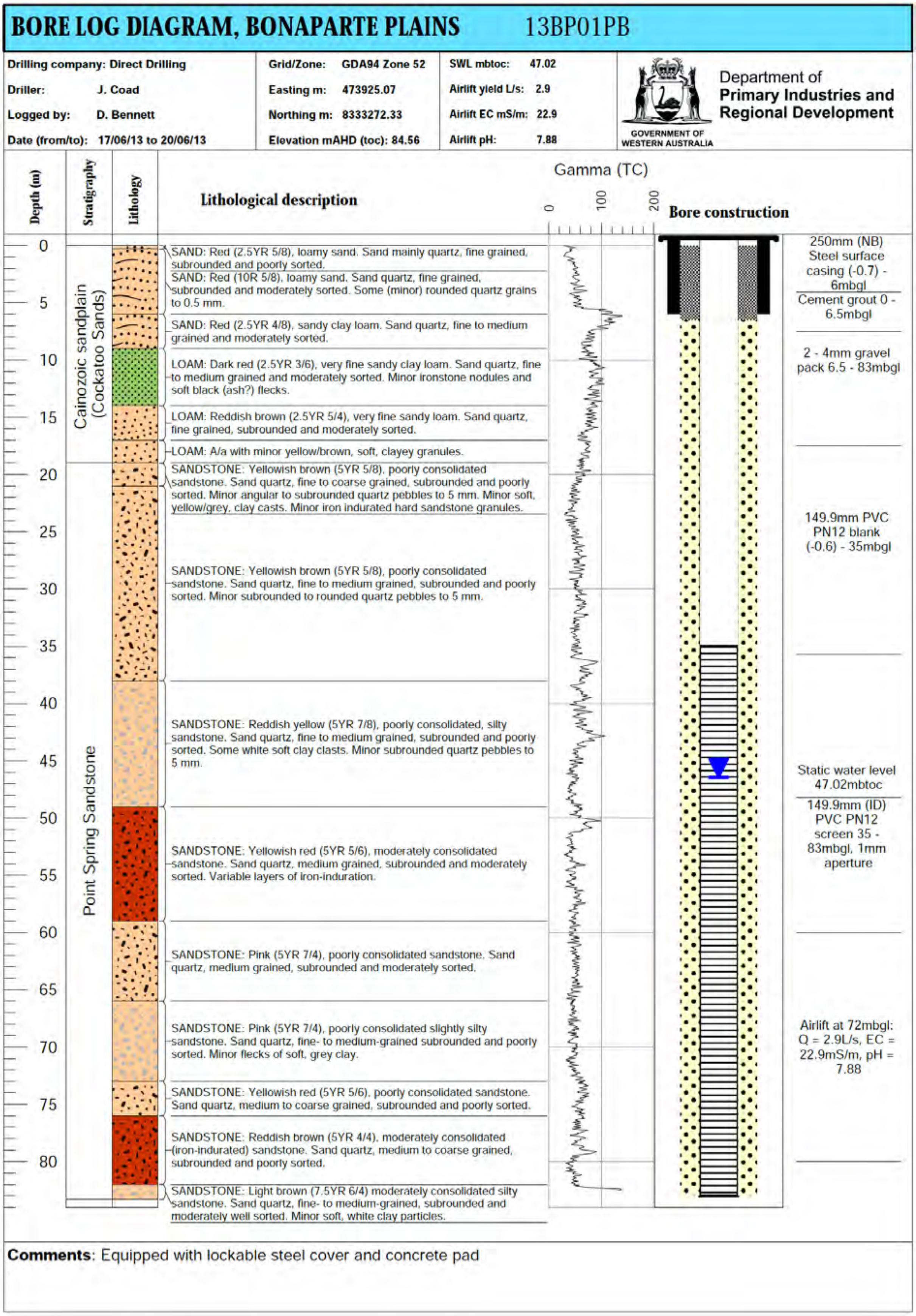


Figure 5.2 Bore diagram for test-pumping bore 13BP01PB

5.2 Site 16BP02

5.2.1 Site description

Site 16BP02 is near one of two small upland lakes, adjacent to the western margin of the Cockatoo Sands area in the south. Observations made between 2013 and 2016 indicate that in some years, both lakes dry out by the end of the dry season, and that their water levels are about 20m higher than the forecast groundwater elevation at each location.

The 2016 shallow auger-drilling focused on intersecting any shallow groundwater and perched layers associated with the lakes. It provided monitoring points from which data loggers could obtain information on the seasonal dynamics of shallow groundwater levels.

5.2.2 Drilling depths and screen placement

Bore 16BP02I was drilled to 7mBGL, the maximum depth that the small auger-drilling rig could penetrate the hard conglomerate. It was screened at 5.2–6.2mBGL, within conglomerate sandstone and beneath a sandy clay layer at 3.8–5mBGL.

Bore 16BP02S was drilled about 4m to the south of 16BP02I. It was drilled to 4mBGL and screened at 2.45–3.45mBGL, within the clayey sand layer overlying the sandy clay.

Both bores were dry at completion.

5.2.3 Bore stratigraphy and lithology

Table 5.5 and Table 5.6 show the formation stratigraphy and the lithology, respectively, for monitoring bore 16BP02I. Figure 5.3 shows the bore completion diagram.

Table 5.7 and Table 5.8 show the formation stratigraphy and the lithology, respectively, for monitoring bore 16BP02S. Figure 5.4 shows the bore completion diagram.

Table 5.5 Summary formation log for monitoring bore 16BP02I

Depth (mBGL)	Stratigraphy
0–5	Quaternary colluvium (Pago Sand)
5–7	Point Spring Sandstone Formation (possibly)

Table 5.6 Lithology log for monitoring bore 16BP02I

Depth (mBGL)	Lithology	Description
0–1	Sand, loamy	Pale-brown loamy sand and ironstone gravel.
1–3.8	Sand, clayey	Red/brown clayey sand.
3.8–5	Clay, sandy	Yellow and brown sandy clay.
5–7	Sandstone conglomerate	Hard conglomerate sandstone.

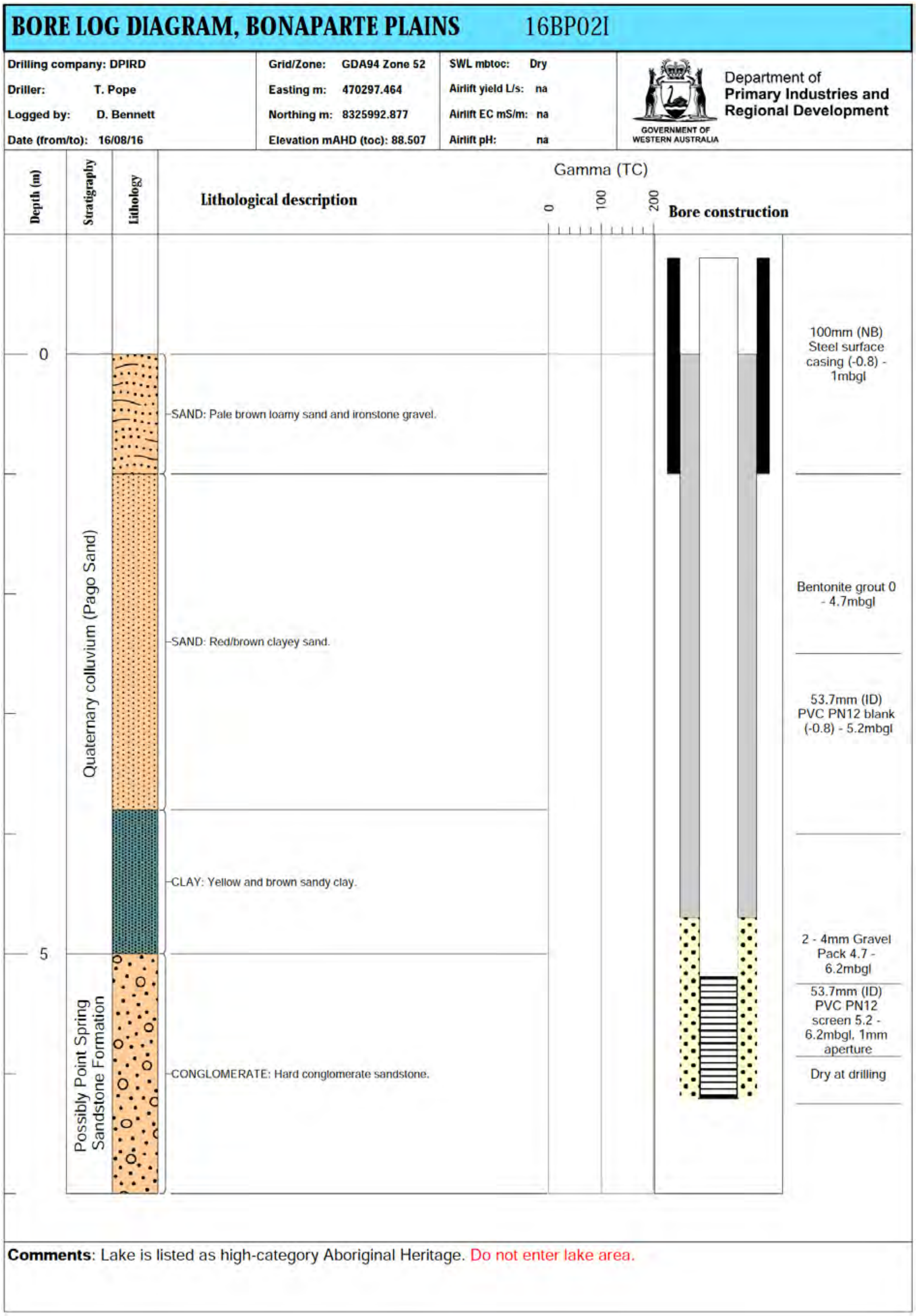


Figure 5.3 Bore diagram for monitoring bore 16BP02I

Table 5.7 Summary formation log for monitoring bore 16BP02S

Depth (mBGL)	Stratigraphy
0–4	Quaternary colluvium (Pago Sand)

Table 5.8 Lithology log for monitoring bore 16BP02S

Depth (mBGL)	Lithology	Description
0–1	Sand, loamy	Pale-brown loamy sand and ironstone gravel.
1–3.8	Sand, clayey	Red/brown clayey sand.
3.8–4	Clay, sandy	Yellow and brown sandy clay.

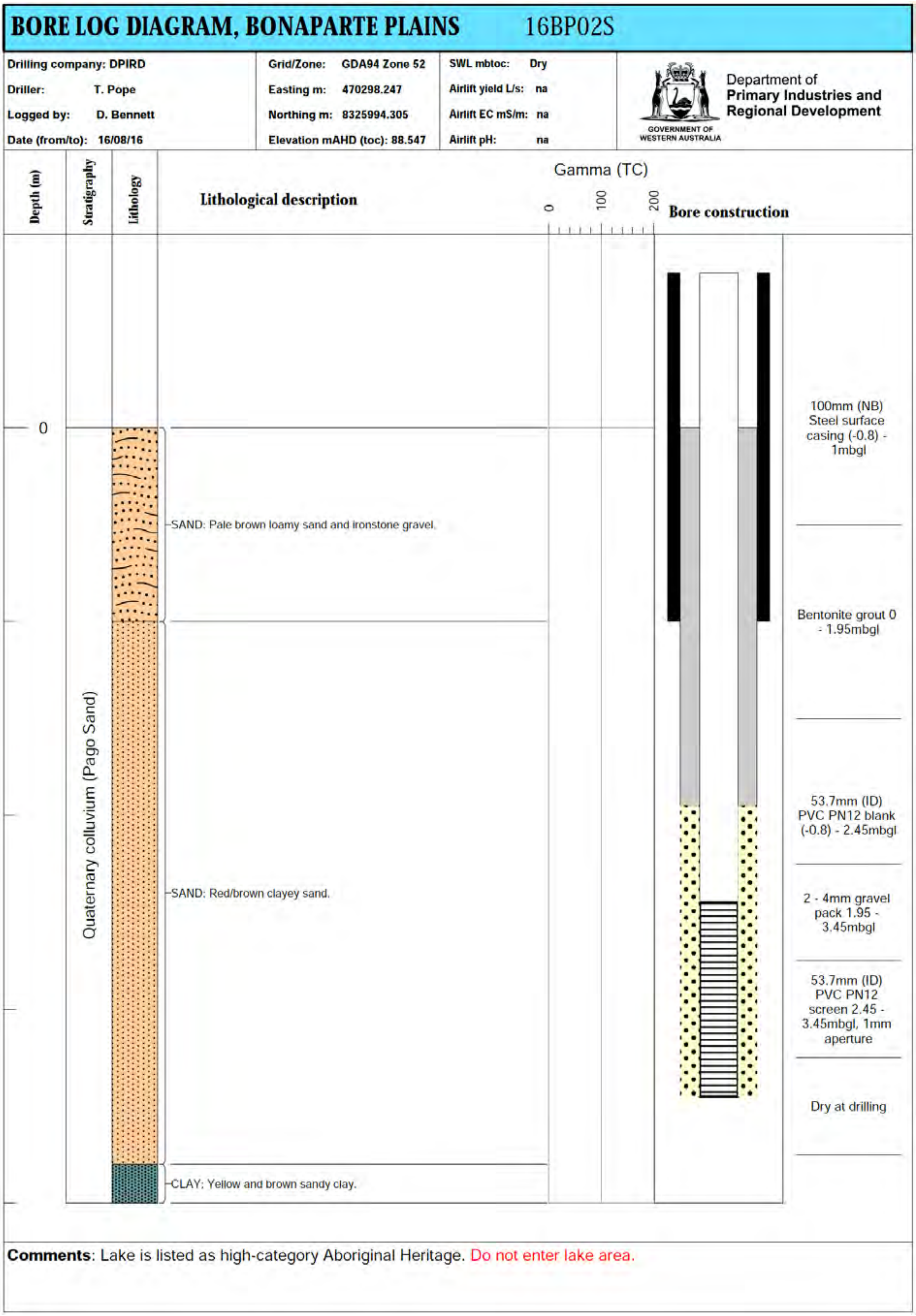


Figure 5.4 Bore diagram for monitoring bore 16BP02S

5.3 Site 16BP03

5.3.1 Site description

As for site 16BP02, the 2016 shallow auger-drilling at 16BP03 focused on intersecting any shallow groundwater and perched layers associated with the nearby lake. It provided monitoring points from which data loggers could obtain information on the seasonal dynamics of shallow groundwater levels.

5.3.2 Drilling depths and screen placement

Bore 16BP03I was drilled to 11.5mBGL, finishing within hard, sandy clay that became difficult to penetrate. It was screened at 9.43–11.43mBGL, straddling the boundary at 10mBGL between the soft and hard sandy clay.

5.3.3 Bore stratigraphy and lithology

Table 5.9 and Table 5.10 show the formation stratigraphy and the lithology, respectively, for monitoring bore 16BP03I. Figure 5.5 shows the bore completion diagram.

Table 5.9 Summary formation log for monitoring bore 16BP03I

Depth (mBGL)	Stratigraphy
0–11.5	Quaternary colluvium

Table 5.10 Lithology log for monitoring bore 16BP03I

Depth (mBGL)	Lithology	Description
0–0.5	Sand, loamy	Brown loamy sand.
0.5–5	Sand, loamy	Red/brown, loamy and clayey sand.
5–6	Clay, sandy	Red/brown, sandy light clay.
6–6.5	Clay, sandy	Red/brown, sandy light clay. Numerous ironstone nodules.
6.5–8	Sandstone, iron induration	Light-brown and yellow, variably soft and hard sandstone. Numerous iron-indurated sandstone clasts.
8–10	Clay, sandy	Red/brown, uniformly soft, sandy clay.
10–11.5	Clay, sandy	Light-grey, moderately hard, sandy clay.

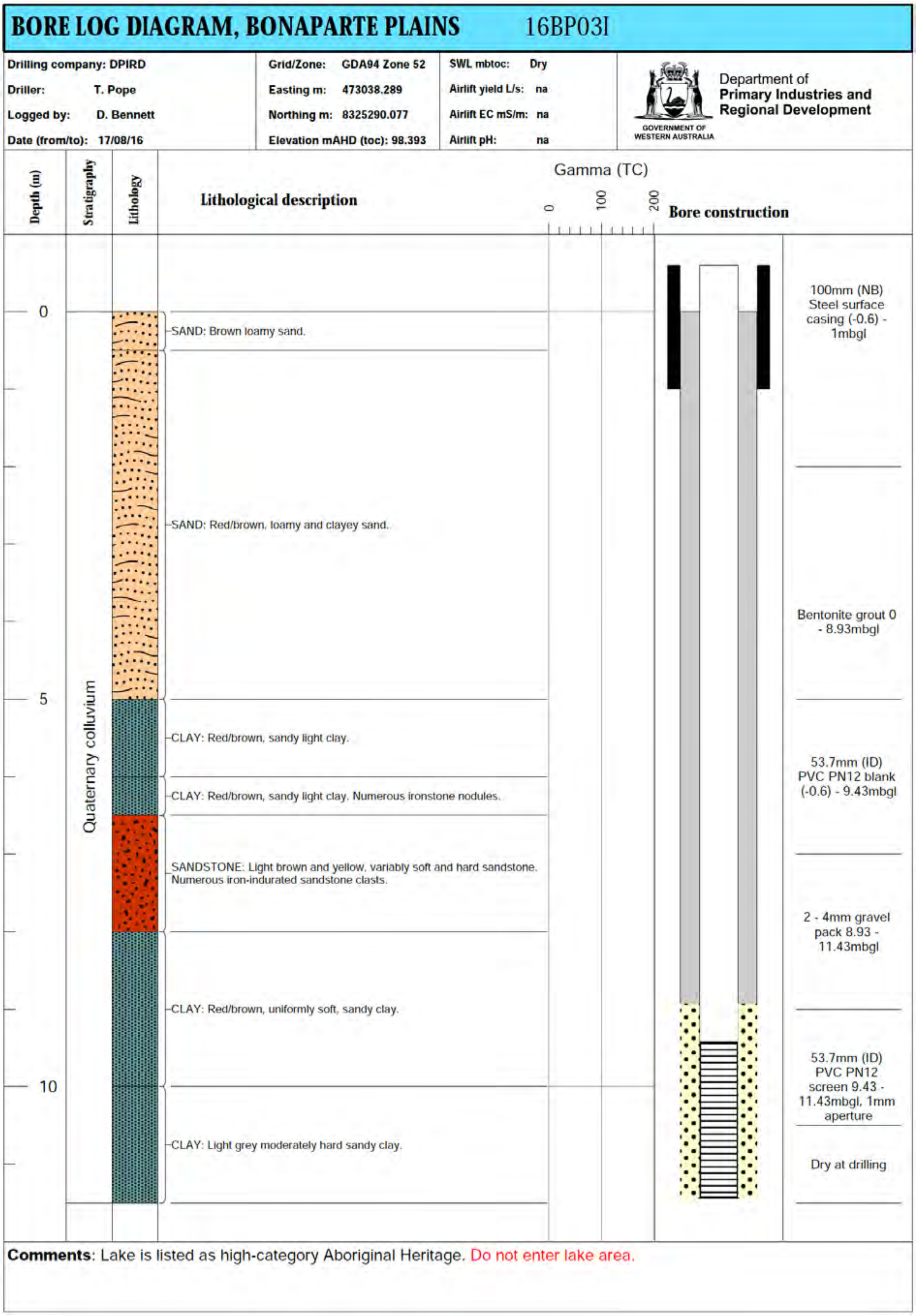


Figure 5.5 Bore diagram for monitoring bore 16BP03I

5.4 Site 17BP01

5.4.1 Site description

Site 17BP01 was selected to:

- obtain information about groundwater conditions and lithology at the eastern margin of the Cockatoo Sands
- form the eastern extent of an east–west transect of bores
- locate a test-pumping bore to determine aquifer parameters and test the aquifer yield along the eastern edge of the Cockatoo Sands, where the groundwater head was forecast to be relatively shallow (10mBGL).

5.4.2 Drilling depths and screen placement

Bore 17BP01I was drilled entirely using the mud rotary technique. A feature of the sandstone formation at this site was its general hardness, possibly a result of the relatively high proportion of iron induration, compared to other sites. This was unexpected, based on the relative ease of drilling encountered at site 13BP01. The original drill bit (non-tungsten carbide insert) had to be replaced after 80m of drilling, with a tungsten carbide insert fixed-cutter that was used at all other sites.

The target shale layer was intercepted at 125mBGL — similar to the 120mBGL depth forecast from the AEM results. Monitoring bore 17BP01I was screened at 112.75–124.75mBGL, within well-consolidated, iron-indurated, medium- to coarse-grained sandstone. A 1.5m-long sump was installed below the screen. Prior to installing the casing, a 30-minute period of airlifting of the open hole gave a groundwater return of about 50L/s.

Test-pumping bore 17BP01PB was installed at the same site. It was screened at 112.75–124.75mBGL, above a 1.5m-long sump.

A shallow bore (17BP01S) was also installed, screened at 12–15mBGL.

5.4.3 Bore stratigraphy and lithology

Table 5.11 and Table 5.12 show the formation stratigraphy and the lithology, respectively, for monitoring bore 17BP01I. Figure 5.6 shows the bore completion diagram.

Table 5.13 and Table 5.14 show the formation stratigraphy and the lithology, respectively, for monitoring bore 17BP01S. Figure 5.7 shows the bore completion diagram.

Table 5.15 and Table 5.16 show the formation stratigraphy and the lithology, respectively, for test-pumping bore 17BP01PB. Figure 5.8 shows the bore completion diagram.

Table 5.11 Summary formation log for monitoring bore 17BP01I

Depth (mBGL)	Stratigraphy
0–3.5	Quaternary colluvium (Pago Sand)
3.5–126.1	Point Spring Sandstone Formation

Table 5.12 Lithology log for monitoring bore 17BP01I

Depth (mBGL)	Lithology	Description
0–3.5	Sand, loamy	Quaternary colluvium (Pago Sand).
3.5–8	Sandstone, silty	Light-red (10YR 7/6) and light-grey (7.5YR 7/1), poorly consolidated silty sandstone. Sand quartz, fine- to medium-grained, subrounded and poorly sorted.
8–16	Sandstone	Light-grey (7.5YR 7/1) and brownish-yellow (10YR 6/6), moderately consolidated, sandstone. Sand quartz, fine- to medium-grained, subrounded and poorly to moderately sorted.
16–23.5	Sandstone, interbedded siltstone, iron induration	Light-grey (10YR 7/1), moderately consolidated, porous sandstone and dark brownish-grey (7.5YR 3/1) well-consolidated (iron-indurated) siltstone. Sand quartz, fine- to medium-grained, subrounded and poorly sorted.
23.5–42	Sandstone, iron induration	Pinkish-grey (5YR 7/2), variably moderately to well-consolidated, porous sandstone. Bands of hard iron induration throughout. Sand quartz, fine- to coarse-grained, subrounded and poorly sorted.
42–44	Sandstone conglomerate	Rounded cobbles of very hard, fine-grained pinkish quartz sandstone (returning as shards) within matrix of reddish-yellow (7.5YR 6/6), moderately consolidated sandstone. Sand quartz, medium- to coarse-grained, subrounded and poorly sorted.
44–49	Sandstone	Grey (5YR 6/1), variably moderately to well-consolidated, slightly porous sandstone. Sand quartz, medium-grained, subrounded and well sorted.
49–55	Sandstone, interbedded siltstone, iron induration	Grey (5YR 6/1), moderately consolidated, slightly porous sandstone. Bands of hard iron induration present throughout. Some thin bands of light-grey (5Y 7/1) hard siltstone. Sand quartz, medium- to coarse-grained, subrounded and well sorted.
55–67	Sandstone, iron induration	Pinkish-grey (5YR 7/2), moderately consolidated slightly porous sandstone. Bands of iron induration present throughout. Sand quartz, medium- to coarse-grained, subrounded and well sorted. Some angular shards plus granules of quartzite.
67–72	Sandstone	Pinkish-grey (5YR 7/2) and grey (5YR 7/1), well-consolidated sandstone. Sand quartz, fine- to medium-grained, subrounded and poorly to well sorted.
73–81	Sandstone	Grey (7.5YR 7/1), well-consolidated sandstone. Sand quartz, fine- to medium-grained, subrounded and moderately sorted.

(continued)

Table 5.12 continued

Depth (mBGL)	Lithology	Description
81–93	Sandstone, iron induration	Pinkish-grey (7.5YR 7/2), well-consolidated sandstone. Bands of iron induration present throughout Sand quartz, fine- to medium-grained, subrounded and moderately sorted. Some (minor) jagged quartz clasts to 4mm.
93–95	Sandstone, silty	Reddish-yellow (7YR 7/6), well-consolidated, silty sandstone. Sand quartz, fine-grained, subrounded and moderately sorted.
95–106	Sandstone, iron induration	Pinkish-grey (7.5YR 7/2), well-consolidated sandstone. Bands of iron induration present throughout. Sand quartz, medium-grained, subrounded and moderately sorted. Some (minor) angular quartz clasts to 4mm.
106–118	Sandstone, iron induration	Pinkish-grey (7.5YR 7/2), well-consolidated sandstone. Bands of iron induration present throughout. Sand quartz, medium- to coarse-grained, subrounded and moderately sorted. Some (minor) angular quartz clasts (shards).
118–120	Sandstone, interbedded siltstone, iron induration	As above, with layers of brown, hard siltstone. Likely fractured.
120–124	Sandstone, iron induration	Light-grey (5YR 7/1), well-consolidated sandstone. Fine- to medium-grained, subrounded and moderately sorted. Bands of iron induration present throughout.
124–125	Sandstone, conglomerate	Rounded cobbles of very hard, fine-grained pinkish quartz sandstone (returning as shards) within matrix of light-grey (5YR 7/1), well-consolidated sandstone.
125–126.5	Shale	Grey (Gley 6/1) soft shale. Micaceous siltstone at 125–125.1m.

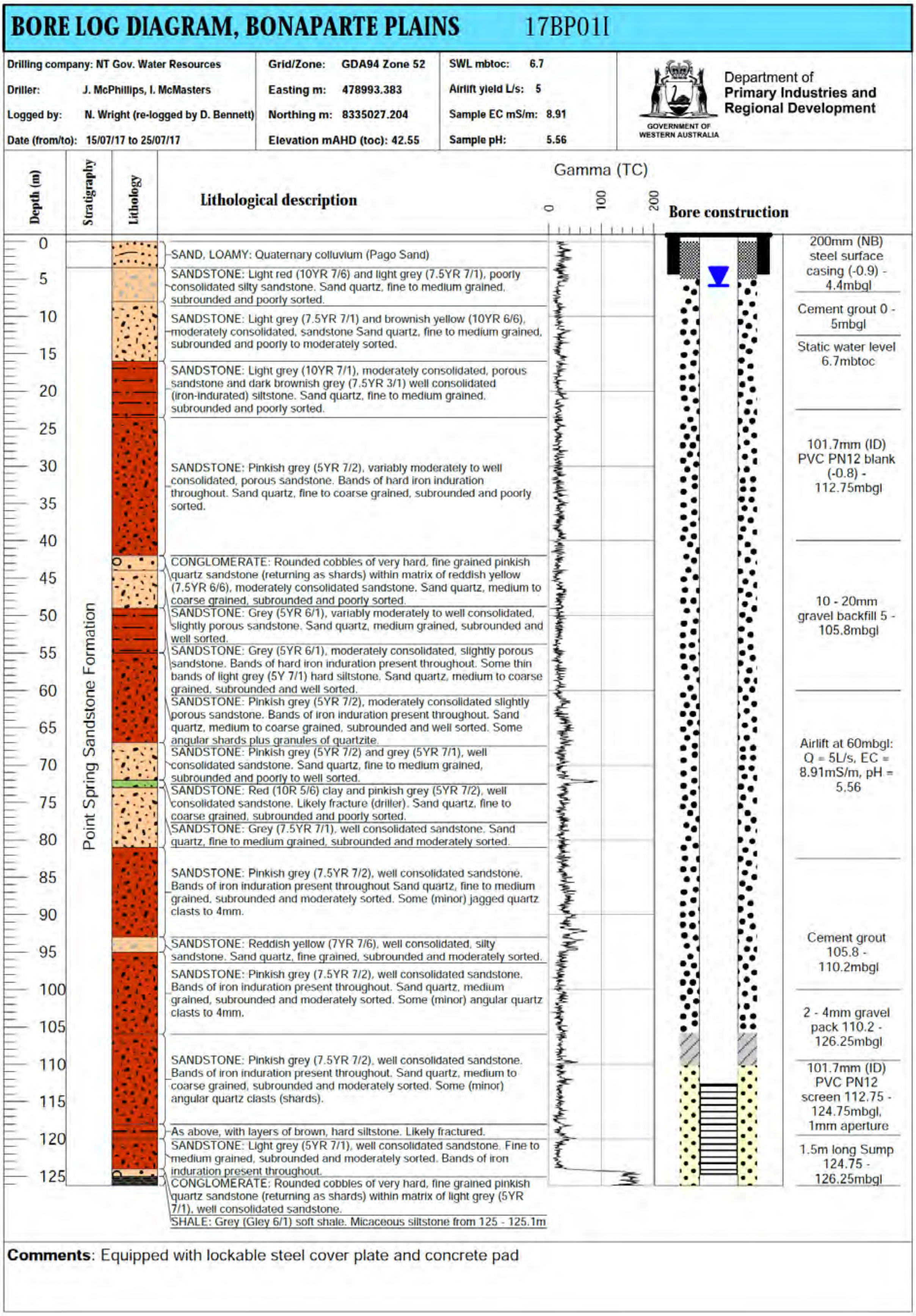


Figure 5.6 Bore diagram for monitoring bore 17BP01I

Table 5.13 Summary formation log for monitoring bore 17BP01S

Depth (mBGL)	Stratigraphy
0–3.5	Quaternary colluvium (Pago Sand)
3.5–126.1	Point Spring Sandstone Formation

Table 5.14 Lithology log for monitoring bore 17BP01S

Depth (mBGL)	Lithology	Description
0–1	Sand, loamy	Pinkish-white (7.5YR 8/2) loamy sand. Sand mainly quartz, fine- to medium-grained, subrounded and poorly sorted.
1–2	Sand, clayey	Pinkish-grey (5YR 7/2) clayey sand. Sand mainly quartz, fine- to medium-grained, subrounded and poorly sorted.
2–3	Loam, sandy	Reddish-yellow (5YR 6/6) sandy loam. Sand mainly quartz, fine-grained, subrounded and poorly sorted.
3–3.5	Clay, sandy	Light-red (10YR 6/6) sandy clay. Sand mainly quartz, fine-grained, subrounded and poorly sorted.
3.5–7	Sandstone, silty	Light-red (10YR 7/6), poorly consolidated silty sandstone. Sand quartz, fine- to medium-grained, subrounded and poorly sorted.
7–8	Sandstone, silty	Light-grey (7.5YR 7/1), poorly consolidated, silty sandstone. Sand quartz, fine- to medium-grained, subrounded and poorly sorted.
8–14	Sandstone	Light-grey (7.5YR 7/1), moderately consolidated, sandstone Sand quartz, fine- to medium-grained, subrounded and moderately sorted.
14–15.3	Sandstone	Brownish-yellow (10YR 6/6), moderately consolidated sandstone. Sand quartz, fine- to medium-grained, subrounded and poorly sorted.

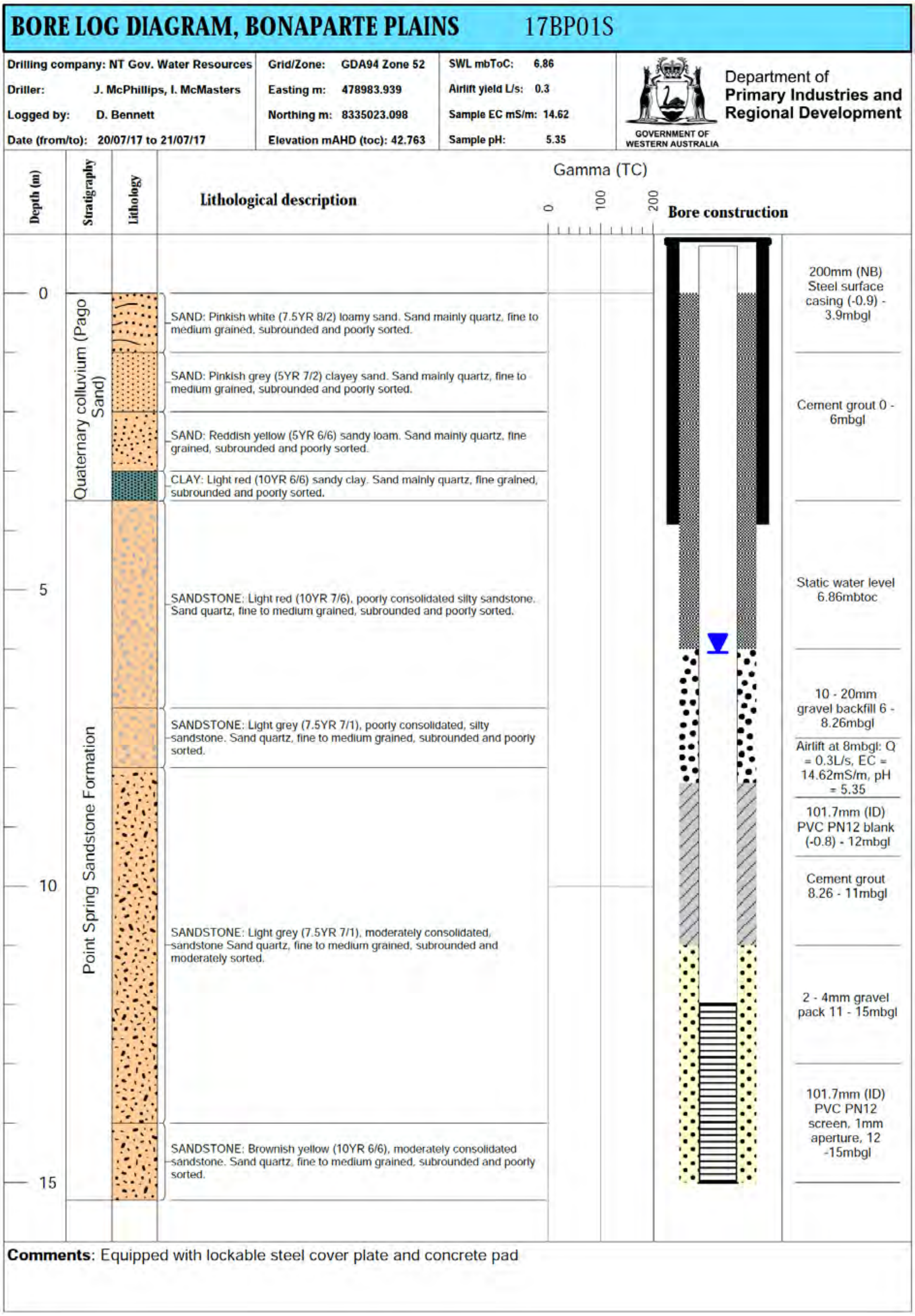


Figure 5.7 Bore diagram for monitoring bore 17BP01S

Table 5.15 Summary formation log for test-pumping bore 17BP01PB

Depth (mBGL)	Stratigraphy
0–4	Quaternary colluvium (Pago Sand)
4–126.25	Point Spring Sandstone Formation

Table 5.16 Lithology log for monitoring bore 17BP01PB

Depth (mBGL)	Lithology	Description
0–4	Sand, loamy	Quaternary colluvium (Pago Sand).
4–8	Sandstone, silty	Light-grey (7.5YR 7/1), poorly consolidated, silty sandstone. Sand quartz, fine- to medium-grained, subrounded and poorly sorted.
8–16	Sandstone	Light-grey (7.5YR 7/1) and brownish-yellow (10YR 6/6), moderately consolidated, sandstone. Sand quartz, fine- to medium-grained, subrounded and poorly to moderately sorted.
16–23	Sandstone, interbedded siltstone, iron induration	Light-grey (10YR 7/1), moderately consolidated, porous sandstone and dark brownish-grey (7.5YR 3/1) well-consolidated (iron-indurated) siltstone. Sand quartz, fine- to medium-grained, subrounded and poorly sorted.
23–42	Sandstone, iron induration	Pinkish-grey (5YR 7/2), variably moderately to well-consolidated, porous sandstone. Bands of hard iron induration throughout. Sand quartz, fine- to coarse-grained, subrounded and poorly sorted.
42–44	Sandstone, conglomerate	Rounded cobbles of very hard, fine-grained pinkish quartz sandstone (returning as shards) within matrix of reddish-yellow (7.5YR 6/6), moderately consolidated sandstone. Sand quartz, medium- to coarse-grained, subrounded and poorly sorted.
44–49	Sandstone	Grey (5YR 6/1), variably moderately to well-consolidated, slightly porous sandstone. Sand quartz, medium-grained, subrounded and well sorted.
49–55	Sandstone, interbedded siltstone, iron induration	Grey (5YR 6/1), moderately consolidated, slightly porous sandstone. Bands of hard iron induration present throughout. Some thin bands of light-grey (5Y 7/1) hard siltstone. Sand quartz, medium- to coarse-grained, subrounded and well sorted.
55–67	Sandstone, iron induration	Pinkish-grey (5YR 7/2), moderately consolidated slightly porous sandstone. Bands of iron induration present throughout. Sand quartz, medium- to coarse-grained, subrounded and well sorted. Some angular shards plus granules of quartzite.
67–68	Sandstone	Pinkish-grey (5YR 7/2), well-consolidated sandstone. Sand quartz, fine- to medium-grained, subrounded and well sorted.

(continued)

Table 5.16 continued

Depth (mBGL)	Lithology	Description
68–72	Sandstone	Grey (5YR 7/1), well-consolidated sandstone. Sand quartz, fine- to coarse-grained, subrounded and poorly sorted.
72–73	Sandstone, clayey	Red (10R 5/6) clay and pinkish-grey (5YR 7/2), well-consolidated sandstone. Sand quartz, fine- to coarse-grained, subrounded and poorly sorted.
73–81	Sandstone	Grey (7.5YR 7/1), well-consolidated sandstone. Sand quartz, fine- to medium-grained, subrounded and moderately sorted.
81–93	Sandstone, iron induration	Pinkish-grey (7.5YR 7/2), well-consolidated sandstone. Bands of iron induration present throughout. Sand quartz, fine- to medium-grained, subrounded and moderately sorted. Some (minor) jagged quartz clasts to 4mm.
93–95	Sandstone	Reddish-yellow (7YR 7/6), well-consolidated, silty sandstone. Sand quartz, fine-grained, subrounded and moderately sorted.
95–120	Sandstone, iron induration	Pinkish-grey (7.5YR 7/2), well-consolidated sandstone. Bands of iron induration present throughout. Sand quartz, medium- to coarse-grained, subrounded and moderately sorted. Some (minor) jagged quartz shards.
120–124	Sandstone, iron induration	Light-grey (5YR 7/1), well-consolidated sandstone. Fine- to medium-grained, subrounded and moderately sorted. Bands of iron induration present throughout.
124–125	Sandstone	Light-grey (5YR 7/1), well-consolidated sandstone. Sand quartz, fine- to coarse-grained, subrounded and poorly sorted. Some shards of very hard, fine-grained pinkish quartz sandstone.
125–126.25	Shale	Grey (Gley 6/1) soft shale.

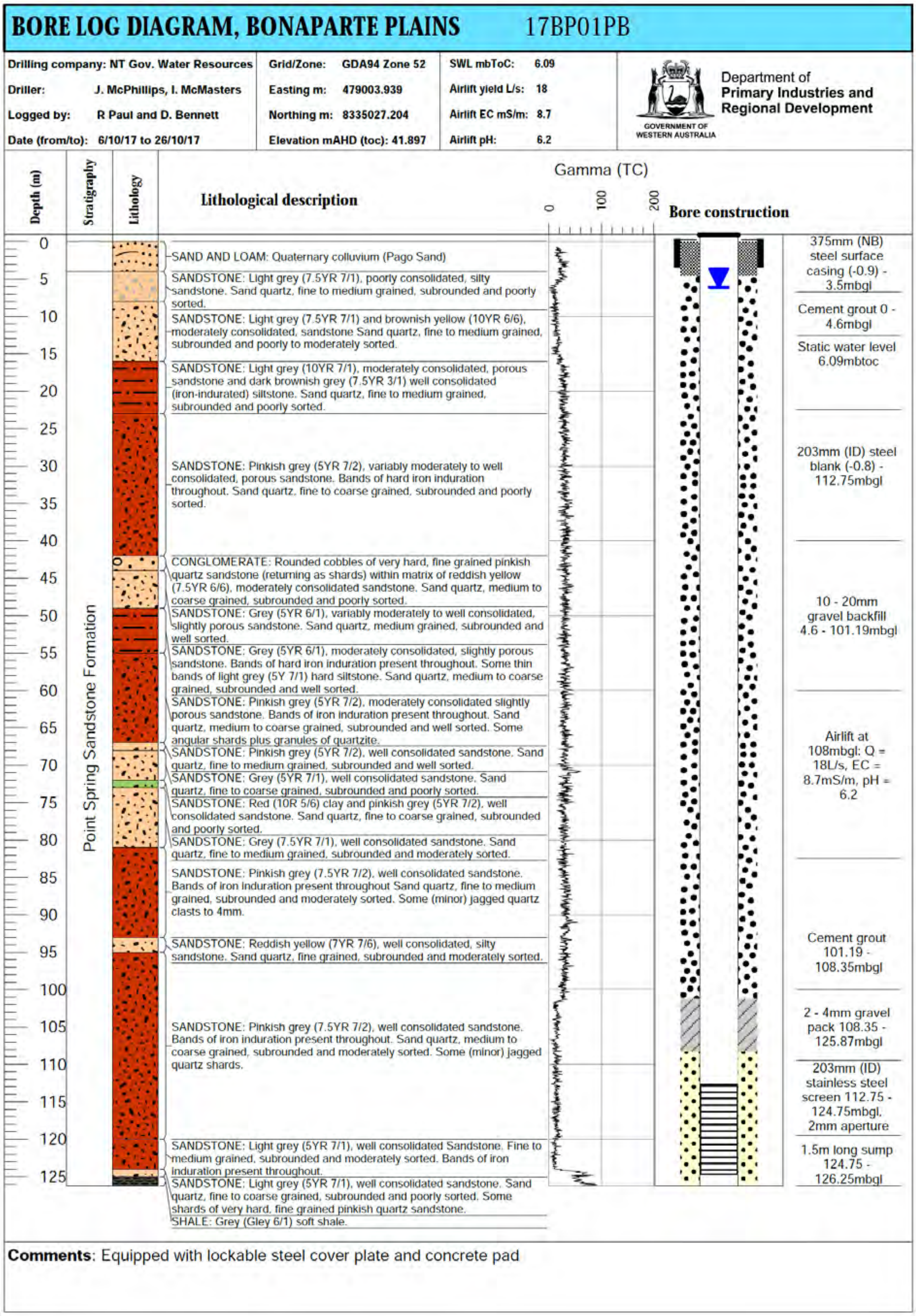


Figure 5.8 Bore diagram for test-pumping bore 17BP01PB

5.5 Site 17BP02

5.5.1 Site description

Site 17BP02 is located near the north-eastern edge of the Cockatoos Sands, near to, and hydraulically up-gradient of, groundwater springs to the north-east. The location was selected to determine the groundwater gradient towards the springs, obtain information about groundwater conditions and lithology in the area and to provide a long-term monitoring site close to the springs.

5.5.2 Drilling depths and screen placement

Drilling finished at 132mBGL in iron-enriched, fine-grained sandstone, interbedded with thin layers of shale, clay and siltstone. The target shale layer — forecast from the AEM data to be located from 110mBGL — was not encountered. Bore 17BP02I was screened at 102–114mBGL, within very poorly consolidated, medium- to coarse-grained sandstone. A 16.5m-long sump was installed below the screen.

After the bore annulus was cemented, a pinch in the casing was discovered at about 10mBGL, preventing objects larger than about 0.02m in diameter from passing through. Unfortunately, this was not rectified before the end of the 2017 program. However, in 2018 the drillers opened the approximately 1m-long pinched zone by coring through it with a 75mm diameter bit. The solid cement grout now forms the casing wall in this zone.

The accompanying shallow bore, 17BP02S, was screened at 30–33mBGL.

5.5.3 Bore stratigraphy and lithology

Table 5.17 and Table 5.18 show the formation stratigraphy and the lithology, respectively, for monitoring bore 17BP02I. Figure 5.9 shows the bore completion diagram.
Table 5.19 and Table 5.20 show the formation stratigraphy and the lithology, respectively, for bore 17BP02S. Figure 5.10 shows the bore completion diagram.

Table 5.17 Summary formation log for monitoring bore 17BP02I

Depth (mBGL)	Stratigraphy
0–9	Cainozoic sandplain (Cockatoo Sands)
9–34	Point Spring Sandstone Formation

Table 5.18 Lithology log for monitoring bore 17BP02I

Depth (mBGL)	Lithology	Description
0–9	Sand, loamy	Cainozoic sandplain (Cockatoo Sands).
9–15	Sandstone, silty	Reddish-yellow (7.5YR 7/8), well-consolidated siltstone/sandstone. Sand quartz, very fine- to fine-grained, subrounded and moderately sorted.
15–27	Sandstone, silty	Pink (7.5YR 8/3), well-consolidated sandstone/siltstone. Sand quartz, fine- to medium-grained, rounded to subrounded and poorly sorted.
27–38	Sandstone	Pinkish light-grey (5YR 7/3), poorly consolidated sandstone. Sand quartz, fine- to medium-grained, subrounded and moderately sorted.
38–42	Sandstone	Light-grey (5YR 7/1), well-consolidated sandstone. Porous. Sand quartz, medium-grained, subrounded and well sorted.
42–64	Sandstone	Pinkish light-grey (7.5YR 7/2), poorly consolidated sandstone. Sand quartz, medium- to coarse-grained, subrounded and moderately sorted. Minor flecks of soft, white feldspar.
64–81	Sandstone	Pinkish light-grey (5YR 7/1), well-consolidated sandstone. Sand quartz, fine- to medium-grained, subrounded and poorly sorted. Contains minor smoky- to pink-coloured, angular quartz shards 2–10mm.
81–89	Sandstone	Very pale-brown (10YR 8/2), well-consolidated sandstone. Sand quartz, fine- to medium-grained, subrounded and poorly sorted. Contains some (minor) frosted, subrounded quartz pebbles to 10mm.
89–90	Sandstone, iron induration	As above, but variably enriched with light reddish-brown (5YR 6/3) iron oxide, returning as hard flakes. Likely fractures.
90–95	Sandstone	Pinkish-white (5YR 8/2), moderately consolidated sandstone. Sand quartz, fine- to medium-grained, subrounded and well sorted.
95–97	Sandstone, iron induration	As above, but variably iron-indurated.
97–107	Sandstone	Pinkish light-grey (7.5YR 7/1 and 5YR 7/1), poorly to very poorly consolidated sandstone. Sand quartz, medium-grained, subrounded, and poorly sorted. Minor rounded, frosted quartz pebbles to 5mm. Minor soft, white clay (feldspar?) flecks and siltstone clasts. Minor (crystalline) small micaceous clasts at 102–107m.
107–115	Sandstone	Pinkish light-grey (5YR 7/1), very poorly consolidated sandstone. Sand quartz, medium- to coarse-grained, subrounded and poorly sorted. Moderately consolidated at 113–115m.
115–120	Sandstone, iron induration	Pink (7.5YR 7/3), well-consolidated (iron-indurated) sandstone. Sand quartz, fine- to medium-grained, subrounded and mainly well sorted. Some large (to 20mm), angular quartz shards.
120–123	Sandstone, interbedded siltstone	Layers of light reddish-grey (2.5YR 7/1), very well-consolidated, fine-grained sandstone with alternating thin layers of soft clay and microbanded grey and purple hard siltstone.
123–132	Sandstone, interbedded shale, iron induration	Mainly reddish-grey (2.5YR 5/1), well-consolidated (iron-indurated), fine-grained sandstone, and pinkish-grey (5YR 7/2), moderately consolidated, fine-grained sandstone. Contains thin layers of hard, light-grey shale and soft, grey and brown shale.

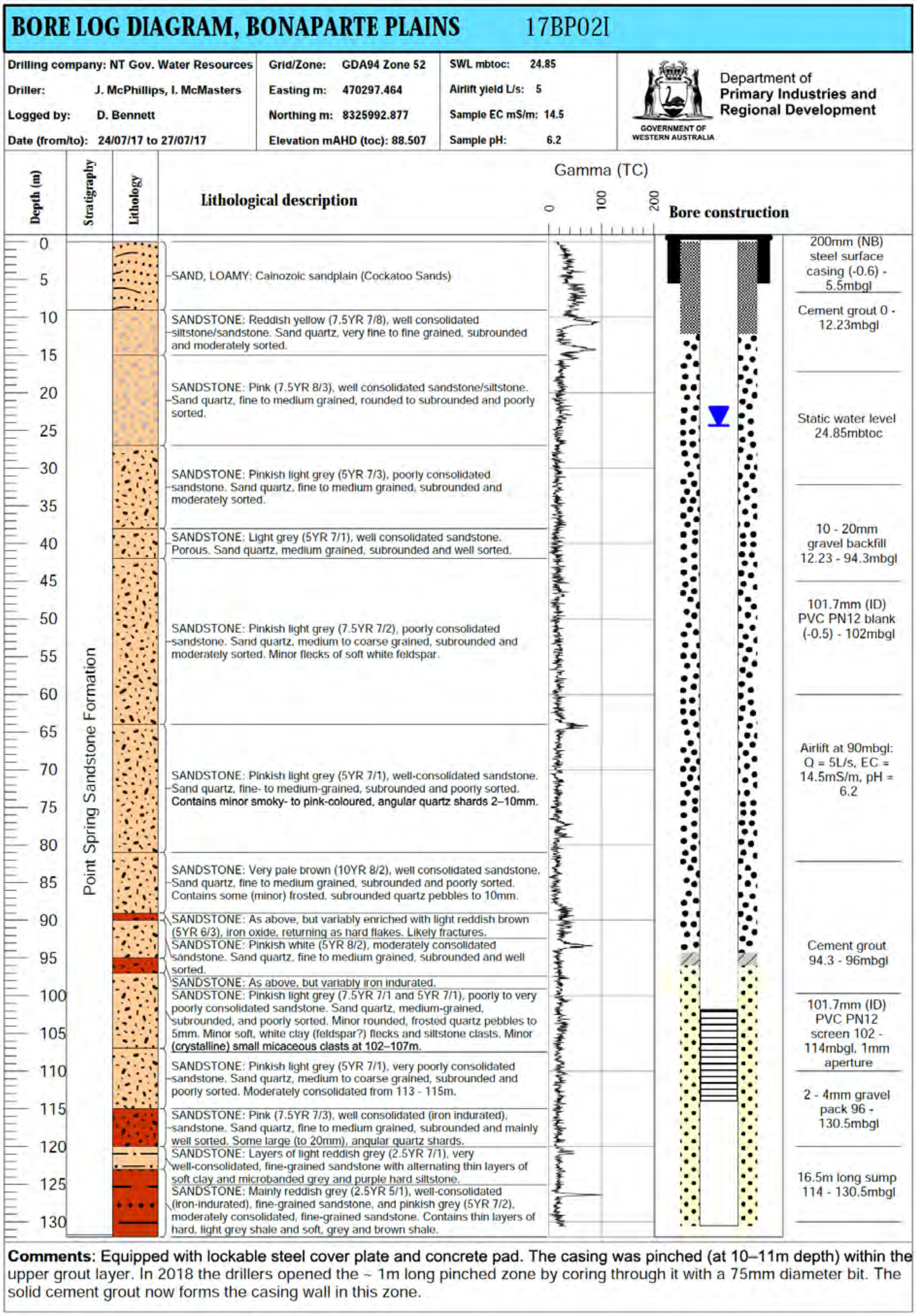


Figure 5.9 Bore diagram for monitoring bore 17BP02I

Table 5.19 Summary formation log for monitoring bore 17BP02S

Depth (mBGL)	Stratigraphy
0–9	Cainozoic sandplain (Cockatoo Sands)
9–34	Point Spring Sandstone Formation

Table 5.20 Lithology log for monitoring bore 17BP02S

Depth (mBGL)	Lithology	Description
0–1	Sand, loamy	Red (2.5YR 4/8), loamy sand. Sand mainly quartz, fine-grained, sub-angular and moderately sorted.
1–9	Loam, sandy	Red (10R 4/8), sandy loam. Sand mainly quartz, very fine-grained, sub-angular and moderately sorted.
9–15	Sandstone, silty	Reddish-yellow (7.5YR 7/8), well-consolidated siltstone/sandstone. Sand quartz, very fine- to fine-grained, angular and moderately sorted.
15–27	Sandstone, silty	Pink (7.5YR 8/3), well-consolidated sandstone/siltstone. Sand quartz, fine- to medium-grained, rounded to subrounded and poorly sorted.
27–34	Sandstone	Pinkish light-grey (5YR 7/3), poorly consolidated sandstone. Sand quartz, fine- to medium-grained, subrounded and moderately sorted. Wet from 27m.

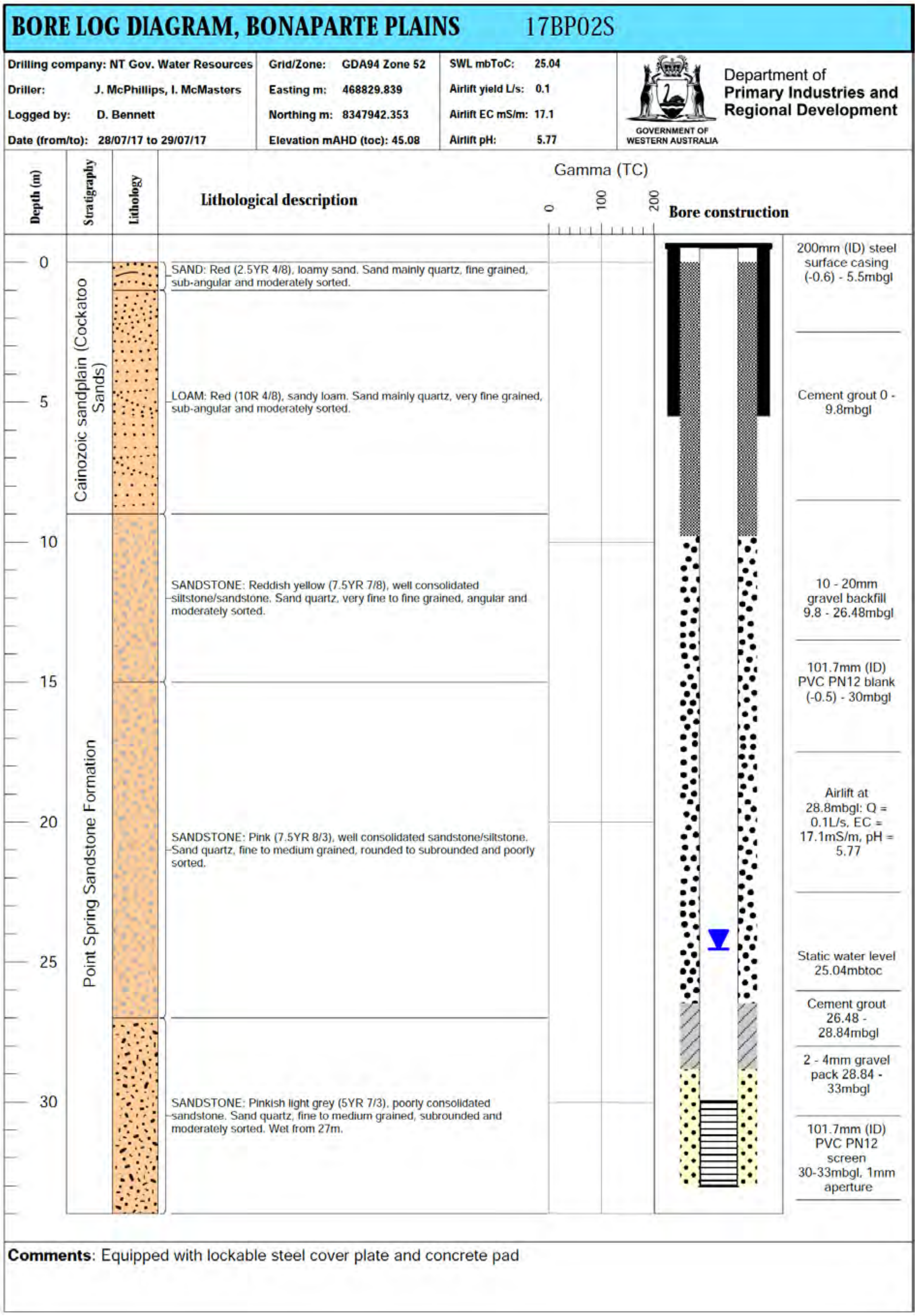


Figure 5.10 Bore diagram for monitoring bore 17BP02S

5.6 Site 17BP03

5.6.1 Site description

Site 17BP03 is located on the topographic high point of the Cockatoo Sands, which was forecast to have the highest groundwater level. Its location allowed groundwater gradients to be determined between it and several other bores in different directions. Being in the approximate centre of the large northern half of the Cockatoo Sands area, it was also an important representative location for determining lithology and groundwater conditions, and providing future monitoring.

5.6.2 Drilling depths and screen placement

Drilling progression for bore 17BP03I finished at 52mBGL, once the shale layer — forecast from the AEM data to be located from 60mBGL — was encountered at 51mBGL. The groundwater level was estimated to be 42mBGL during drilling. Therefore, the screen was configured as a shallow bore for isotope sampling, with a 3m-long screen placed about 6m below the watertable. Bore 17BP03I was screened at 44.7–47.7mBGL within conglomerate and poorly consolidated, medium-grained sandstone. A 2m-long sump was installed below the screen.

No shallow bore was installed because it was assumed there would be little lithological difference between the two bore screens.

5.6.3 Bore stratigraphy and lithology

Table 5.21 and Table 5.22 show the formation stratigraphy and the lithology, respectively, for monitoring bore 17BP03I. Figure 5.11 shows the bore completion diagram.

Table 5.21 Summary formation log for monitoring bore 17BP03I

Depth (mBGL)	Stratigraphy
0–8	Cainozoic sandplain (Cockatoo Sands)
8–52	Point Spring Sandstone Formation

Table 5.22 Lithology log for monitoring bore 17BP03I

Depth (mBGL)	Lithology	Description
0–1	Sand, loamy	Red (2.5YR 5/6) loamy sand. Sand mainly quartz, fine-grained, subrounded, and moderately sorted.
1–3	Loam, sandy	Red (10R 4/8) sandy loam. Sand mainly quartz, fine-grained, subrounded, and moderately sorted.
3–5	Loam, clayey	Red (10R 4/6), clayey loam. Sand mainly quartz, very fine-grained, subrounded, and mainly moderately sorted. Minor ironstone nodules to 10mm.
5–6	Loam, clayey	Red (10R 5/8), clayey loam. Sand mainly quartz, very fine-grained, subrounded, and moderately sorted. Contains about 20% ironstone nodules and some (very minor) frosted, rounded quartz pebbles to 5mm.
6–8	Sand, loamy	Red (10R 4/8) loamy sand. Sand mainly quartz, very fine-grained, subrounded, and moderately sorted.
8–11	Sandstone, iron induration	Red (2.5YR 4/8), poorly consolidated sandstone. Sand quartz, fine- to coarse-grained (up to fine gravel), subrounded and rounded, and poorly sorted. Also contains iron-indurated clasts, and some (minor) grey, hard siltstone clasts.
11–19	Sandstone, iron induration	Yellowish-red (5YR 5/8), poorly consolidated sandstone. Some layers of hard iron induration. Sand quartz, fine- to coarse-grained (with some rounded fine gravel), subrounded and poorly sorted.
19–23	Sandstone, iron induration	Yellowish-red (5YR 5/8), moderately consolidated (iron-indurated) sandstone. Some thin layers of light-grey, soft clay. Sand quartz, fine-grained, subrounded and poorly sorted.
23–33	Sandstone	Pinkish-white (5YR 8/2), poorly consolidated sandstone. Sand quartz, medium-grained, subrounded and poorly sorted. Some large angular quartz clasts. Some rounded, frosted, quartz fine gravel.
33–34	Sandstone, iron induration	As above but light-red (2.5YR 6/6) and well-consolidated (iron-indurated) sandstone.
34–42	Sandstone	Pinkish-brown (5YR 7/3), poorly consolidated sandstone. Sand quartz, fine- to medium-grained, subrounded to rounded and well sorted. Some (minor) rounded, quartz fine to medium gravel.
42–47	Sandstone, conglomerate	Rounded cobbles of very hard, fine-grained quartz sandstone within a matrix of pinkish-grey (5YR 6/2), poorly consolidated sandstone. Sand quartz, medium-grained, subrounded and sorted (of sandstone matrix). Wet from 42m.
47–50	Sandstone, iron induration	Pink (7.5YR 7/4), moderately consolidated (iron-indurated) sandstone. Sand quartz, medium-grained, subrounded to rounded and sorted. Some (minor) rounded, frosted, quartz fine to medium gravel.
50–51	Siltstone	Light-grey (2.5YR 8/1), with minor microbands of purple, hard, fine siltstone. Returns as shards and platelets.
51–52	Shale	Grey (Gley 7/N), soft shale. Returns as platelets.

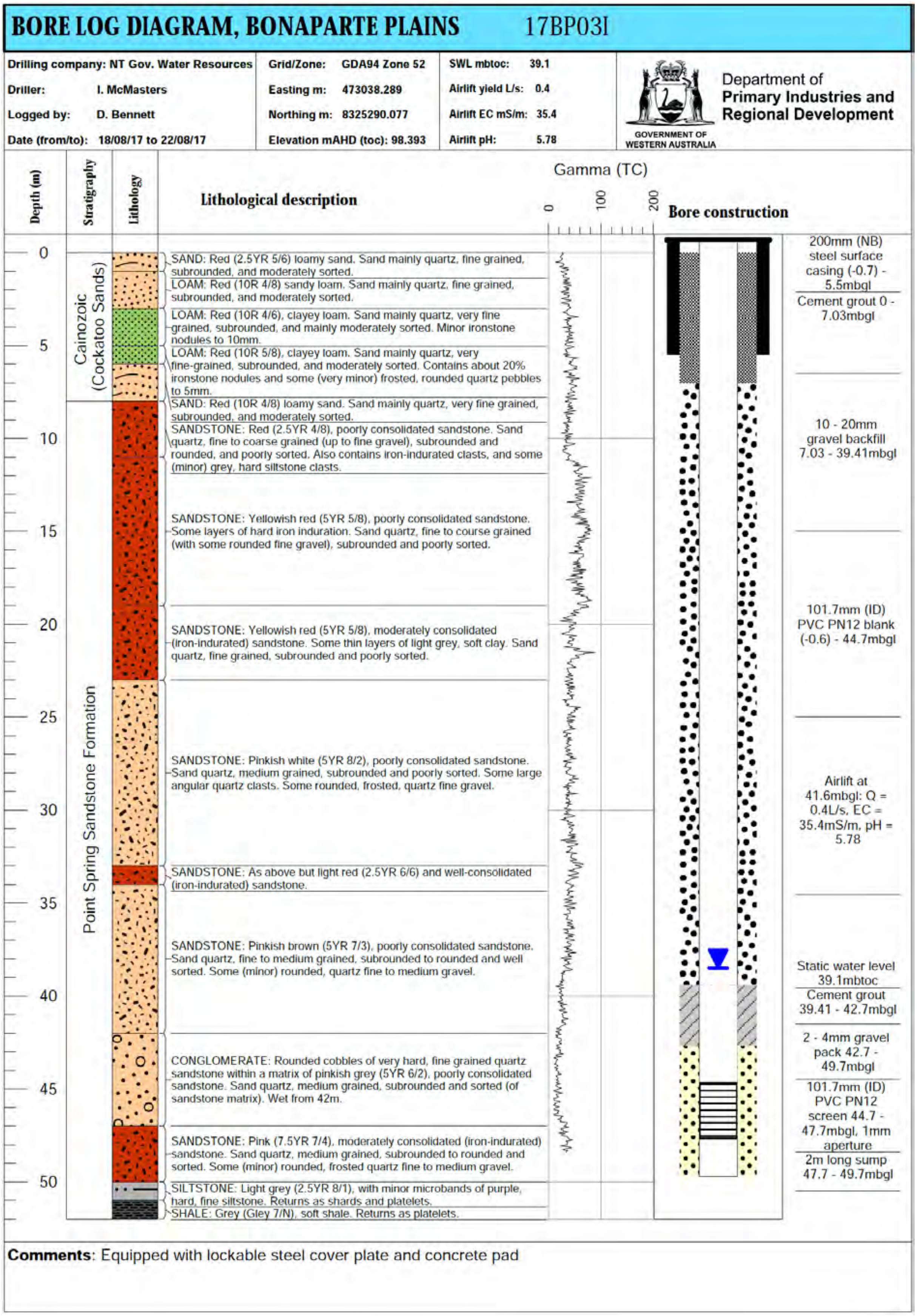


Figure 5.11 Bore diagram for monitoring bore 17BP03I

5.7 Site 17BP04

5.7.1 Site description

Site 17BP04 was selected to obtain information about groundwater conditions and lithology beneath the northern area of Cockatoo Sands, and in conjunction with site 17BP05, to determine the groundwater gradient towards the springs to the north.

5.7.2 Drilling depths and screen placement

The target shale layer was intercepted at 57mBGL, which was similar to the 60mBGL forecast from the AEM data. Bore 17BP04I was screened at 45–57mBGL, within very poorly consolidated, porous, medium- to coarse-grained sandstone and quartz gravel. A 4.2m-long sump was installed below the screen. During drilling, the groundwater yield returned in the airstream was 9L/s.

The accompanying shallow bore, 17BP04S, was screened at 45–48mBGL.

5.7.3 Bore stratigraphy and lithology

Table 5.23 and Table 5.24 show the formation stratigraphy and the lithology, respectively, for monitoring bore 17BP04I. Figure 5.12 shows the bore completion diagram.
Table 5.25 and Table 5.26 show the formation stratigraphy and the lithology, respectively, for monitoring bore 17BP04S. Figure 5.13 shows the bore completion diagram.

Table 5.23 Summary formation log for monitoring bore 17BP04I

Depth (mBGL)	Stratigraphy
0–4	Cainozoic sandplain (Cockatoo Sands)
4–62	Point Spring Sandstone Formation

Table 5.24 Lithology log for monitoring bore 17BP04I

Depth (mBGL)	Lithology	Description
0–4	Sand, loamy	Cainozoic sandplain (Cockatoo Sands).
4–5	Sandstone, interbedded siltstone	Yellowish-brown (10YR 5/6), poorly consolidated sandstone and siltstone. Sand quartz, fine- to medium-grained, subrounded and moderately sorted. Some (minor) ironstone nodules.
5–21	Sandstone, interbedded siltstone	Grey (7.5YR 5/1) and very pale-brown (10YR 8/2) poorly consolidated sandstone and siltstone. Siltstone occurs as several thin layers at various intervals. Sand quartz, fine- to medium-grained, subrounded and moderately sorted. Some (minor) small iron-indurated granules.
21–27	Sandstone	Uniformly light-grey (2.5Y 8/1), poorly consolidated sandstone. Sand quartz, medium-grained, subrounded and well sorted. Some (minor) rounded, fine quartz gravel.
27–28	Sandstone interbedded siltstone, iron induration	Dark red/brown (10R4/6), well-consolidated (iron-indurated) sandstone and siltstone. Yellow/brown (7.5YR 7/7) siltstone occurring in fine layers. Sand quartz, fine- to medium-grained and subrounded.
28–31	Sandstone, iron induration	Light-brown (5YR 6/6) well-consolidated sandstone. Sand quartz, fine- to medium-grained, subrounded and moderately sorted. Some (minor) iron-indurated sandstone clasts.
31–40.5	Sandstone, interbedded siltstone	Layers of brown, light-grey and yellowish-grey poorly consolidated sandstone and siltstone. Sand quartz, fine-grained, subrounded and well sorted. Moisture at 39m.
40.5–43.5	Siltstone	Light-grey (2.5YR 8/1), with microbands of purple, well-consolidated siltstone.
43.5–57	Sandstone	Light brownish-grey (2.5YR 7/1) very poorly consolidated and porous sandstone. Sand quartz, medium to coarse-grained, subrounded and well sorted. Water return was 9L/s by 57m.
57–60.55	Shale	Layered grey (2.5Y 8/1), brown and maroon, well-consolidated to hard shale. Returns as platelets. Micaceous layer at 60.5–60.55m.
60.55–62	Shale	Grey (Gley 7/N) soft shale. Returns as platelets.

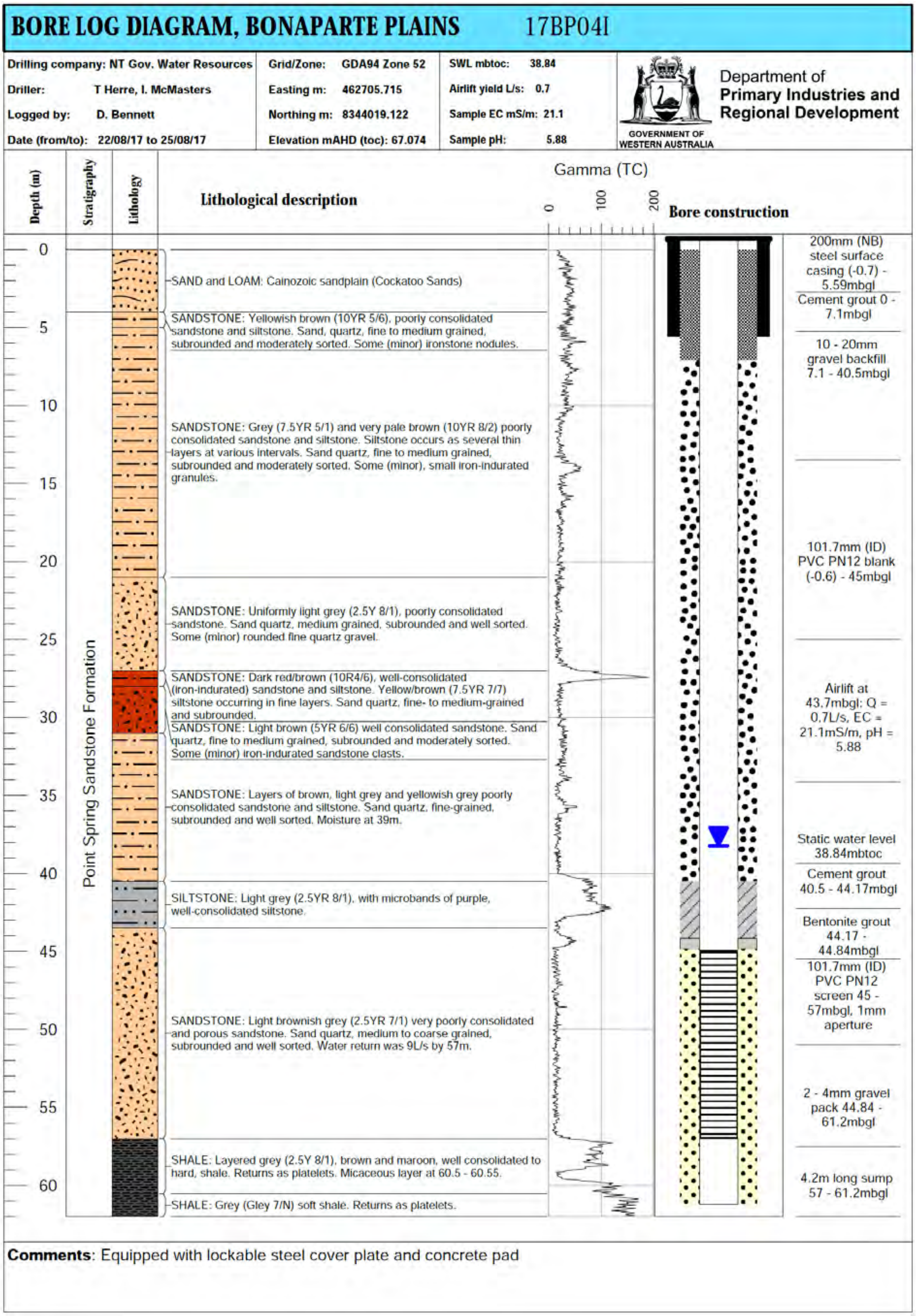


Figure 5.12 Bore diagram for monitoring bore 17BP04I

Table 5.25 Summary formation log for monitoring bore 17BP04S

Depth (mBGL)	Stratigraphy
0–4	Cainozoic sandplain (Cockatoo Sands)
4–49	Point Spring Sandstone Formation

Table 5.26 Lithology log for monitoring bore 17BP04S

Depth (mBGL)	Lithology	Description
0–1	Sand, loamy	Red (2.5YR 5/6) loamy sand. Sand mainly quartz, fine-grained, subrounded, and moderately sorted.
1–2	Loam, sandy	Red (2.5YR 4/8) sandy loam. Sand mainly quartz, fine-grained, subrounded, and moderately sorted.
2–4	Loam, clayey	Red (2.5YR 4/8) clayey loam. Sand mainly quartz, very fine-grained, subrounded, and moderately sorted.
4–5	Sandstone, interbedded siltstone	Yellowish-brown (10YR 5/6), poorly consolidated sandstone and siltstone. Sand quartz, fine- to medium-grained, subrounded and moderately sorted. Some (minor) ironstone nodules.
5–21	Sandstone, interbedded siltstone	Grey (7.5YR 5/1) and very pale-brown (10YR 8/2), poorly consolidated sandstone and siltstone. Siltstone occurs as several thin layers at various intervals. Sand quartz, fine- to medium-grained, subrounded and moderately sorted. Some (minor) small iron-indurated granules.
21–27	Sandstone	Uniformly light-grey (2.5Y 8/1), poorly consolidated sandstone. Sand quartz, medium-grained, subrounded and well sorted. Some (minor) rounded, quartz fine gravel.
27–28	Sandstone, interbedded siltstone, iron induration	Dark red-brown (10R4/6), well-consolidated, iron-indurated sandstone and siltstone. Yellow/brown (7.5YR 7/7) siltstone occurring in fine layers. Sand quartz, fine- to medium-grained and subrounded.
28–31	Sandstone, iron induration	Light-brown (5YR 6/6), well-consolidated sandstone. Sand quartz, fine- to medium-grained, subrounded and moderately sorted. Some (minor) iron-indurated sandstone clasts.
31–40.5	Sandstone, interbedded siltstone	Layers of brown, light-grey and yellowish-grey poorly consolidated sandstone and siltstone. Sand quartz, fine-grained, well sorted and subrounded. Moisture at 39m.
40.5–43.5	Siltstone	Light-grey (2.5YR 8/1), with microbands of purple, well-consolidated siltstone.
43.5–49	Sandstone	Light brownish-grey (2.5YR 7/1), very poorly consolidated and porous sandstone. Sand quartz, medium to coarse-grained, subrounded and well sorted.

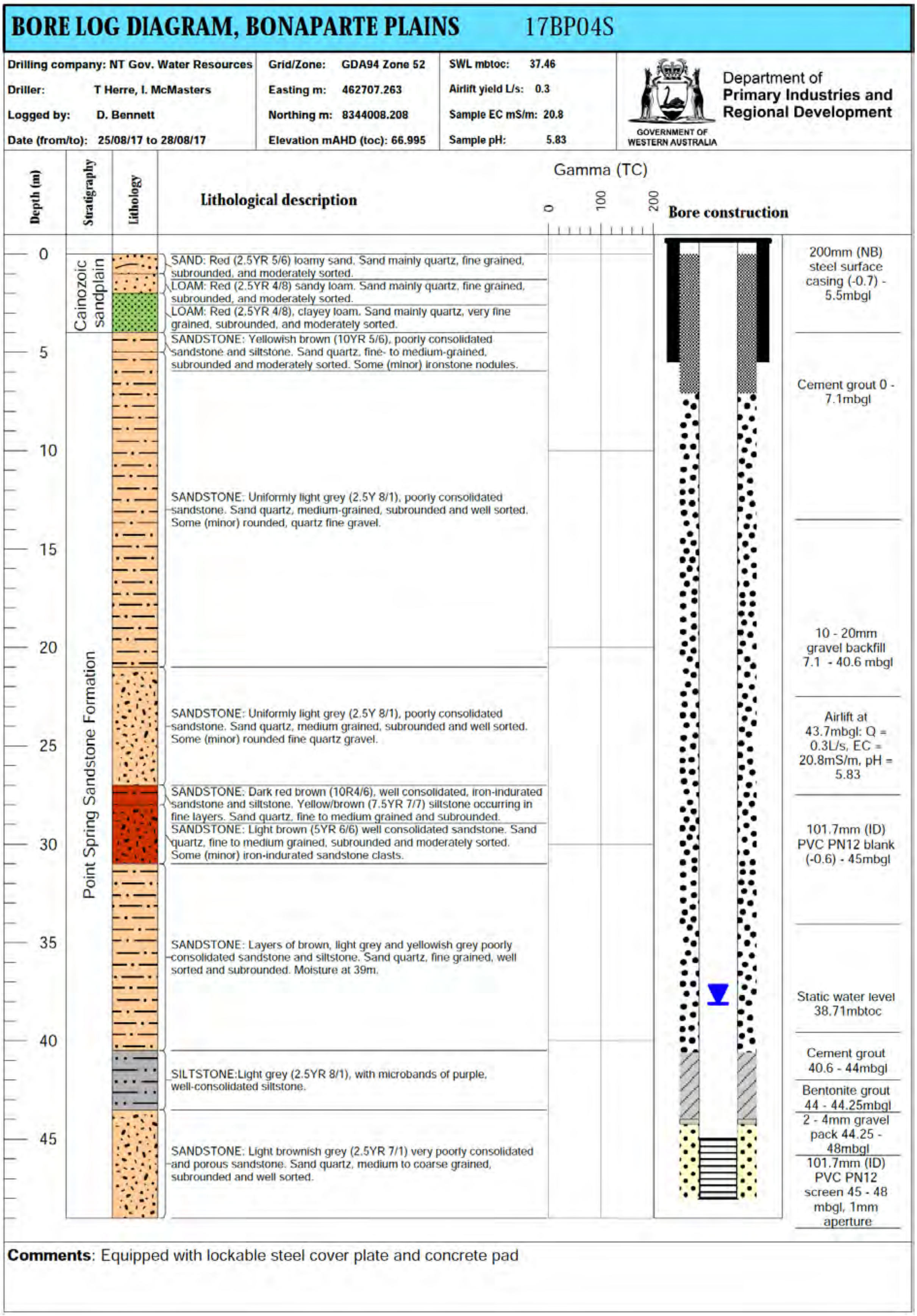


Figure 5.13 Bore diagram for monitoring bore 17BP04S

5.8 Site 17BP05

5.8.1 Site description

Site 17BP05 was selected to:

- obtain information on groundwater conditions and lithology beneath the northern area of Cockatoo Sands, close to the groundwater springs to the north (Figure 2.1)
- provide a long-term monitoring site close to the northern springs
- in conjunction with site 17BP04, determine the groundwater gradient towards the northern springs
- if aquifer conditions were suitable, install a test-pumping bore to determine aquifer parameters and test the aquifer yield near the large uniform area of Cockatoo Sands where the groundwater head was forecast to be relatively shallow (20mBGL).

5.8.2 Drilling depths and screen placement

The target shale layer was intercepted at 90.5mBGL, which was similar to the 95mBGL depth forecast from the AEM data. Bore 17BP05I was screened at 77.13–89.13mBGL within very poorly consolidated, porous, medium- to coarse-grained sandstone and quartz gravel. During drilling, the groundwater yield returned in the airstream was 35L/s. A 6m-long sump was installed below the screen.

Because of the relatively shallow water level and high-yielding aquifer encountered in bore 17BP05I, the test-pumping bore 17BP05PB was screened at 76.97–88.97mBGL, above a 2.3m-long sump.

The accompanying shallow bore (17BP05S) was screened at 26–29mBGL.

5.8.3 Bore stratigraphy and lithology

Table 5.27 and Table 5.28 show the formation stratigraphy and the lithology, respectively, for monitoring bore 17BP05I. Figure 5.14 shows the bore completion diagram.

Table 5.29 and Table 5.30 show the formation stratigraphy and the lithology, respectively, for monitoring bore 17BP05S. Figure 5.15 shows the bore completion diagram.

Table 5.31 and Table 5.32 show the formation stratigraphy and the lithology, respectively, for test-pumping bore 17BP05PB. Figure 5.16 shows the bore completion diagram.

Table 5.27 Summary formation log for monitoring bore 17BP05I

Depth (mBGL)	Stratigraphy
0–2	Cainozoic sandplain (Cockatoo Sands)
2–95.8	Point Spring Sandstone Formation

Table 5.28 Lithology log for monitoring bore 17BP05I

Depth (mBGL)	Lithology	Description
0–2	Sand, loamy	Cainozoic sandplain (Cockatoo Sands).
2–6	Sandstone conglomerate	Rounded cobbles of very hard, fine-grained quartz sandstone (returning as shards) within a matrix of reddish-yellow (5YR 7/6), well-consolidated sandstone. Sand quartz, medium- to coarse-grained, subrounded and moderately sorted. Some grey, hard siltstone clasts.
6–15	Sandstone	Very pale-brown (10YR 7/4), moderately consolidated sandstone. Sand quartz, fine- to medium-grained, subrounded and poorly sorted. Some (minor) rounded, quartz fine gravel.
15–17	Sandstone, iron induration	As above, but dark reddish-brown, well-consolidated (iron-indurated) sandstone.
17–19	Sandstone	Pink (5YR 7/4), moderately consolidated sandstone. Sand quartz, fine- to medium-grained, subrounded and moderately sorted.
19–24	Sandstone	Red (2.5YR 5/6), poorly consolidated and porous sandstone. Sand quartz, fine-grained, subrounded and moderately sorted.
24–26	Sandstone	Yellow (10YR 7/8), poorly consolidated sandstone. Sand quartz, fine-grained, subrounded and well sorted.
26–34	Sandstone	Light-grey (10YR 7/2), moderately consolidated, porous sandstone. Sand quartz, medium- to coarse-grained, subrounded and moderately sorted.
34–36	Sandstone, iron induration	As above, but with layers of dusky red (10R 3/4), well-consolidated (iron-indurated) sandstone.
36–38	Sandstone	Light-grey (10YR 7/2), poorly consolidated sandstone. Sand quartz, fine- to medium-grained, subrounded and moderately sorted.
38–40	Sandstone, iron induration	Pink (10YR 8/2), very well-consolidated (iron-indurated) sandstone. Sand quartz, fine- to medium-grained, subrounded and poorly sorted. Water return was 5L/s by 40m.
40–47	Sandstone	Very pale-brown (10YR 7/3) and white (2.5Y 8/1), moderately consolidated sandstone. Sand quartz, medium-grained, subrounded and moderately to well sorted. Water return was 10–15L/s by 47m.
47–47.5	Sandstone, iron induration	Dark reddish-grey (10R 3/1), well-consolidated (iron-indurated) sandstone. Sand quartz, fine- to medium-grained, subrounded and well sorted. Some (minor) jagged quartz clasts.
47.5–49	Sandstone	White (2.5YR 8/1), moderately consolidated sandstone. Sand quartz, medium-grained, rounded, and well sorted.

(continued)

Table 5.28 continued

Depth (mBGL)	Lithology	Description
49–49.5	Sandstone, iron induration	Very dark greyish-brown (10R 3/2), well-consolidated (iron-indurated) sandstone and (minor) yellow (2.5Y 7/6) clay. Sand quartz, medium- to coarse-grained, subrounded and poorly sorted.
49.5–50.5	Siltstone	Light-grey (GLEY 8/7), with minor microbands of purple (10R 5/2), well-consolidated siltstone. Returns as shards and platelets.
50.5–52	Siltstone	Light reddish-grey (2.5Y 7/1), well-consolidated siltstone. Returns as platelets.
52–57.2	Sandstone	Light reddish-grey (2.5Y 7/1) and very pale-brown (10YR7/3), very poorly to poorly consolidated sandstone. Sand quartz, fine- to medium-grained, subrounded and well sorted.
57.2–63	Sandstone	Very pale-brown (10YR 7/3), poorly consolidated sandstone. Sand quartz, fine- to medium-grained, subrounded and well sorted.
63–76.4	Sandstone	Pale-red (2.5YR 7/2), moderately consolidated sandstone. Sand quartz, medium- to coarse-grained, subrounded and well sorted. Some (minor) rounded frosted quartz fine gravel. Water return was 34L/s by 76.4m.
76.4–77.2	Siltstone	Layers of light-red (10Y 7/6), very well-consolidated (iron-indurated) siltstone; dark grey (Gley 4/N), very well-consolidated siltstone; and yellow (10YR 7/6) and light-red (10R 7/6), well-consolidated siltstone.
77.2–89.5	Sandstone	Light-grey (7.5YR 7/1), very poorly consolidated, porous, sandstone. Sand quartz, medium- to coarse-grained, subrounded, and well sorted. Minor rounded, quartz coarse gravel to 40mm.
89.5–90.5	Sandstone, iron induration	Dusky red (10R 3/3), very well consolidated (iron-indurated) sandstone. Sand, quartz, fine-grained, subrounded and well sorted. Water return was 35L/s by 90m.
90.5–95.8	Shale	Grey (GLEY 7/N) soft shale. Returns as platelets.

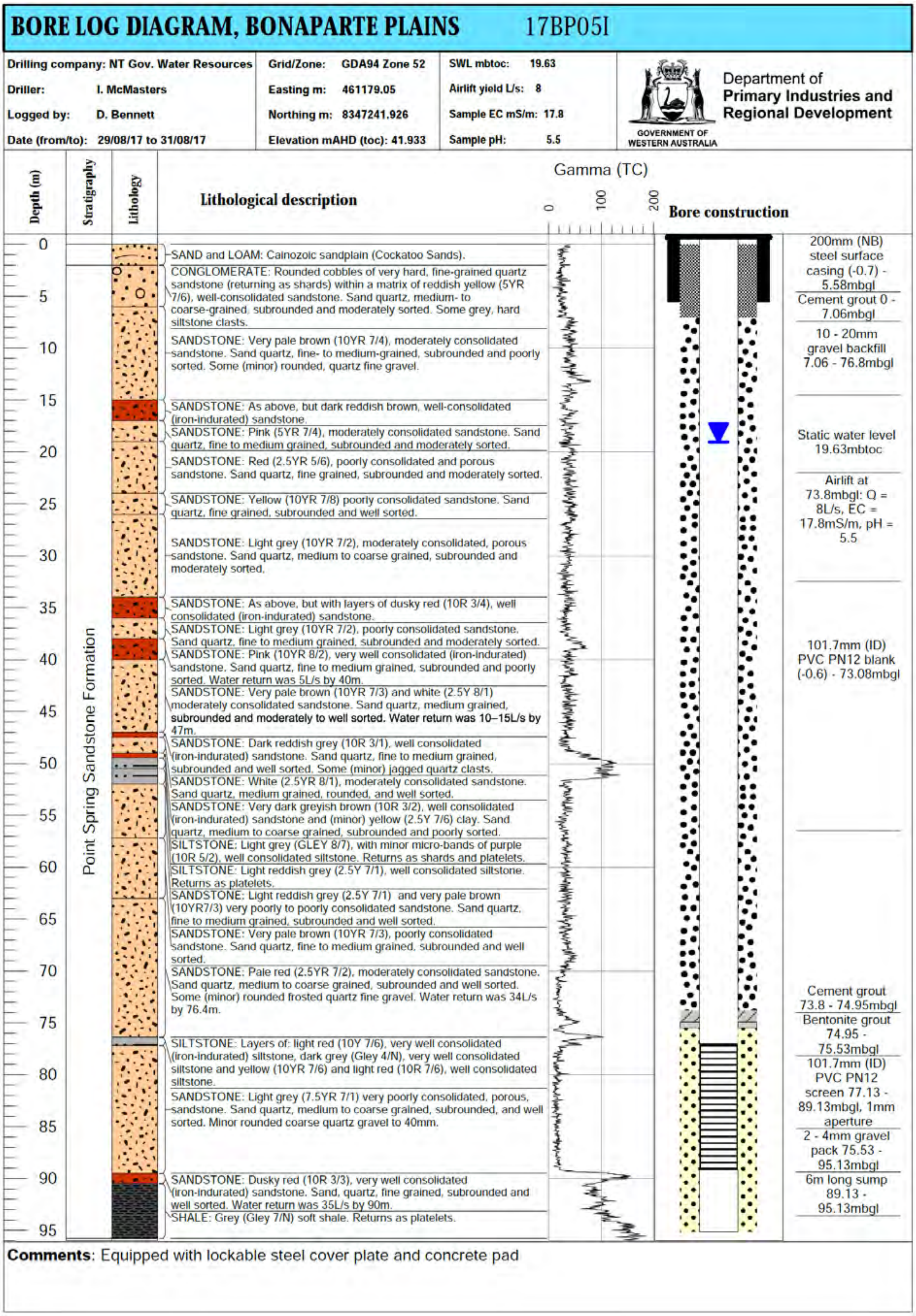


Figure 5.14 Bore diagram for monitoring bore 17BP05I

Table 5.29 Summary formation log for monitoring bore 17BP05S

Depth (mBGL)	Stratigraphy
0–2	Cainozoic sandplain (Cockatoo Sands)
2–29.5	Point Spring Sandstone Formation

Table 5.30 Lithology log for monitoring bore 17BP05S

Depth (mBGL)	Lithology	Description
0–0.5	Sand, loamy	Reddish-yellow (5YR 6/6) loamy sand. Sand mainly quartz, fine-grained, subrounded, and moderately sorted.
0.5–2	Loam, sandy	Red (10R 4/8) sandy loam. Sand mainly quartz, fine- to medium-grained, subrounded, and moderately sorted.
2–5	Sandstone conglomerate	Rounded cobbles of very hard, fine-grained quartz sandstone (returning as shards) within a matrix of reddish-yellow (5YR 7/6), well-consolidated sandstone. Sand quartz, medium- to coarse-grained, subrounded and moderately sorted.
5–6	Sandstone conglomerate	As above but containing some grey, hard siltstone clasts.
6–15	Sandstone	Very pale-brown (10YR 7/4), moderately consolidated sandstone. Sand quartz, fine- to medium-grained, subrounded and poorly sorted. Some (minor) rounded, quartz fine gravel.
15–17	Sandstone, iron induration	As above, but dark reddish-brown, well-consolidated (iron-indurated) sandstone.
17–19	Sandstone	Pink (5YR 7/4), moderately consolidated sandstone. Sand quartz, fine- to medium-grained, subrounded and moderately sorted.
19–24	Sandstone	Red (2.5YR 5/6), poorly consolidated and porous sandstone. Sand quartz, fine-grained, subrounded and moderately sorted.
24–26	Sandstone	Yellow (10YR 7/8) poorly consolidated sandstone. Sand quartz, fine-grained, subrounded and well sorted.
26–29.5	Sandstone	Light-grey (10YR 7/2), moderately consolidated, porous sandstone. Sand quartz, medium- to coarse-grained, subrounded and moderately sorted.

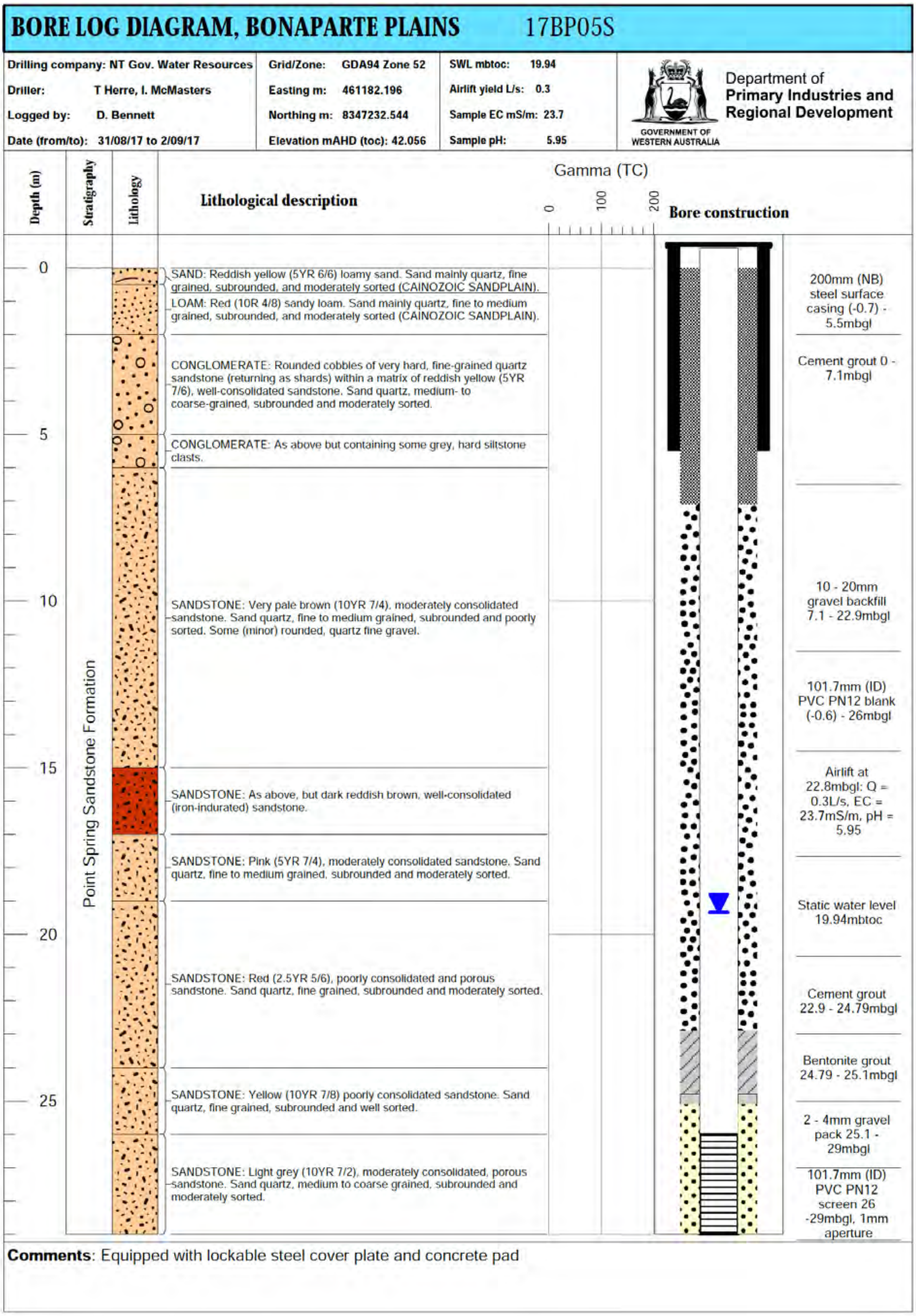


Figure 5.15 Bore diagram for monitoring bore 17BP05S

Table 5.31 Summary formation log for test-pumping bore 17BP05PB

Depth (mBGL)	Stratigraphy
0–5	Cainozoic sandplain (Cockatoo Sands)
5–93	Point Spring Sandstone Formation

Table 5.32 Lithology log for test-pumping bore 17BP05PB

Depth (mBGL)	Lithology	Description
0–5	Sand, loamy	Cainozoic sandplain (Cockatoo Sands).
5–15	Sandstone	Very pale-brown (10YR 7/4), moderately consolidated sandstone. Sand quartz, fine- to medium-grained, rounded and poorly sorted.
15–17	Sandstone, iron induration	As above, but dark reddish-brown, well-consolidated (iron-indurated) sandstone.
17–19	Sandstone	Pink (5YR 7/4), moderately consolidated sandstone. Sand quartz, fine- to medium-grained, subrounded and moderately sorted.
19–26	Sandstone	Red (2.5YR 5/6), poorly consolidated and porous sandstone. Sand quartz, fine-grained, subrounded and moderately sorted.
26–34	Sandstone	Light-grey (10YR 7/2), moderately consolidated, porous sandstone. Sand quartz, medium- to coarse-grained, subrounded and moderately sorted.
34–36	Sandstone, iron induration	As above, but with layers of dusky red (10R 3/4), well-consolidated (iron-indurated) sandstone.
36–38	Sandstone	Light-grey (10YR 7/2), poorly consolidated sandstone. Sand quartz, fine- to medium-grained, subrounded and moderately sorted.
38–40	Sandstone, iron induration	Very pale-brown (10YR 8/2), very well-consolidated (iron-indurated) sandstone. Sand quartz, fine- to medium-grained, subrounded and poorly sorted.
40–47	Sandstone	Very pale-brown (10YR 7/3) and white (2.5Y 8/1), moderately consolidated sandstone. Sand quartz, medium-grained, subrounded and moderately to well sorted.
47–49	Sandstone, iron induration	Dark reddish-grey (10R 3/1), well-consolidated, iron-indurated sandstone. Sand quartz, fine- to medium-grained, subrounded and well sorted. Some (minor) angular quartz clasts (shards) returned.
49–51	Sandstone	White (2.5Y 8/1), moderately consolidated sandstone. Sand quartz, medium-grained, rounded, and well sorted.

(continued)

Table 5.32 continued

Depth (mBGL)	Lithology	Description
51–52	Siltstone	Light-grey (GLEY 8/N), with minor micro-bands of purple (10R 5/2), well-consolidated siltstone. Returns as shards and platelets.
52–56	Siltstone	Grey (2.5Y 6/1), well-consolidated siltstone. Returns as platelets.
56–63	Sandstone	Light-grey (2.5Y 7/1) and very pale-brown (10YR 7/3) very poorly to poorly consolidated sandstone. Sand quartz, fine- to medium-grained, subrounded and well sorted.
63–73	Sandstone	Yellow (10YR 8/6), poorly consolidated sandstone. Sand quartz, fine-grained, subrounded and well sorted.
73–78	Sandstone	Very pale-brown (10YR 7/3), poorly consolidated sandstone. Sand quartz, fine- to medium-grained, subrounded and well sorted.
78–79	Siltstone	Dark grey (Gley 4/N), very well consolidated siltstone.
79–91	Sandstone	Light-grey (7.5YR 7/1) very poorly consolidated, porous sandstone. Sand quartz, medium- to coarse-grained, subrounded, and well sorted.
91–93	Shale	Light-grey (Gley 7/N) soft shale.

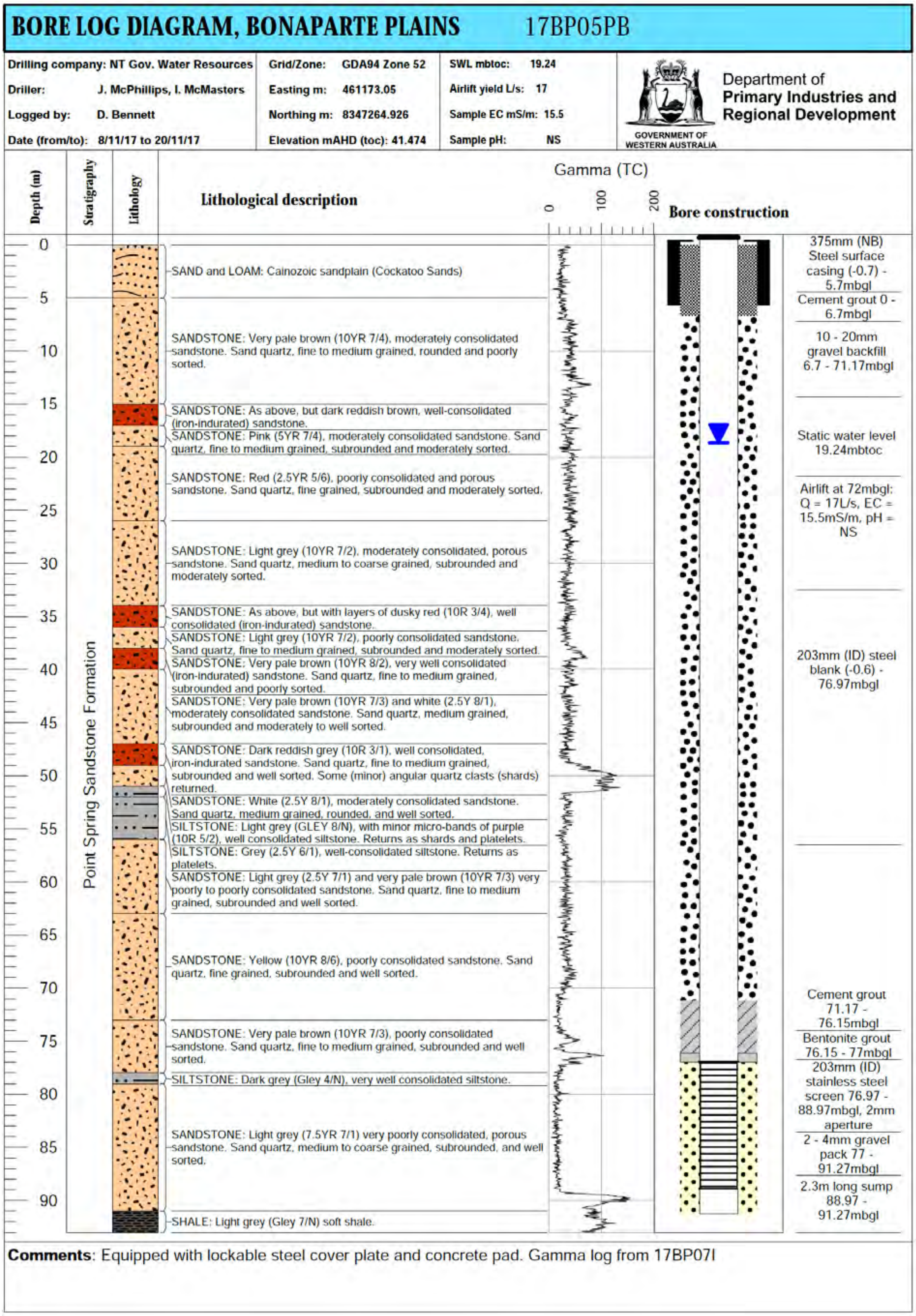


Figure 5.16 Bore diagram for test-pumping bore 17BP05PB

5.9 Site 17BP06

5.9.1 Site description

Site 17BP06 was selected to obtain information about groundwater conditions and lithology beneath the southern area of Cockatoo Sands.

5.9.2 Drilling depths and screen placement

The shale layer was interpreted from the AEM data to be located from 100mBGL. Shale was not encountered by 107.7mBGL in bore 17BP06I and drilling progression finished in fine-grained, moderately consolidated, silty sandstone. The bore screen was installed at 85–91mBGL within fine- to medium-grained, poorly consolidated, slightly silty sandstone. A 12m-long sump was installed below the screen to 103mBGL.

Circulation and drill rotation was lost at 67mBGL because of fall-back of conglomerate and clayey material from above. When trying to free the drill string, the drill bit assembly became disconnected, causing a delay of over three weeks until the drillers eventually retrieved it.

On the basis of the water level observed in the open hole during the delay in drilling, the shallow bore (17BP06S) was designed and later installed. When water levels were compared in the two bores after completion, an 18m difference in water elevation was observed. The large head difference and the clayey lithology at 42–46mBGL suggests that the inlet of bore 17BP06S is located within a perched aquifer.

5.9.3 Bore stratigraphy and lithology

Table 5.33 and Table 5.34 show the formation stratigraphy and the lithology, respectively, for monitoring bore 17BP06I. Figure 5.17 shows the bore completion diagram.
Table 5.35 and Table 5.36 show the formation stratigraphy and the lithology, respectively, for test-pumping bore 17BP06SB. Figure 5.18 shows the bore completion diagram.

Table 5.33 Summary formation log for monitoring bore 17BP06I

Depth (mBGL)	Stratigraphy
0–6.5	Cainozoic sandplain (Cockatoo Sands)
6.5–107.7	Point Spring Sandstone Formation

Table 5.34 Lithology log for monitoring bore 17BP06I

Depth (mBGL)	Lithology	Description
0–6.5	Sand, loamy	Cainozoic sandplain (Cockatoo Sands).
6.5–11	Sandstone conglomerate, iron induration	Rounded cobbles of very hard, fine-grained quartzite/sandstone (returning as shards) and ironstone nodules within a matrix of red (2.5YR 5/8), well-consolidated (variably iron-indurated) sandstone. Sand quartz, fine- to medium-grained, rounded and poorly sorted.
11–22	Sandstone, interbedded siltstone	Pink (5YR 7/4), moderately consolidated sandstone and white siltstone. Sand quartz, fine-grained, subrounded, and moderately sorted. Siltstone is poorly consolidated and present in thin layers. Some (minor) rounded quartz pebbles to 5mm.
22–29	Sandstone	Reddish-yellow (5YR 7/6) and pink (7.5YR 7/4), poorly to very poorly consolidated sandstone. Sand quartz, medium-grained, subrounded, and moderately sorted.
29–34	Sandstone, interbedded siltstone	Pink (7.5YR 7/4), poorly consolidated sandstone and white siltstone. Sand quartz, fine- to medium-grained, subrounded, and moderately sorted. Siltstone is poorly consolidated and present in thin layers.
34–39.5	Sandstone	Pinkish-grey (7.5YR 7/2), very poorly consolidated sandstone. Sand quartz, medium- to coarse-grained, subrounded, and moderately sorted. Water return was 4L/s by 34m.
39.5–40	Siltstone, iron induration	Dusky red (10R 3/3), very well consolidated (iron-indurated), hard siltstone.
40–40.5	Siltstone	Light-grey (10YR 8/1), with minor microbands of purple (10R 5/2), well-consolidated siltstone. Returns as shards and platelets.
40.5–41	Shale	Light-grey (Gley1 7/N) soft shale.
41–42	Sandstone	Pink (5YR 7/4), moderately consolidated, porous sandstone. Sand quartz, medium- to coarse-grained, subrounded and poorly sorted. Some rounded, frosted quartz pebbles to 15mm. Water return was 20L/s by 42m.
42–46	Clay, sandy	Reddish-brown (5YR 4/3) hard clay. Returns as chips.
46–47	Siltstone, iron induration	Weak red (10R 4/2) and light-grey (Gley 7/N) layered, very well-consolidated (variably iron-indurated) siltstone.
47–52	Sandstone	Light-brown (7.5YR 6/4), moderately consolidated sandstone. Sand quartz, fine- to coarse-grained, subrounded, and poorly sorted. Numerous subrounded, quartz pebbles to 10mm.
52–54	Sandstone conglomerate	Rounded cobbles of very hard, fine-grained and coarse-grained sandstone (returning as shards) within a matrix of light-brown (7.5YR 6/4), poorly consolidated sandstone. Sand quartz, coarse-grained, rounded and poorly sorted.

(continued)

Table 5.34 continued

Depth (mBGL)	Lithology	Description
54–61	Sandstone	Yellowish-red (5YR 4/6), poorly consolidated sandstone. Sand quartz, coarse-grained, subrounded and poorly sorted.
61–67	Sandstone, interbedded siltstone, iron induration	As above, but contains well-consolidated (iron-indurated), fine-grained sandstone and siltstone in layers. Numerous frosted and white rounded quartz pebbles to 20mm.
67–69	No data	Lost circulation.
69–75	Sandstone	Light-red (10R 6/6), poorly consolidated sandstone. Sand quartz, medium- to coarse-textured, subrounded and poorly sorted.
75–79	Sandstone, interbedded siltstone, iron induration	Red (2.5YR 5/6), moderately consolidated sandstone. Sand quartz, coarse-grained, subrounded and poorly sorted. Contains thin layers of red (10R 6/2), well-consolidated (iron-indurated) fine-grained siltstone. Large drilling fluid losses.
79–91	Sandstone, silty	Pink (5YR 7/4), poorly consolidated, slightly silty sandstone. Sand quartz, fine- to medium-grained, subrounded, poorly sorted. Some angular clasts of quartzite.
91–99	Sandstone, silty	Pink (2.5YR 7/3) and light-red (2.5YR 6/8), moderately consolidated silty sandstone. Sand quartz, fine- to very fine-grained and moderately sorted.
99–102	Siltstone	Reddish-brown (5YR 4/4), moderately consolidated sandy siltstone. Sand quartz, very fine-grained and well sorted.
102–107.7	Sandstone, silty	Light-grey (2.5Y 7/2) and pinkish-grey (5YR 6/2), moderately consolidated silty sandstone. Sand quartz, fine-grained, subrounded and well sorted.

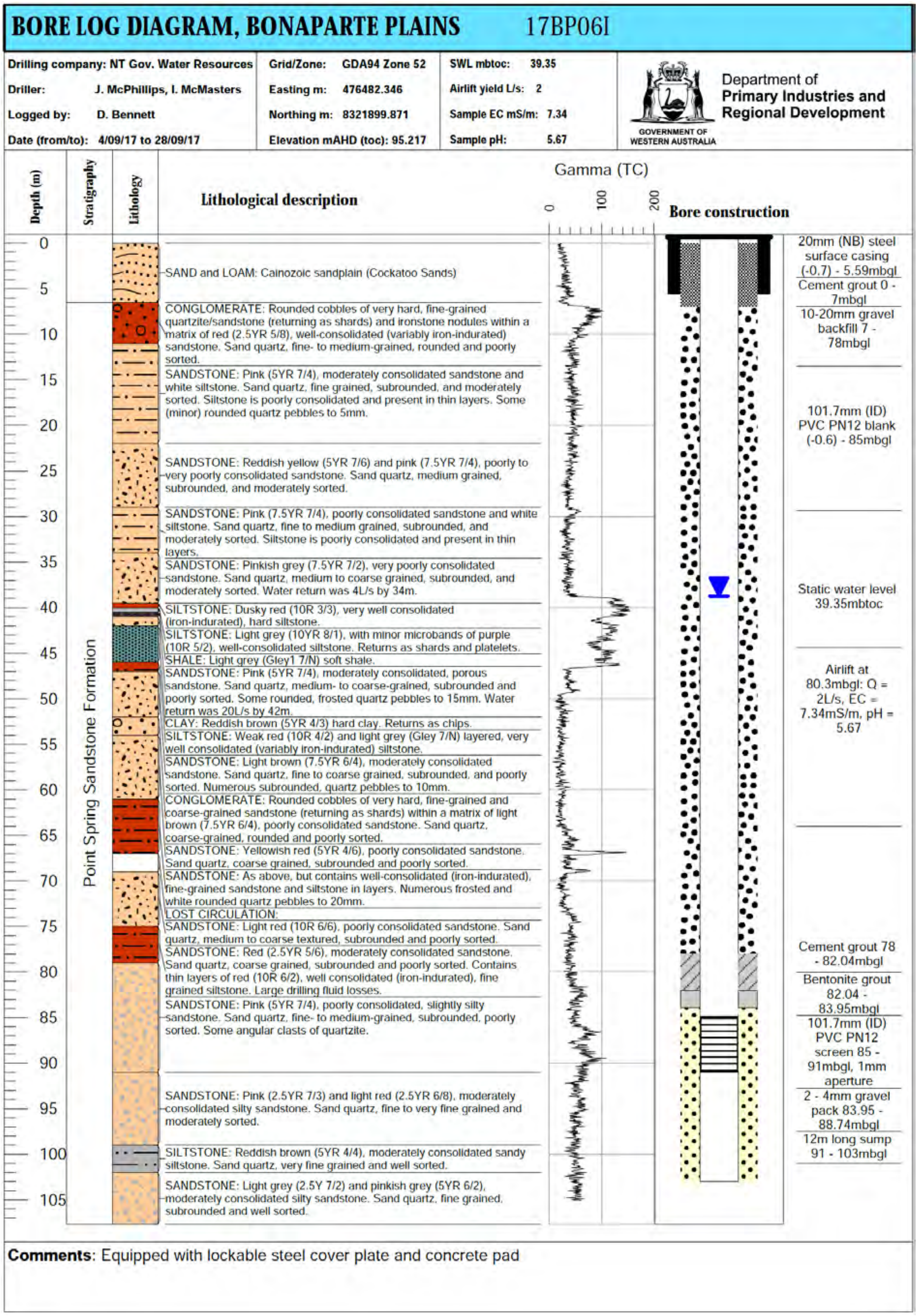


Figure 5.17 Bore diagram for monitoring bore 17BP06I

Table 5.35 Summary formation log for monitoring bore 17BP06S

Depth (mBGL)	Stratigraphy
0–6.5	Cainozoic sandplain (Cockatoo Sands)
6.5–34.5	Point Spring Sandstone Formation

Table 5.36 Lithology log for monitoring bore 17BP06S

Depth (mBGL)	Lithology	Description
0–0.7	Sand, loamy	Red (2.5YR 5/6) loamy sand. Sand mainly quartz, fine-grained, subrounded, and moderately sorted.
0.7–2.5	Loam, sandy	Red (10R 4/8) sandy loam. Sand mainly quartz, fine-grained, subrounded, and moderately sorted.
2.5–4	Sand, clayey	Red (10R 4/6) clayey sand. Sand mainly quartz, fine-grained, subrounded, and poorly sorted.
4–6.5	Loam, sandy	Red (10R 5/8) sandy loam. Sand mainly quartz, fine- to medium-grained, subrounded, and poorly sorted.
6.5–7.5	Sandstone conglomerate, iron induration	Rounded cobbles of very hard, fine-grained quartzite/sandstone (returning as shards) and ironstone nodules within a matrix of red (2.5YR 5/8), well-consolidated (variably iron-indurated) sandstone. Sand quartz, fine- to medium-grained, rounded and poorly sorted.
7.5–11	Sandstone conglomerate, iron induration	As above, but also contains numerous rounded quartz pebbles up to 15mm.
11–22	Sandstone, interbedded siltstone	Pink (5YR 7/4), moderately consolidated sandstone and white siltstone. Sand quartz, fine-grained, subrounded, and moderately sorted. Siltstone is poorly consolidated and present in thin layers. Some (minor) rounded quartz pebbles to 5mm.
22–25	Sandstone	Reddish-yellow (5YR 7/6), poorly consolidated sandstone. Sand quartz, medium-grained, subrounded, and moderately sorted.
25–29	Sandstone	Pink (5YR 7/3), very poorly consolidated sandstone. Sand quartz, fine- to medium-grained, subrounded, and moderately sorted. Wet.
29–34	Sandstone, interbedded siltstone	Pink (7.5YR 7/4), poorly consolidated sandstone and white siltstone. Sand quartz, fine- to medium-grained, subrounded, and moderately sorted. Siltstone is poorly consolidated and present in thin layers.
34–34.5	Sandstone	Pinkish-grey (7.5YR 7/2), very poorly consolidated sandstone. Sand quartz, medium- to coarse-grained, subrounded, and moderately sorted. Water return was 4L/s by 34m.

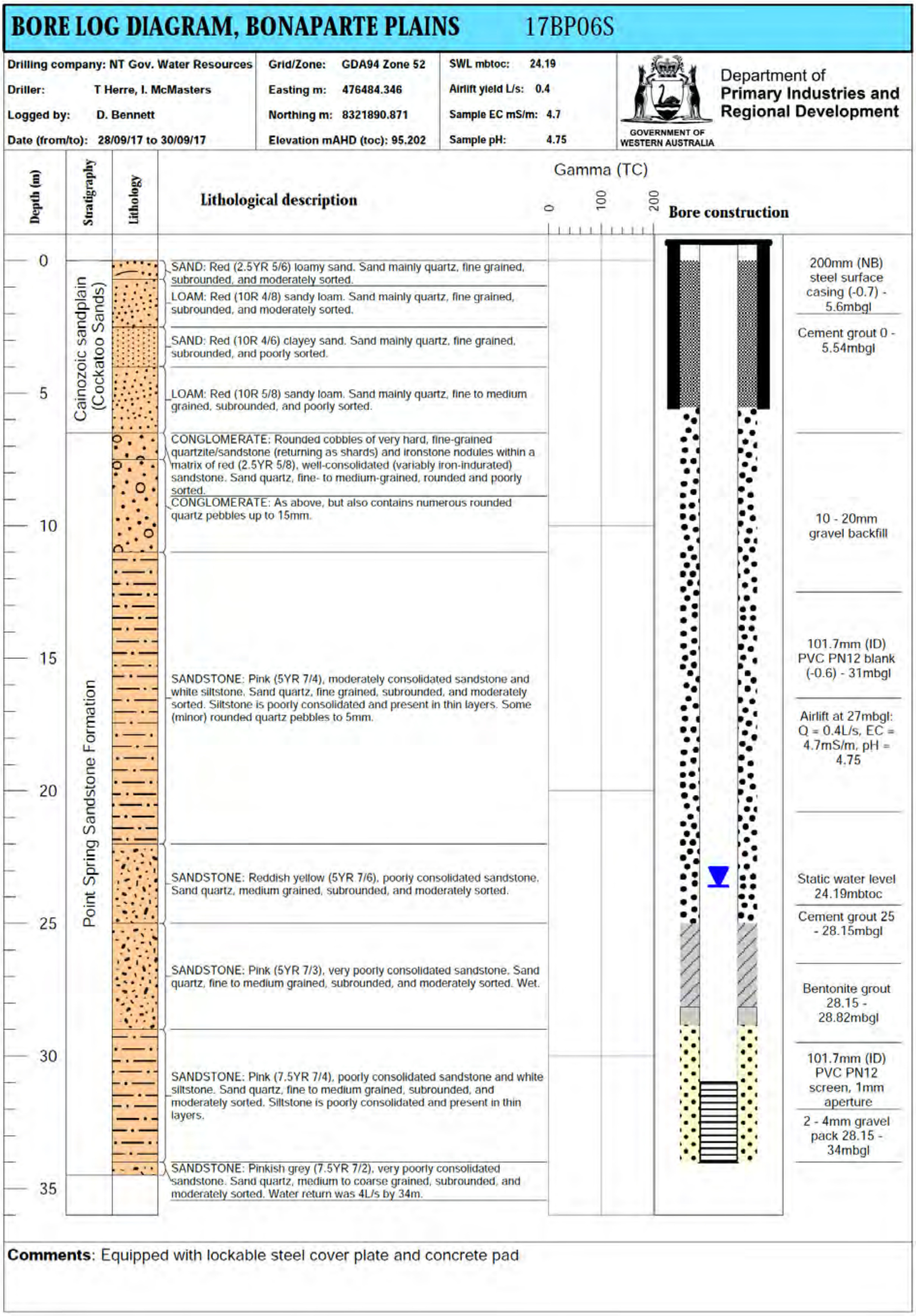


Figure 5.18 Bore diagram for monitoring bore 17BP06S

5.10 Site 17BP07

5.10.1 Site description

Site 17BP07 was selected to determine the groundwater conditions under the general north–south oriented topographic ridge and to obtain the groundwater gradient westward towards Bonaparte2 water bore and Tanmurra bores, and eastwards towards sites 13BP01 and 17BP01. In addition, the location allowed comparison of formation lithology encountered in the drill hole with that observed in outcrop to the north and that recorded in the drill log for Bonaparte2 oil well to the east. It was also chosen to help determine if there was a saddle, as suspected, in the groundwater mound that has a general north–south axis under the area of Cockatoo Sands.

5.10.2 Drilling depths and screen placement

Drilling progression finished at 83.77mBGL in clayey material when it was apparent that the target shale layer — forecast from the AEM data to be located from 70mBGL — was likely to be absent. Bore 17BP07I was screened at 50–56mBGL, within medium- to coarse-silty sandstone. A 23m-long sump was installed below the screen.

No shallow bore was installed because it was assumed that there would be little lithological difference between the two bore screens.

5.10.3 Bore stratigraphy and lithology

Table 5.37 and Table 5.38 show the formation stratigraphy and the lithology, respectively, for monitoring bore 17BP07I. Figure 5.19 shows the bore completion diagram.

Table 5.37 Summary formation log for monitoring bore 17BP07I

Depth (mBGL)	Stratigraphy
0–9	Cainozoic sandplain (Cockatoo Sands)
9–83.77	Point Spring Sandstone Formation

Table 5.38 Lithology log for monitoring bore 17BP07I

Depth (mBGL)	Lithology	Description
0–0.5	Sand, loamy	Reddish-grey (5YR 5/2) loamy sand. Sand mainly quartz, fine-grained, rounded to subrounded, moderately sorted.
0.5–9	Loam, sandy	Red (10R 5/8 to 10R 4/8) sandy loam. Sand mainly quartz, medium- to fine-grained, rounded to subrounded, moderately sorted.
9–11	Sandstone, silty, iron induration	Pink (2.5YR 8/3) silty sandstone. Sand mainly quartz, medium- to fine-grained, rounded to subrounded, moderately sorted. Contains minor hard, iron-indurated, fine-grained sandstone clasts.
11–16	Sandstone, silty	Pinkish-white (2.5YR 8/2), slightly silty sandstone. Sand quartz, mainly fine-grained, minor medium-grained, rounded to subrounded, moderately sorted.
16–17.5	Sandstone, silty	Pink (2.5YR 8/3) silty sandstone. Sand mainly quartz, medium- to fine-grained, rounded to subrounded, moderately sorted.
17.5–22	Siltstone	Light-grey (GLEY 8/7), with minor microbands of purple (10R 5/2), well-consolidated siltstone. Returns as shards and platelets.
22–23.5	Sandstone, interbedded siltstone	Pale-red (10R 6/2), layered siltstone and sandstone. Siltstone layers have grey and purple microbands.
23.5–37	Sandstone, silty	Light-grey (5Y 8/1) and pale-yellow (5Y7/3), slightly silty sandstone. Sand quartz, fine- to coarse-grained, subrounded and poorly sorted.
37–38	Siltstone	Light-grey (5Y 8/1) sand and reddish-yellow (7.5YR 6/8) sandy siltstone. Some jagged clasts and subrounded pebbles of quartz/quartzite to 15mm.
38–48	Sandstone, silty	White (5Y 8/1), slightly silty sandstone. Sand quartz, fine- to coarse-grained, rounded to subrounded and poorly sorted.
48–56	Sandstone, silty	Pale-yellow (5Y 8/2), slightly silty sandstone. Sand quartz, medium- to coarse-grained, rounded to subrounded and moderately sorted. Some quartzite pebbles (to 15mm).
56–57.5	Clay, sandy	Dusky red (10R 3/2), slightly sandy clay.
57.5–60	Clay, sandy	Brownish-yellow (10YR 6/6), slightly sandy, puggy clay. Minor mottled yellow (10YR 7/6) and red (10R 4/6) clay. Minor iron-indurated clasts of fine-grained sandstone. Some dark grey, hard, fine-grained sandstone clasts.
60–71	Clay, sandy	Pale-yellow (2.5Y 7/4) to yellow (2.5Y 7/6), slightly sandy clay. Minor puggy, mottled light-grey (10R 5/3) and weak red (10R 5/3) clay.
71–78	Clay, calcareous	As above, but contains numerous pale-yellow (2.5Y 8/2 to 2.5Y 7/4) calcareous flakes.
78–83	Clay, calcareous	Olive yellow (2.5Y 6/8) clay and (minor) calcareous flakes.
83–83.77	Sandstone, clayey	Olive yellow (2.5Y 6/8), slightly clayey sandstone and conglomerate. Sandstone quartz, medium- to coarse-grained, rounded to subrounded and poorly sorted. Rounded quartz pebbles to 10mm.

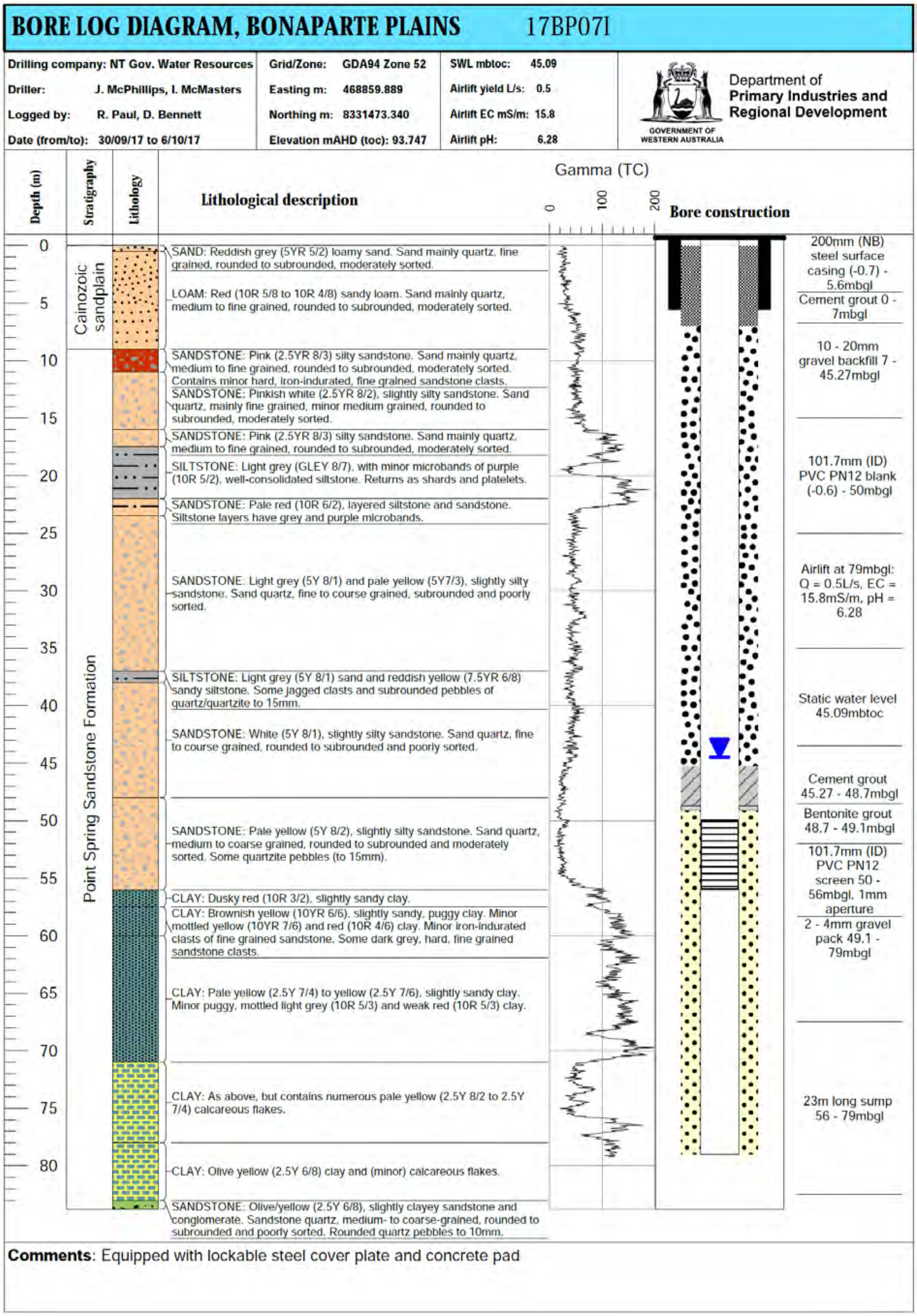


Figure 5.19 Bore diagram for monitoring bore 17BP07I

Appendices

Appendix A Summary information of existing bores

Appendix B Report on drilling-mud test results at site 13BP01

Appendix C Bore location survey uncertainty data

Appendix D Palynology analysis report

Appendix A Summary information of existing bores

Bore name	Easting (GDA94 Z52)	Northing (GDA94 Z52)	Casing elevation (mAHD)	Depth drilled (mBGL)	Inlet top (mBGL)	Inlet bottom (mBGL)	Inferred geological formation at inlet	Water level (mRGL)	Water level date	SC (mS/m)	pH
2_95	464967	8314674	62.906	26	14.55	25.95	Ningbing Group/Milligans contact	−1.91	14/11/2014	51.3	7.4
Attack	467111	8351526	21.544	Unknown	Unknown	Unknown	Unknown	−3.42	15/05/2016	ND	ND
Bonaparte1 water bore1	475605	8340606	57.953	40	35.5	41.5	Point Spring Sandstone	−24.62	15/11/2017	2.8	6.7
Bonaparte1 water bore2	476256	8340827	47.525	28		28	Point Spring Sandstone	−15.23	30/08/2017	ND	ND
Bonaparte2 water bore	467779	8328405	68.281	31	24.7	30.7	Point Spring Sandstone	−9.36	15/11/2017	3.1	6.5
Brolga	453332	8353128	10.135	>10.5	>10.5	Unknown	Quaternary alluvium	−1.04	11/11/2017	112	7.7
Calf Spring	486168	8338208	9.838	22	16.55	21.55	Keep Inlet	>0.45[a]	9/11/2017	24.5	7.6
CGDH5 Fishermans	472404	8351462	4.265	200	50[b]	74[b]	Point Spring Sandstone[c]	13.39	20/09/2017	10.1	6.3
CGDH6 New Attack	470932	8351824	6.763	114	46[b]	88[b]	Point Spring Sandstone[c]	3.67	15/11/2017	8.1	5.9
CGDH7	477332	8349855	4.237	134	76[b]	134[b]	Point Spring Sandstone[c]	>0.2[a]	16/08/2017	9.3	5.9
CGDH8 Kemp	478826	8347625	5.395	128	74[b]	128[b]	Point Spring Sandstone[c]	7.25	16/08/2017	13.6	6.8
Cleanskin	492122	8331754	18.019	45.7	25.85	43.85	Keep Inlet	−3.14	9/11/2017	47.1	7.9
Hotplate	470796	8321055	70.68	49.8	43.8	49.8	Point Spring Sandstone	−8.25	8/11/2017	6.8	6.3
Lewis	464069	8317617	55.136	Unknown	157.6	Unknown	Ningbing Group	1.64	23/08/2017	19.8	7.7
Matera	448492	8361708	5.05	Unknown	Unknown	Unknown	Quaternary alluvium	−1.21	4/09/2017	413	7.9
No.8 Paddy's	456798	8345047	66.462	20.9	14.9	20.9	Ningbing Group	−7.41	11/11/2017	62.4	8
Grant Creek	481902	8328502	32.702	22.25	Unknown	22.25	Keep Inlet	−1.44	9/11/2017	15.3	7.1
Oaks Creek	494634	8309462	34.886	Unknown	40.60	46.6	Keep Inlet/Point Spring Sandstone	−0.10	9/11/2017	12.1	7
RN029226	511340	8311308	12.667	31	25	31	Keep Inlet	−4.42	9/11/2017	16.9	6.8
RN029229	511700	8306778	10.155	16	10	16	Quaternary alluvium	−1.78	9/11/2017	11.5	6.2
Tanmurra	460590	8331330	38.643	50.9	44.9	50.9	Milligans	−5.50	11/11/2017	8.5	7
WBN5008	461184	8331204	35.035	443	>22.7	Unknown	Ningbing Group	−3.09	7/07/2017	ND	ND
WBN5002	460693	8331232	38.458	410	>194.9	Unknown	Ningbing Group	−2.47	11/11/2017	33.3	7.9
WBN5006	457323	8342589	45.658	Unknown	>123	Unknown	Ningbing Group	0.93	11/11/2017	63.9	7.6
Wilson	490281	8324255	30.183	>75	>75	Unknown	Keep Inlet	−1.22	8/11/2017	41.3	7.9

GSA94 Z52 = Geocentric Datum of Australia Zone 52; SC = specific conductivity; ND = no data

a Flowing bore

b Partially cased hole; estimate of inlet top and inlet bottom is interval most likely to contribute observed groundwater head — based on lithology from the drilling log.

c The groundwater level and hydrogeochemistry are likely to reflect properties of the underlying Point Spring Sandstone Formation aquifer.

Appendix B Drilling-mud test results at site 13BP01

The following report on the drilling-mud test results at site 13BP01 comes from Clifton (2013).

BAROID INDUSTRAL DRILLING PRODUCTS
A Product and Service Line of Halliburton Energy Services
PO Box 1202, Canning Vale, WA 6155

DATE:18th to 21st June 2013	DEPTH, m (current/ TD) **(0 / 83)**

OPERATOR **Department of Agriculture**	CONTRACTOR **Direct Drilling Australia Wide**	RIG NUMBER **Rig #2**
OPERATOR'S REPORT	CONTRACTOR'S REPORT	RIG TYPE Hydco

HOLE NUMBER **13BP01/PB**	PROJECT NAME **Cockatoo Sands Investigation**	COUNTY **Kimberley**	STATE / COUNTRY **WA / Australia**

Review			
Time Sample Taken	9.55 /18th	15.30/18th	8.30/19th
Sample Point(Suction/flowline)	Suction	suction	Suction
Depth (m)	0	80	84
Mud Weight (SG)	1.02	1.05	1.05
Funnel Viscosity (sec/qt)	36	37	42
Plastic Viscosity (Cp)	-	-	-
Yield Point (lb/100ft^2)	-	-	-
Gel Strength 10 sec./ 10 min.(lb/100ft^2)	-/-	-/-	-/-
Filtrate API (ml/30min)	16	15	14
Cake Thickness (/32nds In)	1	2	2
Sand Content (% by Vol.)	trace	0.25	1.5
pH	9	10	10
Alkalinity Mud (P_m) cm^{3}N50 H_2SO_4/cm^3	-	-	-
Alkalinity Mud (P_f /M_f) cm^{3}N50 H_2SO_4/cm^3	-/-	-/-	-/-
Chlorides (mg/L)	-	-	-
Total Hardness as Calcium (mg/L)	120	-	-
Make-up water pretreated (Y/N)	Y	Y	Y

PRESENT ACTIVITY AND PROBLEMS EXPERIENCED

Drill a 9 7/8 drilled hole to 83 m BGL to be used a production bore for testing ground water flows.

MUD PROPERTY SPECIFICATIONS

WEIGHT	VISCOSITY	FILTRATE
<1.06 SG	35-45 sec/qt	<15ml

RECOMMENDED TREATMENT

Per 1000 L
Soda Ash 0.5 to 1 kg, AQUAGEL® 1 ½ to 2 bags, PAC™-L 1 to 2 kg, QUIK MUD® GOLD 0.3 to 1 kg if required. N-SEAL™ ½ to 2 bag as required.

Materials Used :

Soda Ash: 5kg
AQUAGEL®: 29 sx
PAC™-L: 35 kg
N-SEAL™: 2 sx
PENETROL®: 2 x 19L drums.
AQUACLEAR® PFD: 2 x treatments of 10L (20L total)

	ID	OD
BIT SIZE		9 5/8 In TCI
REAMER		-
DRILL STRING		4In
CASING		-

Personal Notes :

This is the first of 2 holes to be drilled for Dept of Ag to investigate the Cockatoo Sands area of Carlton Hill Station for future release as a growing area using center pivots. There has been no previous ground water investigative drilling in the area only bore logs available are 1960's drilled oil and gas investigation work.

Present:
Department of Agriculture - Hydrologist
DDAW – Driller, 3 off siders.
Baroid IDP – Field Service Rep.

Pilot hole drilled with a 6 ½ In drag bit then opened up to 9 5/8 In.
Make up water is tanked from a creek and has a pH of 7.5.
15,000L "U" shaped pit. 2 x 1,700 L mix tanks with hydraulic agitators on bottom.
GD positive displacement pump as mud pump.

Field Engineer: Tom Clifton
Cell Phone: 0410 220 204
E-mail: thomas.clifton@halliburton.com

THE RECOMMENDATIONS MADE HERIN SHALL NOT BE CONSTRUED AS AUTHORIZING THE INFRINGEMENT OF ANY VALID PATENT, AND ARE MADE WITHOUT ASSUMPTION OF ANY LIABILITY BY BAROID DRILLING FLUIDS, INC. OR ITS AGENTS, AND ARE STATEMENTS OF OPINION ONLY.

Personal Notes

18th June 2013: The 15,000 L sumps where filled and initial mix of 4kg Soda Ash, 23 sx AQUAGEL® , 20kg PAC™-L and 19 L of PENETROL® was made . Once fluid was ready drilling commenced with 6 m of 10In steel surface casing cemented into place. The pilot hole was commenced with a 6 ½ In regular step drag bit. Ground water was expected at 25 m but was not encountered until at 48 m. Ground condition was red surface sandy/ clays to medium to coarse sands. There was no defining layer around 80 m which was to be the depth indicator but pilot drilling was stopped, there had only been some surface clay bands seen during drilling. Tripped out of the hole and put on a 9 5/8 In chevron drag bit and began to open to hole up to 18m before the end of day. Fluid testing (see results above) was carried out throughout the day. After the first test an additional 4 sx of AQUAGEL and 10 kg of PAC-L introduced and a mix of 0.5kg Soda Ash , 2 sx AQUAGEL and 2 sx of N-SEAL™ were mixed up and left in the 1,700 L mix tank ready to be used in case very coarse sands were encountered and excess fluid loss occurred.

19th June 2013: Opening of hole continued from 18 m to 84 m. During this drilling the 1,700 of AQUAGEL® and N-SEAL™ in the mix tank was added to active system and 18 L of PENETROL®. 0.5kg of Soda Ash and 2sx of AQUAGEL were mixed and also added (see fluid testing results). Once TD had been reached they tripped out of hole and the running of 155 cl12 uPVC casing installed (48 m of 1.00mm slotted pipe and 36 m of plain casing to surface). Once casing was run gravel pack was placed around the screened area and continued to surface casing.10 L of AQUACLEAR® PFD was added based on a 2% treatment of twice the water volume in hole (9 5/8 In drilled hole = 50 L p/m volume x 48 m of screened area x 2 to allow for the formation x 0.002 = 9.6 L required). It was poured down the drill rods which had been tripped back in the hole after having a jetting tool fitted to the bottom rod prior to developing occurring. Jetting of the screens commenced and to be continued the following morning. A "v" notch weir was set up to monitor flows coming from the well and 2.1 LPS was recorded after 30 minutes of air lifting. A larger flow was expected but due the water table not being at the expected 25 m level this could be why.

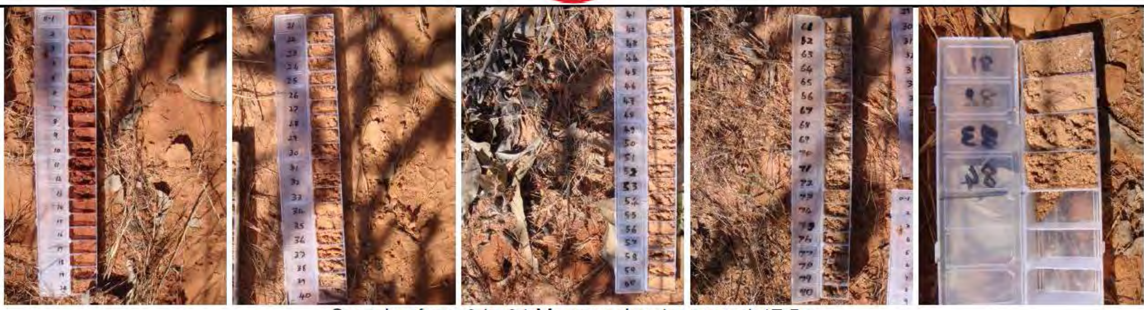
20th June 2013: Jetting of the screens with air continued until top of water table had been reached. There was a slight increase in flow to just fewer than 3 LPS when developing first commenced. A 1.5 hp submersible pump was put down the well to check flows and could produce a constant 1 LPS which was its capacity with larger pump testing being looked at for future works on the well. Re mobilization and set up the drill pad for the second was started. The pump was pulled from the hole and 2 L of Chlorine added to aid in breaking down the PAC™-L polymer and an additional 10 L of AQUACLEAR® PFD was added and left over night to help disperse the AQUAGEL®.

21st June 2013: A 2 In airline was run to near bottom of the hole to agitate the chlorine and AQUACLEAR® PFD that had been left down over night to aid in developing the hole. This airline was run for ½ a day at a low volume with fluid barely just reaching surface. After this the air volume was increase to flush / clean the hole.

A water sample was taken and tested which showed a pH of 7.8, EC of 221uS and temp of 30 c.

L) GD mud pump and hydraulic power pack. C) Mix tank of AQUAGEL® & N-SEAL™. R) Hopper and mix tank.

L) Laydown area. C) Rig and rod trailer set out. R) PENETROL® being added direct to active mix.



Samples from 0 to 84 M ,ground water was at 47.5m

L) Gravel pack installed around screened area. C) V notch weir with 2.1 LPS flowing through. R) 30.8 c groundwater temp.

Air developing of bore with AQUACLEAR® PFD

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BAROID INDUSTRAL DRILLING PRODUCTS
A Product and Service Line of Halliburton Energy Services
PO Box 1202, Canning Vale, WA 6155

	DATE: 21st to 23rd June 2013	DEPTH, m (current/ TD) **(0 / 174)**

OPERATOR **Department of Agriculture**	CONTRACTOR **Direct Drilling Australia Wide**	RIG NUMBER **Rig #2**
OPERATOR'S REPORT	CONTRACTOR'S REPORT	RIG TYPE Hydco

HOLE NUMBER **13BP01/S,I & D**	PROJECT NAME **Cockatoo Sands Investigation**	COUNTY **Kimberley**	STATE / COUNTRY **WA / Australia**

Review			
Time Sample Taken	1630/21st	1315/22nd	1610/22nd
Sample Point(Suction/flowline)	Suction	Suction	Suction
Depth (m)	90 m	154 m	170 m
Mud Weight (SG)	1.05 SG	1.04 SG	1.10
Funnel Viscosity (sec/qt)	38 sec	47 sec	48
Plastic Viscosity (Cp)	8	11	11
Yield Point (lb/100ft^2)	2	3	7
Gel Strength 10 sec./ 10 min.(lb/100ft^2)	0 / 1	1 / 2	2 / 8
Filtrate API (ml/30min)	12 ml	15 ml	12 ml
Cake Thickness (/32nds In)	1/32nd	1/32nd	2/32nd
Sand Content (% by Vol.)	0.5%	0.5%	1.5%
pH	9	8.5	8
Alkalinity Mud (P_m) cm^{3}N50 H_2SO_4/cm^3	-	-	-
Alkalinity Mud (P_f /M_f) cm^{3}N50 H_2SO_4/cm^3	-	-	-
Chlorides (mg/L)	-	-	-
Total Hardness as Calcium (mg/L)	-	-	-
Make-up water pretreated (Y/N)	Y	Y	Y

PRESENT ACTIVITY AND PROBLEMS EXPERIENCED

Drilling a 7 7/8 In hole to 174 m BGL for the installation of 3 x 50mm uPVC casings set at different depths.
13BP01-S, (shallow) – 84 m
13BP01-I, (intermediate) – 118 m
13BP01- D, (deep) 168 m

MUD PROPERTY SPECIFICATIONS

WEIGHT	VISCOSITY	FILTRATE
<1.06 SG	35-45 sec/qt	<15ml

RECOMMENDED TREATMENT

Per 1000 L:
Soda Ash 0.3 kg, AQUAGEL® 1 ½ to 2 bags, PAC™ L 2 kg, QUIK MUD® GOLD 0.3 to 1 kg if required. N-SEAL™ ½ to 2 bag as required.

Materials Used :

QUIK-SET™ 30: 8 pails
Soda Ash: 10 kg
AQUAGEL®: 40 sx
PAC™ L: 56 kg
QUIK MUD® GOLD: 5 kg
PENETROL®: 3x 19L drums.
AQUACLEAR® PFD: L (refer below)

	ID	OD
BIT SIZE	Tri Cone	7 7/8 TCI
REAMER	-	-
DRILL STRING		4In
CASING	-	-

Personal Notes :

This is the second of the 2 holes to be drilled for Dept of Ag to investigate the Cockatoo Sands area of Carlton Hill Station for future release as a growing area using center pivots. There has been no previous ground water investigative drilling in the area only bore logs available are 1960's drilled oil and gas investigation work.

Present:
Department of Agriculture - Hydrologist
DDAW – Driller, 3 off siders.
Baroid IDP – Field Service Rep.

7 /78 In Hole to be drilled to 180 M
Make up water is transported from a creek in a 9,500 L water cart and has a pH of 7.5.
24,000L "U" shaped pit. 2 x 1,700 L mix tanks with hydraulic agitators on bottom.
GD positive displacement pump as mud pump.

Field Engineer: Tom Clifton
Cell Phone: 0410 220 204
E-mail: thomas.clifton@halliburton.com

Personal Notes

21st June 2013: Filling of the 24,000 L active pit begun which was comprised of 4 pits in total. These were dug in a "U" shaped pattern, coming from the flow line was pit 1 (7,500 L) and pit 2 (5,500 L) then a third pit (4,000 L) heading across to link up to the 4 pit (8,000 L)/suction pit which headed back to the rig. The active pit volume was reduced in size to 16,000 L in order for the surface casing to be drilled in whilst waiting for the water cart to return. This was done by blocking off the first pit where it flowed into the second pit and diverting it across to the suction pit. In this 16,000 L mix was 3 kg Soda Ash, 27 x AQUAGEL® sx,25 kg PAC™-L and 19 L PENETROL®. Commenced drilling a 7 7/8 In pilot hole to 12 m that was then opened to 12 ¼ In hole for the surface casing 200mm cl12 uPVC run in. It was set in place with 8 pails QUIK-SET™ 30 placed around the backside of the casing to seal it off. Once the water cart returned the remaining sumps number 2 and 3 were filled and additional additives introduced being 2kg Soda Ash, 4 x AQUAGEL sx, 25kg PAC-L which brought the circulating pit volume to 24,000 L . Drilling out the bottom of the surface casing with the 7 7/8 In bit begun. The active pit was topped up during the day with one load from the 1,700 L mix tank which contained 3 x AQUAGEL sx and 2 kg PAC-L .2 kg Soda Ash, 2.5 kg QUIK MUD® GOLD and another 19 L drum of PENETROL was introduced directly to the active pit in anticipation for the expected Tanmurra formation which comprised of clays and limestone bands .As it was not known at what depth we would see this formation or if we would see smaller bands of clays / shale's on the way down these additives were introduced to prevent bit balling of the tri cone bit and control swelling of the encountered clays. This Tanmurra formation would be the defining layer and be the point where end of hole would be called. During the day the additional checks of both the flow line and suction point were carried out to ensure the sumps where working. See below:

15:10 / 82m	Density (SG)	Sand Content %
Flow Line	1.05	1.25
Suction Point	1.03	0.75

The 1,700 L mix tank was filled with makeup water 0.5 kg Soda Ash, 3 x AQUAGEL sx and 2 kg PAC-L and allowed to mix for remainder of afternoon in order to be added the following morning. At 17:30 end of day was called 101 m had been reached.
22nd June 2013: Before drilling ahead commenced the active pit and hole was circulated for at least 30 minutes during which the mix tank was added to the system. The mix tank was then filled once more with 1,700 L of water, 0.5 kg Soda Ash, 3 x AQUAGEL® sx and 2 kg PAC™-L. Once again full fluid tests were carried out during the day and also additional checks of the flow line and suction point to check that cuttings were still dropping out.

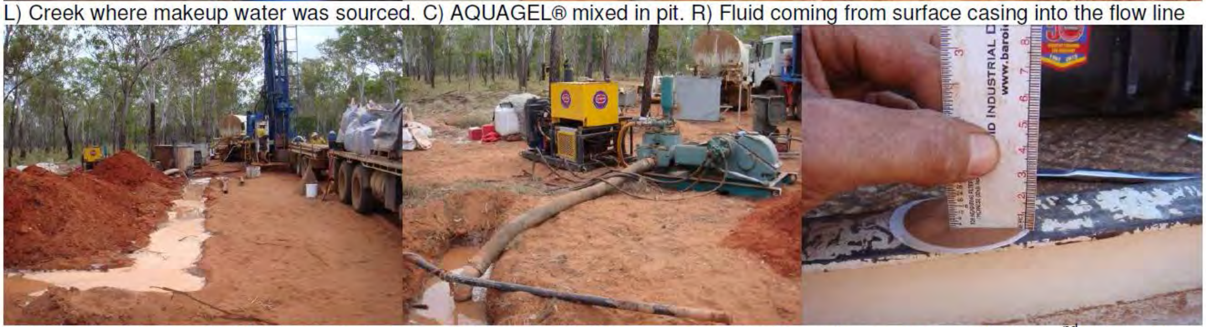
11:45 / 130 m	Density (SG)	Sand Content %
Flow Line	1.08	1.0
Suction Point	1.04	trace

13:40-The mix tank was added to the active pit along with an additional 3 kg Soda Ash, 2.5 kg QUIK MUD® GOLD and 19 L in preparation for the Tanmurra formation. This clay/shale bands (with sandstone bands) formation was first noticed at 145 m so drilling continued on to ensure this was not just a small band and was the actually targeted formation that would mean end of hole. Drilling was ceased at 4 m into the Tanmurra formation (174m) and several rods were pulled from the hole in order for it be shut down overnight.
23rd June 2013: Hole was circulated once again and all rods tripped from hole. Construction of the three 50mm monitoring wells was then undertaken, see table below:

Well ID	Casing Depth	Screened Area	Gravel Packed	Bentonite Plug	AQUACLEAR® PFD
13BP01-S	84 m	82 – 52 m	82.5 - 44.5 m	44.5 - 41.5 m	1.5 L
13BP01-I	118 m	118 – 100 m	150 - 87.5 m	87.5 - 82.5 m	2.3 L
13BP01-D	168 m	168 – 156 m	174 – 155 m	155 - 150 m	3.8 L

Notes: 2% AQUACLEAR® PFD based on 2 x diameter of drilled hole and screened area volume.
Each screened area was developed by air lifting .This was done by running a 1 In line down each hole and developing the screen area of each well. A combination of ¼ In Bentonite Pellets and ¼ In Pel Plug were used to make the bentonite plug after each screened area. Pel Plug was used on the deeper well and BENTONITE PELLETS on the shallower wells. Once constructed each well was treated with AQUACLEAR® PFD and lifted with air in order to develop the screened areas.

L) Creek where makeup water was sourced. C) AQUAGEL® mixed in pit. R) Fluid coming from surface casing into the flow line



L) Pits 1& 2 then heading left in 3. C) Suction point (pit 4) and GD mud pump. R) Filter cake measurement at 1/32nd of an inch.

L) Change in return fluid colour once clays encountered. C) Tanmurra formation samples in grey. R) Cooling off.

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Appendix C Bore location survey uncertainty data

Bore	Horizontal uncertainty (m)	Vertical uncertainty (m)
13BP01D, I, S & PB	0.01	0.03
16BP02I & S	0.065	0.119
16BP03I	0.443	0.193
17BP01I, S & PB	0.035	0.146
17BP02I & S	0.596	0.534
17BP03I	0.02	0.8
07BP04I & S	0.013	0.035
07BP05I, S, PB	0.013	0.035
17BP06I & S	0.014	0.041
17BP07I	0.014	0.041

Appendix D Palynology report

Backhouse Biostrat Pty Ltd

Report BB549

Point Spring Sandstone: palynology of 7 cuttings samples from Bonaparte Plains boreholes

by

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Prepared for
Geological Survey of WA

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BB549. Point Spring Sandstone: palynology of 7 cuttings samples from Bonaparte Plains boreholes

Summary of results for 7 samples (all samples are cuttings)

GSWA Sample no.	Borehole	Depth (m)	Spore-pollen zone	Approximate age
229658	13BP01I	143-152	*S. ybertii*?	Serpukovian-Bashkirian
229659	13BP01I	171-172	*S. ybertii-G. maculosa*?	Serpukovian-Bashkirian
229660	17BP01I	125-126.5	*S. ybertii*?	Serpukovian-Bashkirian
229661	17BP03I	51-52	*S. ybertii*	Serpukovian-Bashkirian
229662	17BP04I	60.55-62	*S. ybertii*?	Serpukovian-Bashkirian
229663	17BP05I	90.5-95.8	*S. ybertii*	Serpukovian-Bashkirian
229664	17BP06I	40.5-41	*S. ybertii*	Serpukovian-Bashkirian

INTRODUCTION

Originally, 8 cuttings samples were supplied by Don Bennett (Department of Primary Industries and Regional Development) via A. J. Mory (Geological Survey of Western Australia) from the Bonaparte Basin. All samples are cuttings from shallow water investigation bores drilled north of Kununurra (Bennett, 2018). One sample, GSWA 229665 from 17BP07I at 71-83 m, consists entirely of oxidised material and was not processed. All other samples yielded palynomorphs, but the yields are low with only one slide available for 3 samples. The results are summarised above and described in more detail below.

Location details and lithology of 8 samples, locations in latitude and longitude

Bore	*Depth (m)*	*sample type*	*GSWA No.*	*S*	*E*	*Lithology (JB)*
13BP01I	143–152	cuttings	229658	15.07593	128.757	Claystone, pale grey
13BP01I	171–172	cuttings	229659	15.07593	128.757	Claystone, grey with brown dust
17BP01I	125–126.5	cuttings	229660	15.06001	128.8045	Claystone, grey with brown dust
17BP03I	51–52	cuttings	229661	15.01044	128.7117	Claystone, pale grey
17BP04I	60.55–62	cuttings	229662	14.97854	128.6531	Claystone, grey with brown particles
17BP05I	90.5–95.8	cuttings	229663	14.94937	128.639	Claystone, pale grey
17BP06I	40.5–41	cuttings	229664	15.17867	128.7811	Claystone, grey with brown dust
17BP07I*	71–83	cuttings	229665	15.09204	128.7102	Claystone, light brown

* not processed

Table 1. Palynomorph distribution chart for all samples analysed.

PALYNOSTRATIGRAPHY

GSWA 229658: 13BP01l, 143-152 m

As with all samples examined for this report, the spore-pollen assemblage is dominated by simple trilete spores included here in *Punctatisporites* and *Retusotriletes*, but also including *Calamospora* spp. There is no firm evidence for a biostratigraphic age younger than the *D. birkheadensis* Zone and the distinctive features of that zone, as represented in the Canning Basin are not observed here. Species present that indicate the *S. ybertii* Zone or an older unit are:

Auroraspora solisorta
Raistrickia corymbiata
Rugospora australiensis

S. ybertii is not recorded in this sample, but is present in small numbers in 3 other samples. Saccate pollen are present in low numbers and place this assemblage above the *G. maculosa* Zone.

The sample is tentatively assigned to the *S. ybertii* Zone of estimated Serpukovian age.

GSWA 229659: 13BP01l, 171-172 m

Unlike all other samples in this report, the spore-pollen assemblage does not contain saccate pollen. This suggests it could be from the *G. maculosa* Zone. However, the yield is very low and the spore-pollen diversity is less than many other samples and these factors may contribute to the apparent absence of saccate pollen. The assemblage contains significant numbers of modern pollen (Poaceae, Myrtaceae and rare Proteaceae) and one specimen of the Cretaceous dinoflagellate cyst *Ovoidinium verrucosum*. The source of the pollen is not certain, but the *O. verrucosum* is almost certainly introduced by a particular type of bentonite used as a drilling mud additive.

The sample is assigned to the range *S. ybertii* to *G. maculosa* zones.

GSWA 229660: 17BP01l, 125-126.5 m

This assemblage does not contain *S. ybertii*, but does contain several saccate pollen. It also has the highest count of *G. frustulentus* of any sample. The yield is particularly low, compared to other samples. It also contains a few very small *Micrhystridium* spp., suggesting some marine influence and a specimen of *Reduviasporonites,* of completely unknown origin.

The sample is tentatively assigned to the *S. ybertii* Zone.

GSWA 229661: 17BP03l, 51-52 m

This sample contains more *S. ybertii* than any other sample, but still relatively few for the *S. ybertii* Zone. It also has a higher count of *Verrucosisporites* than other samples and the only specimen of *Anapiculatisporites amplus* recorded. Taken together with the presence of saccate pollen, this assemblage is more confidently placed in the *S. ybertii* Zone than other assemblages in this report.

An unusual feature of this sample is the relatively high count of *Botryococcus* and the presence of a form of *Deusilites* with low wavy ridges.

GSWA 229662: 17BP04l, 60.55-62 m

This sample contains a significant count of *I. dolianitii* and some *Indotriradites* sp. A (Backhouse in prep). *Secarisporites remotus* is also present and together these data suggest the *S, ybertii* Zone, despite the absence of *S. ybertii*. As in at least one other sample the presence of *Retispora lepidophyta* indicates Devonian reworking.

GSWA 229663: 17BP05l, 90.5-95.8 m

This is an undistinguished assemblage, similar to the others and with rare *S. ybertii*. *Cristatisporites lestai* type spores are a rare component in this sample and the 17BP061l sample. The rarity of *Cristatisporites* generally is a significant difference to the Reeves Formation of the Canning Basin. This sample is also placed in the *S. ybertii* Zone.

GSWA 229664: 17BP06l, 40.5-41 m

The assemblage contains rare *Micrhystridium* that may indicate marine influence, if it is not some form of contamination. *Indotriradites dolianitii*, *G. frustulentus* and *Verrucosisporites* spp. are fairly common and several *S. ybertii* are present together with several monosaccate pollen. This sample is placed in the *S. ybertii* Zone, more convincingly than some other samples.

GENERAL COMMENTS

Though most of these samples seem to belong in the *S. ybertii* Zone, there are significant differences to the assemblages from this zone in the Canning basin. *S. ybertii* is rare or absent in these samples, monosaccate pollen are relatively rare and include many examples of *Plicatipollenites gondwanensis* style pollen, which tend to be more characteristic of the Grant Group in the Canning Basin. *Cristatisporites* type spores are absent in most assemblages, whereas they are consistent and often common in the Canning Basin. *Botryococcus* spp. are recorded in most samples, but are rare in this zone in the Canning Basin. Also, a number of spores could not be identified easily and seem to be species not recorded in the Canning Basin.

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Bennett, D.L., 2018. Investigations of the potential for irrigated agriculture on the Bonaparte Plains: bore completion report. Resource management technical report 409, Department of Primary Industries and Regional Development, Perth

TABLE 1. Palynomorph distribution chart for all samples analysed

Borehole	13BP01I	13BP01I	17BP01I	17BP03I	17BP04I	17BP05I	17BP06I
Depth (m)	143-142	171-172	125-126.5	51-52	60.55-62	90.5-95.8	40.5-41
SPORE-POLLEN							
Spores indet.	10	10	10	6	8	2	4
Ahrensisporites cristatus	1						
Anapiculatisporites amplus				x			
Anapiculatisporites concinnus	x		x	x	2		2
Apiculatasporites spiculatus		1					
Apiculiretusispora arcuatus	x		1	1	x		
Auroraspora solisorta	x	1					
Brevitriletes leptoacaina		1	1				
Caheniasaccites ovatus	1	x	1		1	x	1
Cannanoropollis janakii						2	x
Convolutispora sp. cf. *C. jugosa*	1	1			1	1	x
Cordylosporites asperidictyus							1
Cristatisporites lestai						x	1
Cyclogranisporites firmus				3	3	1	1
Densoisporites sp.	2	3					
Diatomozonotriletes birkheadensis	x						1
Dibolisporites disfacies				x		1	1
Foveosporites pellucidus	x				1	1	2
Grandispora sp. cf. *G. maculosa*	2	9	1				
Granulatisporites frustulentus			12	9	1	5	7
Indotriradites dolianitii		1	2	4	8	6	7
Indotriradites sp. A (JB in prep)				1	1		2
Lophotriletes sp. A (JB in prep)	1						
Meristocorpus explicatus	x			x			x
Plicatipollenites spp.	1		2	x	3		2
Plicatipollenites trigonalis	x						x
Potonieisporites novicus	5		x	1	1	x	1
Punctatisporites, Retusotriletes etc	58	69	54	51	53	64	49
Raistrickia corymbiata	x	x					
Retispora lepidophyta	x				x		
Rugospora australiensis	8	1					
Secarisporites remotus					x		
Spelaeotriletes ybertii				3		1	1
Tumulispora sp.	x	x					
Vallatisporites vallatus	3	x	1		2	6	5
Verrucosisporites andersonii	1	1	1	1		2	x
Verrucosisporites aspratilis	1	1	1	6	6	1	3
Verrucosisporites gregatus			1	x			
Verrucosisporites quasigobbettii	5	1	3	7	5	1	3
Verrucosisporites sp. A of Mory & Playford				?			
Verrucosisporites sp. B (JB in prep)				x			
Verrucosisporites sp. indet			2				
Waltzispora polita			x	1	1	3	2
ACRITARCHS & ALGAE							
Botryococcus spp.			3	6	3	3	4
Deusilites sp.	x			x			
Maculatasporites minimus					x		
Micrhystridium spp.			3				x
Quadrisporites horridus			x				
Reduviasporonites sp.			1				
TOTAL COUNT	100	100	100	100	100	100	100

x = present outside count

Shortened forms

Short form	Long form
AEM	airborne electromagnetic (survey)
DN	*Diametre Nominel* (nominal diameter)
DPIRD	Department of Primary Industries and Regional Development
GDA94 Z52	Geocentric Datum of Australia 1994 Zone 52
ha	hectare
km	kilometre
km^2	square kilometre
L/s	litres per second
m	metre
mAHD	metres Australian Height Datum
mBGL	metres below ground level
mm	millimetre
mRGL	metres relative to ground level
mS/m	millisiemens per metre
NB	nominal bore (diameter)
PVC	polyvinyl chloride
SC	specific conductivity (25°C)
WA	Western Australia

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